ORIGINAL ARTICLE

Early Imaging, Enduring Impact: Making the Case for Investment in Medical Student Radiology Education Within the Preclinical Years

CME

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Abstract

Although radiology has become an increasingly fundamental part of modern health care, undergraduate medical education regarding radiology has not kept pace, and graduating medical students often lack radiology competency. Early integration of radiology within undergraduate medical education can help address this knowledge gap; however, despite the educational value of preclinical radiology education, there are significant economic implications to increased radiologist involvement in medical student education. Radiologist time carries opportunity costs in terms of productivity and, without proper support, an added educational role can lead to radiologist burnout. Such barriers can be addressed through institutional investment in preclinical radiology education roles, faculty development, workload redistribution, and other approaches. Time-saving and cost-efficient educational strategies must also be used, such as use of asynchronous content, trainee staffing of teaching sessions, and web-based PACS tools. When implemented thoughtfully, preclinical radiology education can deliver high returns on investment in terms of creating radiology-competent future physicians, improving imaging utilization and health care efficiency, and potentially inspiring students to pursue careers in radiology. This article explores the educational and economic rationale for preclinical radiology education and offers cost-effective and impactful implementation strategies.

Key Words: Preclinical curriculum, radiology educators, radiology integration, undergraduate medical education

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INTRODUCTION

Radiology is an indispensable part of modern health care with an ever-expanding role in patient care [1,2]. This increasing footprint necessitates a strong foundational knowledge in radiology utilization and imaging interpretation among future physicians. Yet, residency program directors report substantial deficiencies in incoming residents' radiology skills, highlighting gaps in undergraduate medical education (UME) [3]. Medical school deans, radiology department chairs, and students have expressed similar views, with around 70% of medical students feeling current radiology training in UME is insufficient [4,5].

A robust radiology curriculum is necessary to achieve desired levels of competency in imaging utilization, interpretation of critical imaging findings, appropriate action on radiology reports, and engagement with consultant radiologists. Ideally, such a curriculum would span all 4 years of medical school. However, an ACR task force on radiology in UME found most radiology teaching occurs in the final 2 years (ie, the clinical years), with radiology exposure during these years described as inconsistent and rotation dependent [4,6]. In one study, 88% of graduating medical students had little knowledge of ACR Appropriateness Criteria, among other facets of radiology [7]. Although this could be addressed through dedicated radiology rotations, <25% of institutions require participation in such rotations, and they often occur late in training [8]. Addressing current shortfalls in UME radiology education requires early and repetitive exposure to radiologic principles, best achieved through an integrated radiology curriculum beginning in the preclinical years. Such integration demands substantial radiologist involvement in preclinical curricular development, teaching, and coordination—efforts that carry substantial time commitment and economic implications. Rising imaging volumes, constrained departmental resources, and increasing radiologist burnout are some of the many factors that complicate increased radiologist participation in preclinical medical education [9].

Despite these challenges, investing in preclinical radiology education may improve imaging utilization, underscore the importance of radiologists' role in patient care, and inspire students to engage with or even become radiologists. This article explores the educational and economic rationale for preclinical radiology education and offers cost-effective and impactful implementation strategies.

EDUCATIONAL RATIONALE FOR RADIOLOGY INTEGRATION IN THE PRECLINICAL YEARS

Integration of radiology into the preclinical curriculum can have significant downstream effects for students, medical schools, the field of radiology, and health care systems. To start, radiology integration naturally aligns with broader preclinical curricular goals, including the development of clinical decision-making skills, which often involve decisions regarding imaging, and the practice of evidence-based medicine, which can help guide such decisions. Radiology's inclusion in the more standardized preclinical curriculum, in comparison to the heterogenous nature of clinical rotations, ensures uniformity among students through provision of a common and consistent baseline radiologic education [4]. Incorporation of radiology into preclinical pathophysiology courses reinforces the biomedical knowledge taught therein, allows for radiology-pathology correlation, and places imaging in the context (and at the forefront) of disease diagnosis and treatment. This mimics the clinical environment, in which imaging is often the modality by which diseases are initially diagnosed and pathology identified. Students can be further prepared for their clinical rotations through preclinical integration of PACS usage, teaching interpretation of key imaging findings, and practicing application of the ACR Appropriateness Criteria [3,10]. Preclinical inclusion of radiology also supports the development of interprofessional collaboration. Branstetter et al found that early preclinical radiology exposure reduced negative stereotypes about radiologists and increased understanding of radiologists' contributions to patient care [11]. Finally, early radiology exposure helps garner student interest, evidenced by increased participation in clinical radiology electives, and may inspire students to pursue careers in radiology [11]. By providing early exposure, students are given ample time to explore a professional fit by shadowing, performing research, and identifying radiologist mentors.

ECONOMIC RATIONALE FOR RADIOLOGY INTEGRATION IN THE PRECLINICAL YEARS

Although the educational rationale for the preclinical radiology integration is clear, there is also good economic rationale for it, as described below. Both are summarized in Table 1.

On a medical school and departmental level, embedding radiology instruction within the preclinical curriculum may be more cost-effective than during clinical years. Leveraging existing infrastructure, such as classrooms, course coordinators, and existing preceptors (senior medical students, for example), enables efficient and economical integration. Synchronous faculty-led sessions require time away from revenue-generating clinical service, and annual delivery to all students within the preclinical curriculum is less resource intensive than repeating instruction throughout the year across multiple clinical rotations. This preclinical content may then be repurposed for asynchronous course work (videos and self-guided case reviews)

Table 1. Key rationale for increased radiology education within the preclinical curriculum

Educational	Economic
▪ Provides necessary foundational skills in radiology that students can apply and build upon in their future clinical rotations ▪ Aligns with core preclinical learning goals and reinforces content in anatomy, pathophysiology, clinical decision making, and evidence-based medicine courses ▪ Ensures a common, standardized radiology education as compared with heterogenous exposure to imaging on clinical rotations ▪ Fosters better interprofessional collaboration by reshaping student perceptions of radiologists as essential consultants ▪ Increases student interest in radiology careers and encourages participation in radiology electives and research	▪ Improved imaging utilization through improved awareness of clinical decision support guidelines and knowledge of radiology examination indications, decreasing health care costs ▪ Use of existing preclinical infrastructure and implementing educational experiences that reach all students simultaneously is more cost-effective than repeatedly delivering content within clinical rotations ▪ Early exposure and improved education may help alleviate the radiologist shortage, through both increased pursuit of careers in radiology and by equipping nonradiologists with better image interpretation skills for routine examinations

during recurring clinical rotations to reduce faculty burden. Overall, strong preclinical teaching lays the groundwork for more advanced clinical radiology education that is flexible, efficient, and sustainable.

Preclinical introduction of decision-support tools, such as the ACR Appropriateness Criteria, and teaching evidence-based judicious use of imaging may instill a more uniform and cost-conscious imaging approach within students before they begin clinical rotations. On a health care system level, improved ordering of appropriate and indicated radiology examinations, with reduction in redundant, inappropriate, and nonindicated studies, can lead to more effective imaging utilization and significant reductions in downstream health care costs [12,13]. Teaching such concepts early in UME allows application and refinement of this knowledge during clinical rotations, may help cultivate better postgraduation imaging utilization practices, and can minimize risk of misdiagnoses, improving diagnostic accuracy and health care efficiency [14-16].

When considering radiology as a specialty, preclinical radiology exposure may help address the growing shortage of radiologists by increasing the number of students pursuing careers in radiology. Radiology practices are currently facing increased workloads, high rates of burnout, and challenges in recruitment and retention—indicators of a workforce shortage [17-19]. Specialty-specific mentorship has been linked to increased odds of choosing that subspecialty and successfully matching into that subspecialty [20,21]. Anecdotally, students who participate in radiology research and identify mentors early in their training are more likely to successfully match into a radiology residency than those who discover the field later, aligning with findings in other fields.

RADIOLOGISTS AS ESSENTIAL PRECLINICAL EDUCATORS: A NECESSARY INVESTMENT

Preclinical radiology education is most effective when led by radiologists [22]. Despite this, nearly 60% of institutions use nonradiologists as the primary teachers of preclinical radiology content [23]. Within anatomy courses, for instance, a persistent trend toward inclusion of imaging education without radiologist involvement has been observed [24]. Although inclusion of imaging to support preclinical instruction should be encouraged, curricular integration by nonradiologists may lack the depth of knowledge, nuance in image interpretation and PACS usage, and guideline expertise that expert radiologist educators can provide [8]. As Farmakis et al stated, "A family medicine physician does not teach advanced surgical techniques, nor does a surgeon teach psychiatry. Radiology should be no exception" [8].

Despite the potential benefits of radiologist educators leading preclinical radiology curricular integration, such involvement has been constrained by economic and operational barriers. In this context, it is helpful to consider the opportunity cost of a radiologist's time. Time spent developing curriculum, creating content, and teaching comes at the expense of revenue-generating clinical responsibilities. This loss of billable hours is especially consequential as radiologists are faced with rising imaging volumes and productivity expectations in relative value unit-driven practices. Unfortunately, from a practice standpoint, UME has been described as "running at a negative margin" [25]. The balance of increasing clinical demands against teaching (which is often unsupported) results in faculty choosing not to teach [26,27].

In their study of moral distress among radiology clinician-educators, Belfi et al stated, "Now more than ever, clinician-educators are asked to do more with less time, fewer resources, and in an increasingly demanding work environment that is often discordant with providing quality education to their learners" [27]. The question that must then be asked of medical school and departmental leadership is: How can we create time and space for preclinical radiology educators to teach?

SOLUTIONS FOR PRECLINICAL RADIOLOGY EDUCATORS

Teaching medical students should be recognized and supported. This can be accomplished in several ways, including: (1) allocation of salary or "protected time," commonly described as full-time equivalent (FTE) support, or specific compensation for teaching tasks; (2) rebalancing of work—decreasing work or relative value unit requirements for educators and dispersing this work among a larger pool of radiologists; and (3) faculty development [28].

FTE support for UME teaching roles may be paid (at least in part) by the medical school and is typically reserved for major teaching roles, such as course or clerkship directorship and deanship. Many have expressed the need for an FTE-supported director role with the goal of integrating radiology education into the preclinical curriculum [23]. Others have called for similar support for faculty leading radiology involvement in anatomy courses [4].

The creation of such roles is paramount to successfully integrating radiology education across the preclinical curriculum by creating go-to radiologists who can coordinate teaching activities with preclinical course directors, oversee curriculum development, identify lecturers in specific subject areas, and organize small-group teaching sessions (SGSs), among other time-intensive tasks [4]. By consolidating such tasks under a director role, radiologists with strictly teaching roles, such as delivering a lecture or leading a laboratory session, are spared such responsibilities, removing some of the barriers to UME participation. Although FTE support of faculty participating in one or two teaching sessions would be ideal, it is not typically feasible. When this is the case, support may be offered by radiology departments in the form of decreased clinical requirements on their teaching day(s) or financial compensation.

Determining FTE support is essential but can be complex, requiring buy-in from both medical schools and radiology departments. Although some guidelines regarding recommended FTE support for roles such as course and clerkship director have been published, there are no such guidelines for roles that span multiple courses within the preclinical curriculum, much like a director of preclinical radiology education might do. Additionally, FTE support is not equivalent across specialties with different compensation. Consider this simplified example: The same 0.2 FTE support (20%) for a physician making $200,000 and one making $500,000 equates to $40,000 and $100,000, respectively. In this scenario, the same 0.2 FTE of the higher-compensated physician is more "expensive." As a well-compensated specialty, radiologists may therefore be considered expensive from an FTE standpoint. Depending on the institution, this may require medical schools and radiology departments to negotiate FTE cost sharing.

Alongside improved FTE support, radiology workflows can be modified to allow and encourage educational activities with little to no cost to the department. Radiologists may choose to rebalance assignments if a member participates in medical education. For instance, a group of radiologists with eight daily assigned shifts may choose to lower the work requirement for one and spread that work relatively evenly over the remaining seven. This results in substantial work reduction for the teaching radiologist, and only marginally increasing the work for the larger group. Employing a teaching attending at our institution with this model has yielded substantial benefits for both the faculty member and learners.

Faculty development also helps ensure success in preclinical radiology education. Modern medical educators must be familiar with adult learning theory, adept at creating engaging learning materials, understand how to moderate group learning activities, and provide effective feedback [28]. Preclinical radiology integration may require involvement of many radiologists with varying levels of familiarity with these concepts. To address this, many institutions have created free medical education courses. Departments may offer tuition reimbursement, which can support course work or advanced degrees in education. Radiology education leaders should be familiar with available options and promote them among interested faculty. Creating a quorum of educational leaders within the department allows for sharing of resources, ideas, and collaboration within UME, which may translate to less individual time investment.

IMPLEMENTATION STRATEGIES AND ECONOMIC CONSIDERATIONS

Given the significant investment radiologist educators require, their time must be used as efficiently and effectively as possible. Educators should prioritize preclinical radiology curricula that are both high value and cost-effective. Herein, we outline roles and highlight strategies that have proven successful in the integration of radiology education at the authors' institution (Fig. 1).

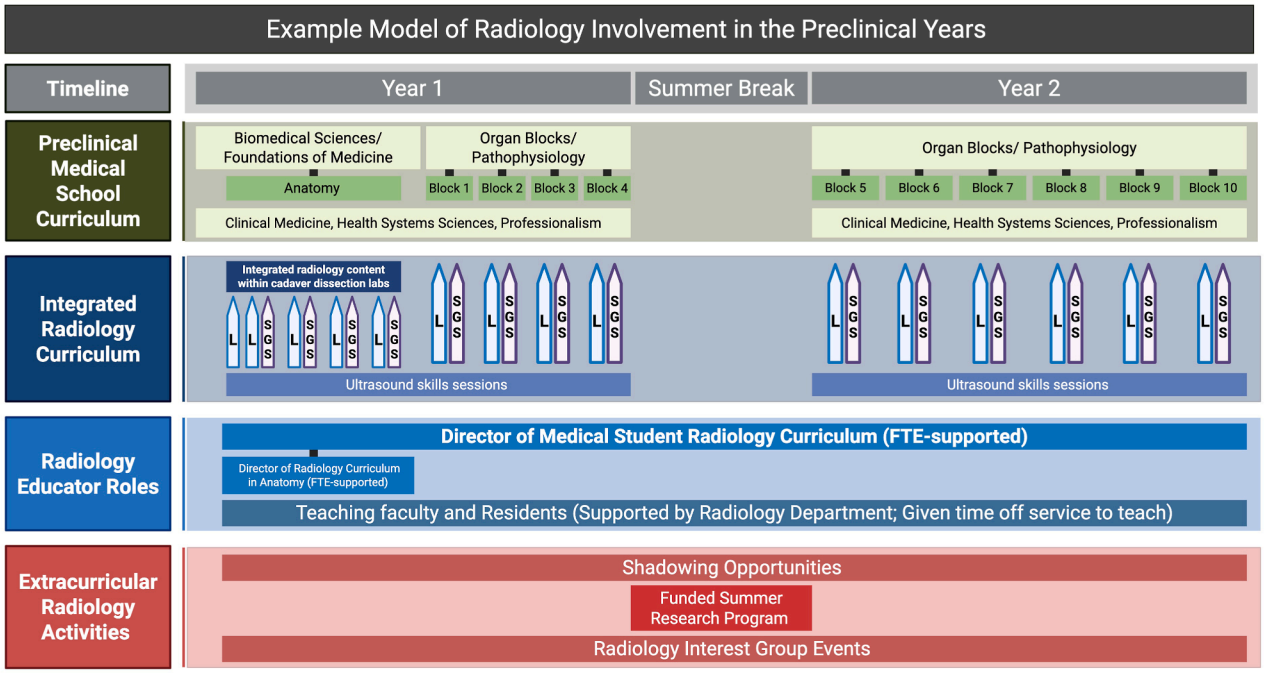

Fig. 1. Example model of radiology curriculum in the preclinical years, highlighting how integrated radiology curriculum lines up with the preclinical medical school curriculum, the role of radiology educator throughout the curriculum, and where extracurricular opportunities exist. FTE = full-time equivalent; L = lecture; SGS = small-group session, in which students work through radiology cases that correlate with curricular content.

Radiology Education Leaders and Curricular Roles

A director of medical student radiology education, whether focused solely on the preclinical curriculum or all of UME, is essential when considering curricular integration. This role must be adequately FTE supported. Directors coordinate when and where radiology content is integrated into preclinical courses, identify who delivers content and precepts SGSs, attend curricular planning meetings, and interface with course directors. Underscoring the importance of preclinical radiology education, our institution recently incorporated an FTE-supported radiologist codirector role within the anatomy course to further expand integration into the anatomy laboratory and classroom, in addition to an existing radiology director role that spans the UME curriculum.

Importantly, it is burdensome for the radiology clinical clerkship director to also oversee the integrative longitudinal radiology curriculum. In our experience, having separate FTE-supported directors is critical to perform both roles successfully. For subspecialty radiology electives, a minimal amount of FTE support is expected, and this should be scaled to account for the average number of students participating in each elective.

Radiology education directors and leaders also serve additional important roles at the interface between the medical school and other radiology educators, playing a critical part in mentoring junior faculty interested in teaching, providing expert guidance in developing and revising educational content, and helping faculty avoid common pitfalls when teaching students. For example, incorporating student feedback can be difficult and may discourage some faculty from engaging in UME. Supportive radiology education leaders can provide insight into effective and efficient revisions, rather than have faculty suffer revision inertia or feedback dissatisfaction that may deter future participation in teaching.

Using Existing Resources

One of the most time- and cost-efficient ways radiologists can introduce new content within the preclinical curriculum is to use existing educational resources. Online content available through Aquifer Radiology and ACR Radiology-TEACHES, for example, offer a broad range of established, validated educational material, and societal websites, like the Society of Thoracic Radiology, often offer robust and organized medical student educational resources. Pre-existing resources, whether free or paid, reduces (often substantially) the burden associated with content and curricular creation, requiring less start-up and maintenance effort. Additionally, involving senior medical students and residents interested in

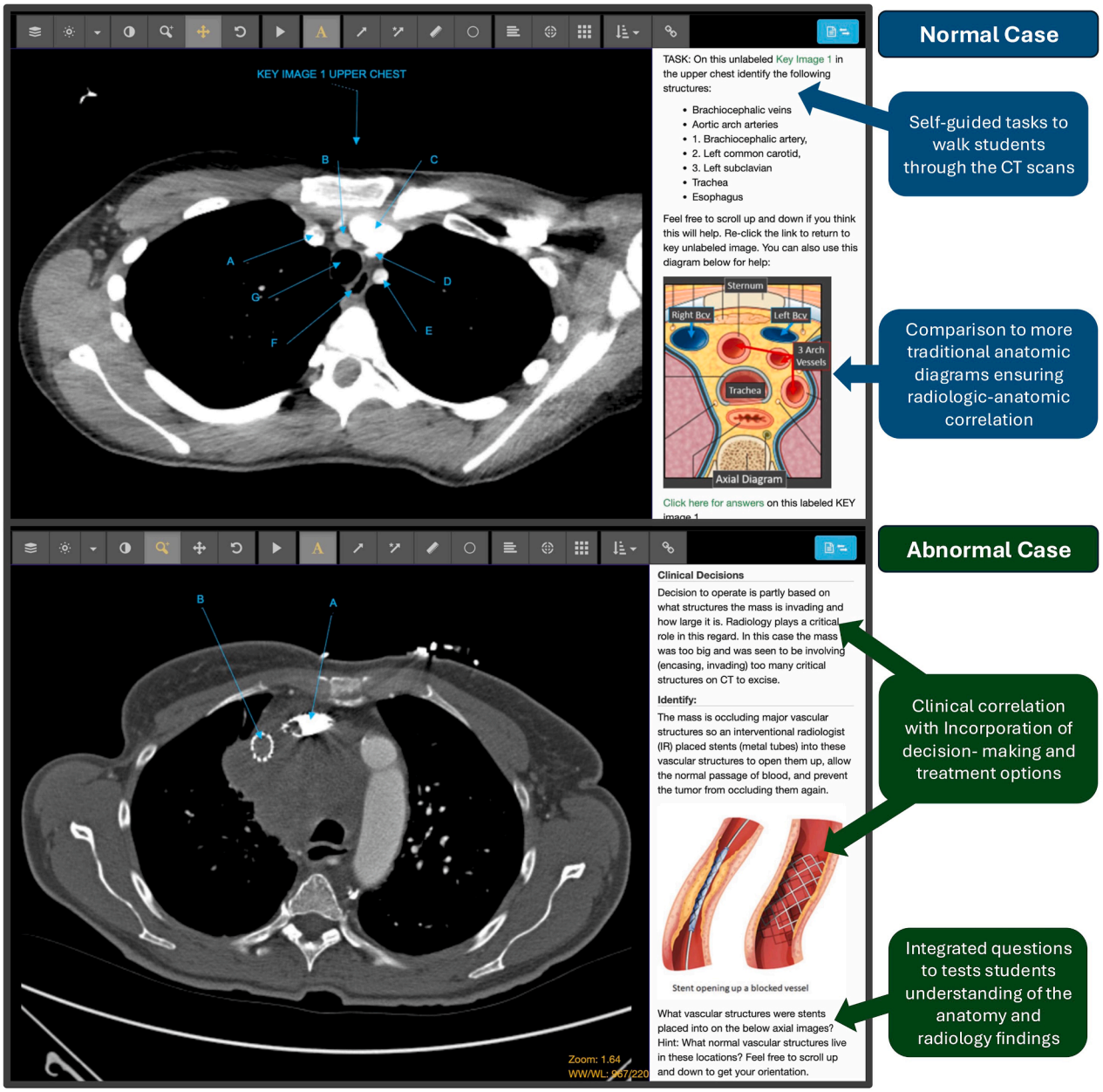

Fig. 2. Example PACS-based cases (pacsbin.com, Orion Medical Technologies, Baltimore, Maryland) used during radiology small-group sessions. Such cases are cost-effective, because such web-based PACS programs are relatively inexpensive, and the side panel allows for self-guided learning instructions (large blue and green arrows with text boxes) that can integrate text, diagrams, questions, and links to specific images, and labels (small arrows and letters overlying images), therefore requiring fewer faculty preceptors. Students learn to use PACS while learning radiologic anatomy, pathophysiology, and how radiology is used in clinical care, achieving multiple objectives of the radiology preclinical curriculum in a single educational tool.

teaching can greatly assist in creation of new content and may even inspire them to become radiology educators.

Curricular Integration and Asynchronous Learning

UME has largely shifted away from traditional, daylong lecture formats and has incorporated more asynchronous, self-directed learning. Live lectures, when still offered, are often recorded and streamed, with sparse in-person attendance at times as students increasingly favor the flexibility of watching recordings at their own pace. This self-directed pacing allows for pausing, note-taking, and rewatching from their preferred study environment and at their preferred study time [29,30]. Although these approaches enhance learner autonomy and efficiency, they also present ways for

radiology educators to reduce the economic impact of education. Leveraging asynchronous online platforms (such as Canvas; Instructure, Salth Lake City, Utah) for delivering recorded lectures, posting assignments, and hosting message boards can significantly reduce the need for faculty to deliver live sessions repeatedly. Though initial video creation and course setup may require time investment, tools like PowerPoint (Microsoft Corporation, Redmond, Washington) make video production readily accessible, and initial investments are offset by time and resources saved later. Once established, these resources can be reused, iterated upon, and refined, substantially minimizing faculty time off clinical service while maintaining effective educational delivery.

Small-Group Sessions

SGSs are increasingly used in UME. These activities require multiple preceptors and may occur multiple times per year, requiring significantly greater resources compared with faculty-delivered lectures. Recruiting enough radiologists for each SGS is challenging. Using radiology residents and senior medical students as preceptors offers a practical and economic solution. This approach reduces faculty staffing burdens, provides valuable teaching experience to trainees, and can foster a more comfortable learning environment through near-peer instruction. Additionally, precepting typically requires less preparation than lecture delivery, may be less intimidating, and does not require as much content expertise, often times making it easier to identify facilitators, as the role is less daunting as compared with lecture development and delivery. Because preceptors change yearly, a lead faculty member should orient them before each SGS, and assigning faculty to prepare trainee preceptors has proven effective for achieving educational goals.

Web-Based DICOM Viewers

Numerous web-based DICOM viewers can be obtained freely or for a subscription fee (often less than a few hundred dollars annually). Some of these DICOM viewers, such as Pacsbin (Orion Medical Technologies, Baltimore, Maryland), allow studies to be exported directly from institutional PACS. Images can be annotated with text and diagrams and can contain links to specific images with key findings, and quizzes can also be created (Fig. 2). Pacsbin cases are accessed via hyperlinks or a QR code that can be embedded in PowerPoint files and Word (Microsoft Corporation) documents, and shared via email. Scrolling through CTs, simulating clinical radiology practice, is immensely popular with students. Given web-based PACS can be accessed from any device, including tablets and smartphones, costs associated with use of clinical PACS stations and computer laboratories are decreased. Although such cases are ideal for SGS formats, they can also be used asynchronously, and they negate time spent arranging student PACS access or reading room entry.

Extracurricular Opportunities

Extracurricular opportunities offer a cost-effective and high-impact way to explore radiology more deeply. Shadowing experiences, when widely promoted and easily accessible, provide invaluable exposure to the day-to-day realities of radiology practice while being virtually cost free. Student-run radiology interest groups, which typically require minimal faculty oversight, can help organize these experiences and coordinate lectures, panel discussions, and other engaging events.

More structured initiatives, such as preclinical summer research, involve greater investment but yield substantial returns. These programs often provide students with stipends to cover living expenses, supporting their participation in meaningful research and mentorship. At the authors' institution, an interventional radiology summer research program tracked outcomes over 12 years, finding 76% of participants presented at national conferences, 68% published in radiology journals, and 23% pursued careers in radiology—a remarkable return on investment [31].

CONCLUSION

Integration of preclinical radiology education has been endorsed by expert panels, societies, program directors, and medical school deans and is supported by multiple case studies [3,4,10,11,32]. Its implementation addresses well-documented gaps in radiology competency among graduating students and depends on early, structured, and repeated exposure to radiologic principles, taught by radiologists and reinforced in interactive sessions and clinical rotations. Key components for success include FTE-supported director roles, leveraging existing infrastructure, investing in PACS-based tools, and using high-impact, low-effort educational formats. When supported thoughtfully, preclinical radiology delivers high return on investment including better imaging utilization, radiology-competent physicians, improved collaboration, and a potential remedy to the looming radiologist shortage. Institutions willing to prioritize these efforts will be well positioned to prepare the next generation of physicians for an image-rich, data-driven health care landscape.

SUMMARY STATEMENT

Early, thoughtfully resourced integration of radiology into preclinical medical education curriculum is both an

educational necessity and a sound economic investment that can help close competency gaps, improve imaging utilization and interpretation across specialties, and increase interest in radiology careers, but requires institutional investment and cost-efficient teaching strategies.

TAKE-HOME POINTS

- Current undergraduate medical education in radiology is often insufficient and inconsistent, resulting in competency gaps amongst graduating medical students regarding imaging utilization and interpretation.
- Early, integrated preclinical radiology teaching can establish a strong foundational radiologic knowledge in students and is educationally high-value, reinforcing other core tenets of the preclinical curriculum including anatomy, pathophysiology, clinical decision-making, and practice of evidence-based medicine.
- Radiologist involvement in undergraduate medical education carries significant economic and burnout risks, as teaching time competes with RVU-driven clinical productivity in an era of rising imaging volumes. Institutional investment, particularly FTE-supported radiology education leadership, is essential to implement and sustain an integrated radiology curriculum and coordinate teaching efforts.
- Cost-efficient and time-saving strategies can substantially reduce the faculty burden, and may include use of asynchronous content, utilization of validated pre-existing external resources, near-peer (resident of senior medical student) teaching, and web-based PACS tools.
- Thoughtful radiology integration into the preclinical curriculum yields high return on investment, ultimately improving imaging utilization and healthcare efficiency, strengthening interprofessional collaboration, and potentially helping address the radiologist workforce shortage.

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