

A Multimedia Strategy to Integrate Introductory Broad-Based Radiation Science Education in US Medical Schools

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Abstract

US physicians in multiple specialties who order or conduct radiological procedures lack formal radiation science education and thus sometimes order procedures of limited benefit or fail to order what is necessary. To this end, a multidisciplinary expert group proposed an introductory broad-based radiation science educational program for US medical schools. Suggested preclinical elements of the curriculum include foundational education on ionizing and nonionizing radiation (eg, definitions, dose metrics, and risk measures) and short- and long-term radiation-related health effects as well as introduction to radiology, radiation therapy, and radiation protection concepts. Recommended clinical elements of the curriculum would impart knowledge and practical experience in radiology, fluoroscopically guided procedures, nuclear medicine, radiation oncology, and identification of patient subgroups requiring special considerations when selecting specific ionizing or nonionizing diagnostic or therapeutic radiation procedures. Critical components of the clinical program would also include educational material and direct experience with patient-centered communication on benefits of, risks of, and shared decision making about ionizing and nonionizing radiation procedures and on health effects and safety requirements for environmental and occupational exposure to ionizing and nonionizing radiation. Overarching is the introduction to evidence-based guidelines for procedures that maximize clinical benefit while limiting unnecessary risk. The content would be further developed, directed, and integrated within the curriculum by local faculties and would address multiple standard elements of the Liaison Committee on Medical Education and Core Entrustable Professional Activities for Entering Residency of the Association of American Medical Colleges.

Key words: ACR Appropriateness Criteria, ionizing radiation, medical school education, nonionizing radiation, radiation science education

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INTRODUCTION

The notable benefits and dramatic increases in diagnostic and therapeutic ionizing and nonionizing radiation procedures since the early 1980s in the United States [1] and worldwide [2] have transformed patient care. CT alone has revolutionized diagnosis and management of many medical conditions that formerly required surgery [3]. Yet, many physicians are unaware of evidence-based guidance for selecting appropriate diagnostic imaging tests [4,5] or therapeutic radiation procedures [6,7]. Physicians may not be fully cognizant of the consequences of failing to order necessary imaging examinations [8] or of overusing of imaging examinations [9,10].

Surveys of fourth-year medical students, postgraduate year 1 residents, US residency educators, and medical school deans [11-14] have underscored gaps in medical school radiology education. Additionally, radiology rotations were required in 24% of US medical schools during 2013 to 2014 but declined to 16% in 2019 to 2020 [15]. The lack of basic radiation oncology knowledge [16] represents a major deficit because 40% of Americans will develop cancer [17], and close to half of those patients will receive radiation therapy [18]. Similarly, medical students receive little education on health effects of low- to moderate-dose ionizing radiation [19,20] or on the benefits and risks of

CT [4,5], MRI [21], and ultrasound [22]; the use of fluoroscopy and fluoroscopically guided interventional procedures [23] (the latter increasingly replacing surgical treatments); or nuclear medicine and molecular imaging procedures [24]. Medical students receive limited education and practice in patient-centered communication about benefits and risks of radiation procedures or addressing patients' questions about health effects, strategies for risk reduction, and trustworthy sources of information about ionizing and nonionizing medical, environmental, and occupational radiation exposures [25-28].

This article uses the term "radiation science education" to include the key educational elements to prepare medical students for postgraduate residency programs and for providing optimal patient care. The elements consist of educational content on ionizing and nonionizing radiation definitions, dose metrics, and health risks; the clinical modalities that employ radiation; patient subgroups with special considerations or contraindications for specific radiation procedures; radiation protection and safety measures; communication and shared decision making with patients about ionizing and nonionizing radiation procedures; and physician and patient education about health effects from medical, environmental, and occupational radiation sources.

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CONVENING EXPERTS TO DISCUSS GAPS AND PROPOSE EDUCATIONAL GOALS

On November 10 to 11, 2020, the National Academies of Sciences, Engineering, and Medicine (NASEM) convened experts to support strategic planning for broad-based radiation science education of US medical students. Invited members had expertise in adult and pediatric radiology, radiation oncology, nuclear medicine, interventional radiology and cardiology, health and medical physics, medical education and curriculum development, resident training and certification, radiation risk communication, and health effects of ionizing and nonionizing radiation. The NASEM-convened experts, who are the authors of this article, discussed current medical school radiation education and shared views on the knowledge, skills, and competencies in radiation science needed to prepare medical students for postgraduate residency programs and how these are related to US medical school certifying requirements [29,30]. The experts noted that the Liaison Committee on Medical Education document “Function and Structure of a Medical School” describes six elements within the curricular content standard relevant to the proposed radiation science education [29] (see Table 1). Among the competencies designated in the Core Entrustable Professional Activities for Entering Residency developed by the Association of American Medical Colleges, five were relevant to the proposed radiation science education [30] (Table 1). The group also discussed interconnections between radiation safety culture and safety in other patient settings.

To address educational needs of most physicians (e-only Supplemental Table 1), introductory broad-based radiation science education in medical school would be optimal, but the expert group was unaware of any medical school providing such education. This article provides content that could be incorporated into medical school curricula, a rationale for such incorporation, trusted sources and references for medical students and faculty, and possible educational strategies.

CONTENT FOR BROAD INTRODUCTORY RADIATION SCIENCE CURRICULUM

Soon after the NASEM meeting, several of the convened experts briefly summarized gaps in radiation science education in US medical schools and prepared a preliminary short outline of proposed content [31]. Based on subsequent interchange, the group noted that some radiation protection organizations have emphasized the incorporation of radiation protection and safety and radiation-related ethical principles in medical school education programs [11,32]. The UK Royal College of Radiology [33] and the European Society of Radiology [34,35] have developed radiology curricula for medical students. However, a

survey has described heterogeneity in radiology education content, teaching methods, and faculty clinical expertise [36]. US medical school faculty and professional societies have developed content suitable for medical school education in radiology [37,38], interventional radiology [39], and radiation oncology [40], but this material has yet to be widely integrated into US educational programs.

During the year after the NASEM-organized meeting, the group developed ideas for a comprehensive clinically relevant ionizing and nonionizing radiation science curriculum and mapped the suggested content to multiple Liaison Committee on Medical Education standards and Association of American Medical Colleges core entrustable professional activities for entering residency. The experts identified nine proposed core competencies and engaging multimedia pedagogical methods for curriculum integration as summarized herein and in Table 2. In the e-only supplemental tables, the authors provide definitions of key radiation terms (see e-only Supplemental Table 2); trusted resources, references, and websites for the proposed curriculum content (e-only Supplemental Table 3); and useful pedagogical references for faculty (e-only Supplemental Table 4). The authors judge that much of this content would also be appropriate for the education of nurses, nurse practitioners, physician’s assistants, radiologic technologists, and dental students.

Preclinical Education

The suggested preclinical educational elements are listed in Table 2. Preclinical knowledge-based competencies needed include ionizing and nonionizing radiation definitions, types, sources, dose measures, and health risks. Medical students would learn about the differences between radiologic procedures that involve ionizing radiation versus those that use nonionizing radiation, dose differences across diagnostic and therapeutic procedures, and the benefits, risks, special requirements and other characteristics of these procedures. For ionizing radiation, students would be introduced to short-term adverse tissue effects at very high doses (including hematologic, gastrointestinal, neurologic, and dermatologic effects) and long-term adverse tissue effects at a broader range of doses (including cataracts, cardiovascular diseases, and fibrosis). Students would learn about stochastic effects (eg, that probability rather than severity is a function of radiation dose likely without a threshold), such as cancer, and hereditary effects [32]. Screening and clinical follow-up recommendations would be introduced for early identification of adverse effects and implementation of appropriate treatment [6,7,41] For nonionizing radiation, information would be presented on the adverse effects and safety issues for clinical MRI (tissue

Table 1. Proposed radiation science* medical school curricular content mapped to Liaison Committee on Medical Education Standards and the Association of American Medical Colleges Core Entrustable Professional Activities

Organization	Standard or Entrustable Professional Activity	Proposed Radiation Science Curricular Content and Rationale
Liaison Committee on Medical Education	Standard and associated elements	
	7. Curricular content: the faculty of a medical school ensure that the medical curriculum provides content of sufficient breadth and depth to prepare medical students for entry into any residency program and for the subsequent contemporary practice of medicine	Most physician specialties need radiation science education (See e-only Supplemental Table 1.)
	7.1. Biomedical, behavioral, social sciences: biomedical sciences mastery is needed to apply to the health of individuals and populations	Biomedical science mastery: <ul style="list-style-type: none"> ■ Ionizing (radiography including x-rays, CT, fluoroscopy, SPECT, PET/CT) and nonionizing radiation (MRI, ultrasound) biologic and health effects ■ Variability in dose levels among diagnostic and therapeutic procedures ■ Cumulative dose levels ■ Justification and optimization ■ Ionizing radiation early (radiation dermatitis) and late (cataracts) tissue effects ■ Ionizing radiation late stochastic effects (cancer) ■ Nonionizing radiation potential adverse effects (MRI: heating and burns, tinnitus and hearing loss, potential need for sedation in certain patient subgroups; ultrasound: slight heating) ■ Contraindications to certain procedures in specific population subgroups ■ Radiation protection measures to reduce radiation exposures of patients and medical staff ■ Radiation safety measures
	7.2. Organ systems, life cycle, prevention, symptoms, signs, differential diagnosis, treatment planning	Organ systems and prevention: <ul style="list-style-type: none"> ■ Medically justified diagnostic or treatment procedures involving radiation to prevent serious acute and chronic disease ■ Institute screening after exposure for late stochastic effects of ionizing radiation Differential diagnosis: <ul style="list-style-type: none"> ■ Late nonstochastic effects of moderate- to high-dose ionizing and nonionizing radiation on specific tissues or organs Treatment planning: <ul style="list-style-type: none"> ■ Medical justification for radiation procedures

(continued)

Table 1. Continued

Organization	Standard or Entrustable Professional Activity	Proposed Radiation Science Curricular Content and Rationale
	7.4. Critical judgment and problem-solving skills	Critical judgment: <ul style="list-style-type: none"> Evidence-based knowledge and key sources of information about ordering or performing medically justified procedures involving ionizing radiation
	7.5. Societal problems	Societal problems: <ul style="list-style-type: none"> Benefits and risks of procedures involving ionizing and nonionizing radiation for diagnosis, prevention, and treatment
	7.8. Communication skills	Communication skills: <ul style="list-style-type: none"> Patient-centered education and shared decision-making about benefits, obstacles, and risks of procedures involving ionizing and nonionizing radiation (including the accuracy of the different procedures, acute and chronic effects, costs)
	7.9. Interprofessional collaborative skills	Interprofessional collaborative skills: <ul style="list-style-type: none"> Knowledge and practice in communication of sufficient clinical information, diagnostic results, therapeutic outcomes, and need for proper surveillance for early and late effects across physician specialties (primary care providers, radiologists, radiation oncologists, and ordering physicians) and among radiology technicians and operators (See EPA 9.)
Association of American Medical Colleges	Core EPAs	
	EPA 3. Recommend and interpret common diagnostic and screening tests	Order and interpret first-line, medically justified, cost-effective diagnostic imaging tests for evaluation of a patient with an acute or chronic disorder or as part of routine health maintenance (such as recommended screening examinations)
	EPA 7. Form clinical questions and retrieve evidence to advance patient care	Evaluate evidence for ionizing and nonionizing radiological procedures including an understanding of the appropriate indication and the associated radiation risk, benefit, and uncertainty of a procedure to advance patient care
	EPA 9. Collaborate as a member of an interprofessional team	Engage in bidirectional communication between physician specialists providing direct care (internal medicine, surgery, ob-gyn, pediatrics) and those conducting radiation diagnostic or therapeutic procedures to include: <ul style="list-style-type: none"> Exchange of relevant demographic, lifestyle, and medical health information to facilitate high-quality clinical care Written (and as needed, direct or verbal) communication between the physician overseeing the radiologic diagnostic or therapeutic

(continued)

Table 1. Continued

Organization	Standard or Entrustable Professional Activity	Proposed Radiation Science Curricular Content and Rationale
	EPA 11. Obtain informed consent	procedure and the ordering physician to facilitate interpretation of results by the ordering physician (See Standard 7.9.) Provide patient-centered education and shared decision making about diagnostic or therapeutic procedures involving ionizing and nonionizing radiation (whether informed consent is to be obtained), to include effective bidirectional communication with patients to ensure understanding about the indications, benefits, risks, complications, and alternatives
	EPA 13. Identify system failures and contribute to a culture of safety and improvement	Apply strategies to select appropriate procedures, (justification using ACR Appropriateness Criteria); aim for radiologist to work in tandem with medical physicist and radiologic technologist to achieve images adequate for diagnosis and treatment while keeping radiation dose as low as reasonably achievable (optimization); take into account special patient-specific considerations and contraindications for certain procedures, and making sure that safety is paramount, while balancing patients' other needs (such as avoidance of clinically problematic delays, lack of access, need for sedation, psychological and cost impacts) and avoid diagnostic and therapeutic procedures that provide no clinical benefit

EPA, Core Entrustable Professional Activities; ob-gyn = obstetrics and gynecology; SPECT = single-photon emission computed tomography. *Radiation science education includes ionizing and nonionizing radiation definitions, dose metrics, and health risks; the clinical modalities that employ radiation; identification of patient subgroups with special considerations or contraindications for specific radiation procedures; radiation protection and safety measures; and communication and shared decision making with patients about ionizing and nonionizing radiation procedures and physician and patient education about health effects from medical, environmental, and occupational radiation sources.

heating and burns, tinnitus and hearing loss, projectile events, psychologic effects), the potential need for sedation in certain patient subgroups, and ultrasound procedures (heating of tissue especially for fetal imaging and pockets of gas in body fluids and tissues). Adverse effects of ultraviolet radiation would be summarized (eg, the short-term effects of erythema and sunburns and the long-term effects of skin cancers, cataracts, other eye damage such as corneal and retinal injuries, and premature aging of skin).

The preclinical education would also include a description of patient subgroups requiring special considerations when selecting specific ionizing and nonionizing diagnostic or therapeutic radiation procedures. All these proposed preclinical components are foundational for ordering and

conducting high-value radiation procedures incorporating protection measures, understanding radiation-related adverse health effects, and communicating with patients. Learning the methods to estimate radiation-related risks, dose–response, and uncertainty [25,42] can also carry over into interpreting risks from clinical trials of medications and other forms of medical care.

Preclinical introductory radiology education has been advocated along with the incorporation of radiology in the teaching of anatomy [43] and correlation with postsurgical pathology [44].

Students would be introduced to the fundamental radiological principle of “justification” (eg, whether a specific imaging procedure is appropriate for a patient’s care

Table 2. Proposed radiation science* competencies, content areas, and educational strategies

Competency and Associated Content Areas	Educational Strategies	
	Pedagogical Method	Associated Curricular Setting
<p>Preclinical</p> <p><i>The student will be able to:</i></p> <p><i>Define and distinguish between ionizing and nonionizing radiation;</i></p> <p><i>List the various sources and types of radiation;</i></p> <p><i>Define dose, risk, dose–response, and uncertainty measures</i></p> <ul style="list-style-type: none"> ■ Ionizing radiation definitions, types, sources (medical, environmental, occupational), units, dose, and cumulative dose measures ■ Nonionizing radiation definitions, types, sources (MRIs; ultrasound radiation; UVR solar and tanning beds; cell phones and other radiofrequency exposures), dose measures ■ Risk measures, dose–response, uncertainty 	<ul style="list-style-type: none"> ■ Online modules ■ Problem-based learning 	<ul style="list-style-type: none"> ■ Self-directed reinforcement in radiology rotation ■ Self-directed reinforcement with statistician expert (Q and A)
<p><i>The student will be able to:</i></p> <p><i>Describe radiation-related adverse effects</i></p> <p><i>Provide brief overview on patient subgroups requiring special considerations for diagnostic or therapeutic procedures involving ionizing or nonionizing radiation exposure</i></p> <ul style="list-style-type: none"> ■ Ionizing radiation from medical and other sources <ul style="list-style-type: none"> □ Short-term tissue effects (high doses: bone marrow, GI, neurological, skin) □ Long-term tissue effects (range of doses: cataracts, cardiovascular, fibrosis) □ Long-term stochastic effects (cancer, hereditary effects) ■ Nonionizing radiation: MRI (heating and burns, tinnitus and hearing loss, projectile events, psychological effects; possible need for sedation in some patient subgroups) ■ Nonionizing radiation: ultrasound (slight heating of tissue, pockets of gas in body fluids and tissues) ■ Nonionizing radiation: ultraviolet <ul style="list-style-type: none"> □ Short term: erythema and sunburns □ Long term: skin cancers, cataracts and other eye damage, premature aging of skin ■ Overview of patient subgroups requiring special considerations for specific ionizing and nonionizing diagnostic or therapeutic radiation procedures 	<ul style="list-style-type: none"> ■ Vertical integration in the existing curriculum ■ Online modules 	<ul style="list-style-type: none"> ■ Histology, pathology (self-directed reinforcement) ■ Genetics
<p><i>The student will be able to:</i></p> <p><i>Outline the indications, benefits, risks, and concepts of justification and optimization for ionizing and nonionizing radiologic procedures;</i></p> <p><i>Describe the methods and content of communication requests to radiologists for ordering imaging examinations;</i></p> <p><i>Describe the roles of radiologist, medical physicist, and radiologic technologist in optimizing dose protection measures</i></p> <p><i>Describe measures for radiation protection of patients and medical staff</i></p>		

(continued)

Table 2. Continued

Competency and Associated Content Areas	Educational Strategies	
	Pedagogical Method	Associated Curricular Setting
<ul style="list-style-type: none"> ■ Benefit vs risk of ordering vs not ordering imaging examination ■ Justification (including strategies for avoiding duplication and low-value radiologic procedures) ■ Methods and content of communication requests to radiologist for ordering imaging examinations ■ Optimization (reinforce dose measures and roles of the radiologist, medical physicist, and radiologic technologist) ■ Radiation protection of patients and medical staff 	<ul style="list-style-type: none"> ■ Online module 	<ul style="list-style-type: none"> ■ Self-directed reinforcement with radiologist and medical physicist experts (Q and A)
Clinical[†]		
<i>Radiology:</i>		
<i>The student will be able to:</i>		
<i>Review key concepts from preclinical radiology education;</i>		
<i>Describe patient and disease-specific radiologic examination selection based on appropriate use criteria;</i>		
<i>Describe patient subgroups requiring special considerations or contraindications for ionizing and nonionizing radiation procedures;</i>		
<i>Describe cumulative dose considerations</i>		
<i>List regulatory reporting requirements</i>		
<ul style="list-style-type: none"> ■ Review concepts from preclinical radiology education ■ Patient- and disease-specific examination selection, considering appropriate use criteria for selecting ionizing and nonionizing radiologic examinations and radiation-related risks and trade-offs ■ Patient subgroups (including children and adolescents, pregnant women, patients with radiosensitive genetic disorders and comorbidities) requiring special considerations regarding justification and optimization ■ Patient-specific contraindications for certain radiologic procedures (such as disorders precluding use of contrast media with CT or MRI; implants and external devices limiting use of MRI) ■ Other patient-specific concerns and needs (sedation for pediatric, mentally ill, and cognitively impaired patients; psychological considerations such as claustrophobia associated with CT and MRI examinations) ■ Cumulative dose considerations ■ Regulatory and reporting requirements ■ Cost considerations 	<ul style="list-style-type: none"> ■ Clinical rotation that includes meeting with medical physicist and observation of optimization strategies and radiation protection measures for patients and medical staff <p><i>Or</i></p> <ul style="list-style-type: none"> ■ Online modules, videos (including video-based observation of optimization strategies) 	<ul style="list-style-type: none"> ■ Radiology rotation for 2-4 wk <p><i>Or</i></p> <ul style="list-style-type: none"> ■ Self-directed (fourth-year course) with instructional videos ■ Elective rotation or mini-rotation for medical students who seek more in-depth education

(continued)

Table 2. Continued

Competency and Associated Content Areas	Educational Strategies	
	Pedagogical Method	Associated Curricular Setting
<p><i>The student will be able to: Describe the fluoroscopically guided procedures used to evaluate and treat specific diseases, including the risks, benefits, associated doses, and protection strategies</i></p> <ul style="list-style-type: none"> ■ Diseases evaluated and treated ■ Equipment used ■ Newer procedures, equipment, and treatments ■ Benefits and risks of procedures ■ Doses to organs targeted and not targeted ■ Need for patient follow-up ■ Radiation protection measures for patients and staff 	<ul style="list-style-type: none"> ■ Vertical integration in existing clinical clerkships ■ Instruction by interventional cardiologist ■ Elective rotations or minirotations with appropriate specialists[†] 	<ul style="list-style-type: none"> ■ Internal medicine clerkship (components on cardiology and neurology) ■ Surgery clerkship (components on orthopedics, vascular surgery, neurosurgery) ■ Ob-gyn clerkship (component on treatment of symptomatic fibroids)
<p><i>The student will be able to: Describe the nuclear medicine procedures used to evaluate and treat specific diseases, including the risks, benefits, associated doses, and protection strategies</i></p> <ul style="list-style-type: none"> ■ Diseases evaluated and treated ■ Equipment used, molecular imaging ■ Newer molecular and hybrid imaging procedures ■ Benefits and risks of procedures ■ Doses to organs targeted and not targeted ■ Need for patient follow-up ■ Radiation protection measures for patients, family members, and medical staff 	<ul style="list-style-type: none"> ■ Vertical integration in existing clinical clerkships ■ Instruction by nuclear medicine expert ■ Elective rotations or minirotations with appropriate specialists[†] 	<ul style="list-style-type: none"> ■ Internal medicine clerkship (components on endocrinology [I-131], oncology [PET/CT, molecular imaging, theranostics])
<p><i>The student will be able to: Describe the radiation oncology procedures used to evaluate and treat specific diseases, including the risks, benefits, associated doses, and protection strategies</i></p> <ul style="list-style-type: none"> ■ Diseases evaluated and treated ■ Equipment used ■ Benefits and risks of procedures ■ Doses to organs targeted and not targeted ■ Need for patient follow-up of current and prior forms of radiotherapy (as well as systemic therapy) ■ Radiation protection measures for patients and staff 	<ul style="list-style-type: none"> ■ Vertical integration in existing clinical clerkships ■ Instruction by radiation oncologist ■ Elective rotations or minirotations with appropriate specialists[†] 	<ul style="list-style-type: none"> ■ Internal medicine clerkship (component on oncology) ■ Surgery clerkship (component on oncology)
<p><i>The student will be able to: Describe strategies and oversee application of effective patient-centered communication to achieve shared decision-making about specific radiological procedures</i></p> <ul style="list-style-type: none"> ■ Learn and apply effective skills to counsel patients about key aspects of radiological procedures with the overarching goal of shared decision making 	<ul style="list-style-type: none"> ■ Online module with video examples ■ Vertical integration in existing clinical clerkships and elective rotations ■ Simulation 	<ul style="list-style-type: none"> ■ Various clinical clerkships and electives including inpatient ward rounds and ambulatory setting ■ Demonstration and role-modeling by medical staff using excellent communication skills

(continued)

Table 2. Continued

Competency and Associated Content Areas	Educational Strategies	
	Pedagogical Method	Associated Curricular Setting
<i>The student will be able to: Outline approach for providing medical student education and strategies for effective communication with patients on the health effects of medical, environmental, and occupational ionizing and nonionizing radiation exposure</i>		
<ul style="list-style-type: none"> ■ Learn key content, trustworthy sources of information, and effective patient-centered communication strategies to address patients' questions about health effects of medical, environmental, and occupational sources of ionizing and nonionizing radiation exposure 	<ul style="list-style-type: none"> ■ Online module ■ Vertical integration in existing clinical clerkships and elective rotations ■ Simulation 	<ul style="list-style-type: none"> ■ Self-directed ■ Various clinical clerkships and electives including inpatient ward rounds and ambulatory settings with patients as questions arise

GI = gastrointestinal; ob-gyn = obstetrics and gynecology; UVR = ultraviolet radiation.

*Radiation science education includes ionizing and nonionizing radiation definitions, dose metrics, and health risks; the clinical modalities that employ radiation; identification of patient subgroups with special considerations or contraindications for specific radiation procedures; radiation protection and safety measures; and communication and shared decision making with patients about ionizing and nonionizing radiation procedures and physician and patient education about health effects from medical, environmental, and occupational radiation sources.

†Elective rotations or minirotations with appropriate specialists for medical students who seek more in-depth education on these various radiological imaging or therapeutic modalities. Educational components may include attending planning meetings (including tumor board meetings); observing the preparation of equipment, radionuclides, radiotherapy contouring; learning about newer procedures and techniques; discussing written patient care guidelines; observing procedures; participating in experiential activities; meeting with medical physicist to receive education on procedural and radiation protection measures; participating in clinics and all elements of patient care and flow.

and that the procedure and associated radiation dose would be expected to do more good than harm) [4,42,45]. Students would learn the ethical shared responsibility between ordering physician and radiologist to identify the clinical benefit of a radiological procedure (*justification*) and how the radiologist works in tandem with the medical physicist and radiologic technologist (the core *optimization* team) to achieve images adequate for diagnosis and treatment while keeping the radiation dose as low as reasonably achievable. Also, the student would learn how to describe the purpose of the requested imaging examination and provide appropriately detailed patient demographic, lifestyle, and medical information to the radiologist for the patient to achieve optimal benefit from the examination. Understanding of the justification principle is critical to consider the fair distribution of limited resources and to avoid ordering radiological examinations of low or no clinical value (eg, overutilization). Students would also learn about patient and medical staff radiation protection and safety measures [45-50].

Clinical Education

Important clinical knowledge, skills, and competencies are listed in Table 2. The clinical education would reinforce the

preclinical educational concepts and focus on clinical application. Emphases would include clear communication between ordering physician and radiologist; justification, optimization, and cumulative dose considerations; and tailoring the examination to key patient characteristics (such as age, body mass index, pregnancy, and comorbidities). Contraindications to procedures would be underscored, such as avoiding use of specific contrast media among patients with certain diseases and of some types of MRI examinations in patients with certain implanted or nonremovable external devices. Students would learn the value of a team approach for protocol optimization and patient and medical staff radiation safety. Trusted sources of information for medical students, physicians, and patients would be identified (see e-only Supplemental Table 3). The clinical radiology applications would emphasize patient- and disease-specific examination selection using the evidence-based ACR Appropriate Use Criteria [4] and other resources [38,46]. Students would also learn when ultrasound and MRI procedures (involving nonionizing radiation) would be appropriate instead of CT or other ionizing radiation examinations. The students would be introduced to the Image Wisely [5,6,42] and Image Gently [47] professional campaigns and other trustworthy sources [46-49] and the reports from the National Council on Radiation Protection and

Measurements (for example, report 180 on the management of exposure to ionizing radiation) [50]. The education would emphasize parallels with clinical decision support used in other areas of medical diagnosis and treatment [29,30]. Radiology reporting requirements [51] and regulatory issues [52] would be introduced.

Medical students would benefit from a detailed introduction to fluoroscopy and fluoroscopically guided procedures [6,39,53], nuclear medicine (including molecular imaging and hybrid procedures) [5,54], and radiotherapy [7,16,40]. The proposed core content for these modalities would include the diseases evaluated or treated; equipment used; types of radiation employed; medical indications, benefits, and risks (tissue and disease effects) of these procedures; range of patient doses to targeted organs and organs not specifically targeted; doses to medical staff and family members (if relevant); radiation protection measures for patients, family and others, and medical staff; and appropriate follow-up postprocedure (Table 2). Medical students could be introduced briefly to the rapidly evolving technologies for these modalities (eg, artificial intelligence, molecular imaging and radiotheranostic procedures, and proton radiotherapy) (e-only Supplemental Table 4).

The education would underscore the appropriate use and optimization of CT scans, nuclear medicine, and fluoroscopically guided procedures because hundreds of millions of these procedures are performed annually in the United States [1]. Students would be introduced to the growing evidence that low to moderate cumulative radiation doses may be associated with small individual radiation-related risks of cancer [19], particularly after early life exposures [55], and possibly also cataracts and circulatory disease [20]. Students would learn about current recommendations from the International Atomic Energy Agency, endorsed by other organizations, including the World Health Organization, that call for greater awareness of cumulative radiation doses in patients undergoing recurrent imaging or fluoroscopically guided interventional procedures. The group suggested that faculty discuss with medical students what is and is not known about interpreting reported cumulative doses (see e-only Supplemental Table 4 for additional references). Students would also be made aware of existing dose monitoring software tools and hospital information systems that are starting to track doses. Measures to ensure the highest levels of radiation protection and safety for patients and medical staff would be emphasized.

Medical students need to learn to communicate clearly with their patients about benefits, doses, risks, and associated uncertainties about ionizing and nonionizing medical radiation procedures [56-58] and to respond to patients'

questions about sources, exposures, and health effects from environmental and occupational ionizing and nonionizing radiation [25-28,56]. When asked, most patients and their families wish to understand radiation procedures' benefits and risks. Knowing about the small risks does not generally dissuade agreement to undergo justified radiation procedures [56]. Randomized controlled trials have shown that teaching patient communication skills improves students' ability to establish rapport and enhances patient autonomy while alleviating apprehension [57]. To teach future medical providers to anticipate and address concerns [56], several useful educational strategies can be employed. These include querying patients' understanding and tailoring information discussed to patients' understanding of and cultural perspectives related to undergoing procedures, asking patients to summarize the information provided, and requesting patients to identify obstacles that might prevent them from undergoing procedures [58]. Trustworthy references are readily available for communicating information about proposed medical procedures [26,27,59,60] and about health effects associated with environmental and occupational radiation exposures [61-66] (e-only Supplemental Table 3).

EDUCATIONAL STRATEGIES

The faculty of each medical school must decide on the specific content, structure, educational strategies, and appropriate educators (see Table 2 and e-only Supplemental Table 4). Approaches showing merit for radiation science education of medical students include case-based, problem-based learning that incorporates decision-making tools and computer-based modules simulating real cases (e-only Supplemental Table 4). Active experiential learning is critical with student and student teams' involvement throughout patient flow from the first encounter through posttreatment follow-up. Knowledge retention could be facilitated through establishment, updating, and critical curating of a web-based central repository of radiation educational materials, each characterized by brief descriptions and searchable using keywords.

Provide Knowledge Base and Introduce Radiation Procedure Skills for Patient Care

Multidisciplinary faculty input would be helpful for decisions about the direction and implementation of the curriculum. Horizontal and vertical integration of the core competencies and skills are recommended (see Table 2). For example, fluoroscopically guided procedures could be integrated within the surgery rotation, focusing on the conditions that can be successfully treated using this

approach (eg, carotid and peripheral vascular disease, pulmonary emboli, and cerebral procedures), contrasted with the limitations of this approach (eg, renal artery stenosis and inferior vena cava stenting). The knowledge and skills could be taught by faculty experienced in performing these procedures. Similarly, nuclear medicine, molecular imaging and hybrid procedure education, and radiotherapy could be integrated within the oncology components of the internal medicine or surgery rotations. Faculty in these radiation-related specialties could liaise with the clinical rotation directors to incorporate the education on these modalities within the standard clinical curriculum components. Recommendations would be useful from residency program directors about the radiation knowledge and skills needed [67].

Teach and Oversee Practice of Effective Patient Communication Skills

References shown in e-only [Supplemental Table 4](#) provide useful knowledge and strategies for patient-centered education about the benefits of radiological procedures, radiation dose, and risks [68-71]. Included in the references are descriptions of several approaches for providing clear and comprehensive information to patients and family members [57,58,68-71] (see additional references in e-only [Supplemental Table 4](#)). Before seeing patients, students could watch videos demonstrating effective strategies and participate in role-playing using standardized patients.

ASSESSMENT OF COMPETENCIES

The types of testing will vary by the competency being evaluated. A bank of examination questions developed by The Alliance of Medical Student Educators in Radiology [72,73] could be expanded to include the preclinical and radiation modality topics described above in addition to radiology. The 2017 UK medical school radiology curriculum prescribes the specific evaluation method including the objective structured clinical examination for testing each competency [33]. The objective structured clinical examination [74] could be used for formal evaluation by a faculty member or chief resident observing each medical student administering patient-centered counseling for a specific radiation procedure as a US medical school graduation requirement. Radiation-specific questions could also be added to the required United States Medical Licensing Examination administered during medical school.

CONCLUSION AND NEXT STEPS

The authors' proposal of nine competencies for an introductory broad-based radiation science educational

curriculum, as developed and vertically integrated within the existing curriculum by local faculty, could improve patient care and patient-centered communication. The knowledge, skills, and competencies proposed would address six curricular elements of the Liaison Committee on Medical Education and five core Entrustable Professional Activities recommended by the Association of American Medical Colleges for entering residency programs.

Next steps in developing an action plan might be for individual medical schools to assemble a multidisciplinary task force of clinical experts and medical school educators to identify core educational priorities. Based in part on the current proposal, radiology educators are implementing a broad-based radiation science educational curriculum at the Washington University School of Medicine in St. Louis highlighting systems-based practice competencies and interpersonal and communication skills for radiation procedures. The new curriculum also incorporates introductory material on biologic effects of ionizing and nonionizing radiation and a culture of radiation safety while underscoring interprofessional patient care in the imaging and radiation oncology departments and emphasizing how to effectively address patients' concerns about radiation procedures. Different approaches may be desirable for schools with different base curricula so the methods of instruction can be tailored accordingly.

The components of the approach we propose need to be tested and revised based on faculty and student feedback. Assessment of the efficacy of the ACR Appropriateness Criteria among US medical students has been limited. A randomized crossover study that compared use versus nonuse of the European Society of Radiology tool for appropriate selection of diagnostic imaging modalities revealed a higher proportion of appropriately justified and optimized imaging methods selected with use of the tool [75]. Literature on long-term benefits of medical school radiology rotations is sparse, but short-term assessments mostly reveal improvements in knowledge but are generally qualitative single-institution reports that rarely describe the instructional approach [76]. Evaluation of retention and, ideally, implementation of evidence-based best practices would be important to determine the extent to which the training is benefitting patients.

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ADDITIONAL RESOURCES

Additional resources can be found online at: <https://doi.org/10.1016/j.jacr.2022.08.010>.

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000 A Multimedia Strategy to Integrate Introductory Broad-Based Radiation Science Education in US Medical Schools

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