Original Articles

Radiology Undergraduate and Resident Curricula: A Narrative Review of the Literature

Kathleen L. Linaker DC, DACBR, PhD*

Dean, Center for Life and Health Sciences, Mohawk Valley Community College, Utica, NY

Received 4 August 2015; received in revised form 18 September 2015; accepted 23 September 2015

Key indexing terms:

Chiropractic;
Clinical clerkship;
Clinical competence;
Curriculum;
Diagnostic imaging;
Education;
Medical

Abstract

Objective: The purpose of this study was to examine the literature regarding radiology curricula for both undergraduates and residents.

Methods: A review of the literature was performed using relevant key words. Articles were retrieved through December 2012 using PubMed, ScienceDirect, ERIC, Proquest, and ICL databases along with a manual review of references.

Results: Of the 4716 unique abstracts reviewed by the author, 142 were found to be relevant to the purpose of this study. Undergraduate radiology education, radiology curriculum, and radiology pedagogy vary widely between disciplines and between colleges within disciplines. Formal radiology education is not taught at all medical programs and little radiology training is incorporated into non-radiology residencies. This results in some medical graduates not being taught how to interpret basic radiology images and not learning contraindications and indications for ordering diagnostic imaging tests. There are no definitive studies examining how to incorporate radiology into the curriculum, how to teach radiology to either undergraduates or residents, or how to assess this clinical competency.

Conclusions: This review shows that radiology education is perceived to be important in undergraduate and residency programs. However, some programs do not include radiology training, thus graduates from those programs do not learn radiology essentials.

© 2015 National University of Health Sciences.

Introduction

Radiology education is a complex mix of varying pedagogy, assessment, and administration – governed

by beliefs about what should be taught, when it should be taught, and how to effectively teach the information. Opinions abound in the literature surrounding radiology education about what constitutes good education, usually presented with authors stating their opinion of what should be taught^{1–4} or how it should be taught.^{5,6} However, a dearth of literature exists examining how radiology is taught, learned, or evaluated. Nor is there much research comparing

* Mohawk Valley Community College, 1101 Sherman Drive, PH301D, Utica, NY, 13501-5394. Tel.: +1 716 931 1952; fax: +1 315 792 5697.

E-mail address: katlinaker@gmail.com.

radiology programs with regard to any of the myriad of variables that exists within a given curriculum. What little literature exists demonstrates that undergraduate radiology education, radiology curriculum, and radiology pedagogy vary widely between disciplines and between colleges *within* disciplines.^{7,8} The paucity of literature addressing these issues was best summarized with the statement: “evidence-based radiology education and radiology education research are glaringly lacking”.⁹

Radiology educational curricula at both the undergraduate and graduate levels have been discussed in the literature since the early 1900s. Significant similarity is found in resident and undergraduate radiology training; they often have similar needs and utilize the same resources¹⁰ However, no summary review has been completed to evaluate literature on Radiology educational curricula of undergraduate and graduate levels. A review is needed in order to provide a foundation of knowledge for informing future curricular research. Therefore, the purpose of this study was to examine the literature regarding radiology curricula for both undergraduates and residents in a variety of health professions educational programs.

Methods

Literature through December 2012 was searched using: PubMed, ScienceDirect, ERIC, Proquest, and ICL databases along with manual review of references. The comprehensive sampling strategy utilized the terms: radiology OR diagnostic imaging AND education OR teaching OR resident OR medical student OR chiropractic student OR curriculum OR medical education OR medical school OR medical students OR medical curriculum OR chiropractic education, OR chiropractic school OR chiropractic students OR chiropractic curriculum. Articles were limited to those in the English language and to humans.

Results

The resultant 4716 unique article abstracts and/or titles were reviewed by the author. All articles that appeared germane to undergraduate and resident radiology curriculum were obtained and reviewed by the author, which led to the inclusion of 142 articles in this paper.

Discussion

Undergraduate Radiology

Approximately 29% of American medical schools in 2000 had have a required core radiology clerkship¹¹ while 72% offer a radiology elective. This is a decrease from a similar study in 1994 that found 32% had required radiology clerkships.⁷ Internationally, hours spent in radiology training in undergraduate medical programs vary dramatically: a 1997 survey of 20 countries and 70 universities revealed hours dedicated to radiology ranged from 0 to 88 hours over medical undergraduate degree programs.¹² However, 87% of 322 surveyed non-radiologist physicians believe that radiology education should be mandatory in medical school¹³ and a 2003 article found that physicians overwhelmingly support radiology electives in the curriculum.¹⁴

Chiropractic education, unlike other healthcare programs, has long incorporated courses in radiology throughout its undergraduate curricula. Chiropractic curricula include courses on radiation physics, radiation protection, normal radiographic anatomy, bone pathology, and soft tissue pathology. On average, in chiropractic education in North America, 360 hours are dedicated to radiology education.¹⁵ Radiology classes generally begin in the first or second term of the program, and continue every term until students enter clinic in year four. In addition, portions of the National Board of Chiropractic Examiners (NBCE) exam are devoted specifically to radiology content.¹⁶

Much of the undergraduate medical radiology education literature centers on the importance of radiology education and, in particular, a formal radiology curriculum,^{17–21} what it should entail,^{22–24,4} when it should be taught,^{25,26} and how it should be incorporated, whether in the form of an integrated curriculum,^{27–29} an independent curriculum, or some combination of the two.^{30–34} Radiology curricula is problematic because not enough hours exist in undergraduate medical programs to adequately accommodate all courses that stakeholders wish to include in the curriculum.^{17,35,36} Additionally, stakeholders often have disparate goals, even when agreeing on curricular content.^{21,37,38} Complicating factors are numerous³⁹ and include poor remuneration for clerkship coordinators and other academic radiologists,^{11,40} changing demands due to health care reform,⁷ faculty members' time constraints,⁴⁰ and the fact that radiology instruction in problem-based learning curricula is often performed by non-radiologists.⁴¹ These issues have been in the literature for decades,^{42–47} cross into the chiropractic

undergraduate literature,⁴⁸ and continue to worsen. The wealth of knowledge undergraduate students must assimilate during their four-year tenure continues to increase with the ever-expanding body of medical knowledge.⁴⁹ Some articles suggest that new medical graduates exhibit a minimal level of radiology knowledge with approximately half of graduates not knowing the risks of common investigations or how to select the appropriate clinical investigation.^{50–54} This could possibly result in a potential risk to patients in clinical practice.

Lack of proper radiological knowledge and skill is not a new concern. Bloomfield (1977) argued that a comprehensive radiology-teaching program was needed in the undergraduate medical curriculum in order for all physicians to adequately interpret images when a radiologist is not immediately available and to know what imaging modality to order.⁵⁵ Interacting with radiologists is something all practitioners will do throughout their practice lives. Bloomfield presents his experiences as the sole developer and instructor of a radiology educational program at a medical school in Tasmania and suggests that a similar program needs to be incorporated into all medical colleges.^{47,55–57} He believes that radiology should be “the *key* subject in the medical curriculum”⁵⁷ (p. 981). Bloomfield (1978) develops this argument by explaining how he structured the courses to be in the form of tutorials and not lecture format. He found that students respond favorably to this teaching style and that evaluations ensured students grasped the information. In the 1980s, the University of Adelaide Medical School in Australia incorporated a six-week clinical skills training program that included nine hours in radiology: this inclusion was greatly appreciated by both the faculty and students.⁵⁸ The University of Adelaide Medical School program echoed an earlier teaching program in radiology in a clinical undergraduate course at the University of Liverpool in England.⁵⁹

The American Association of Dental Schools published curricular guidelines for oral radiology in 1980 that specify not only what needs to be taught, but also how to teach it, specifying that the students must have didactic and demonstration-type teaching, in addition to taking and interpreting radiographs.⁶⁰ These guidelines also specify the qualifications required of the individuals teaching these courses.

Several articles describe ways to alter a medical curriculum to integrate radiology in a variety of courses and times during students’ training. For instance, integration of radiology lectures into third-year student internal medicine clerkships has been attempted and was found to be just as favorably received by students as

independent radiology lectures. However, while the study evaluated compensation for the instructors for the two different courses, it did not assess the courses’ effectiveness by comparing their outcomes.⁶¹ Therefore, it is unclear from the article whether, academically, this is a worthwhile curricular revision.

Another form of curricular integration, studied at Emory University College of Medicine and the University of Iowa College Of Medicine, is the merging of radiology and anatomy courses,^{62–69} including using digital radiographic images alongside the cadaver in digital anatomy teaching suites.⁷⁰ This was shown to be effective at both institutions and is dependent on neither the instructor nor the institution.⁶⁷ Similar curricular reform has been implemented at the University of Maryland School of Medicine, with radiology education integrated into the second- and third-year core clinical clerkships.⁷¹ Other colleges are incorporating radiology into the basic anatomy classes at the start of the students’ program.⁷² A recent curricular change at Wake Forest University School of Medicine has resulted in a radiology clerkship supported by web technology and preliminary evaluations have found that the students learned well with this approach but administration and implementation of the clerkship has been problematic.^{32,73,74} An earlier attempt at integrating radiology into another course was undertaken in the 1960s through the use of cinefluorography in a medical pharmacology course.⁷⁵

A small subsection of this area of literature deals with the debate of what should be taught to undergraduates. For instance, 1 article proposes a specific set of educational objectives for medical student radiology training to prepare qualified future junior medical staff in a general practice setting.⁴ Other articles propose general curricular content for medical student instruction. The authors posit radiation protection⁷⁶ or suggest components of an overall radiology curriculum for medical students, such as cardiothoracic radiology, sonographic diagnosis, or the use of PACS for case presentation.^{31,77,78}

Radiology Residencies

Articles have been published discussing the need for a well-defined, quality curriculum for radiology residencies. Arguments supporting a national curriculum for radiology abound, with editorials, political articles, and letters addressing the topic. Some discuss the definition of curriculum, arguing it is more than a simple list of subjects. Others borrow heavily from educational literature presenting concepts such as: goals and objectives, the dynamic nature of curricular content, methods of instruction, faculty training, infrastructure

needs, and methods of evaluating both faculty and students.^{1,6,40,79,80} The authors explain that it is imperative that radiology education adopt these educational models to adequately educate future radiologists.⁸¹

Many articles propose curricula in specific areas of radiology, including cardiothoracic, musculoskeletal, mammography, or pediatric radiology.^{82–90} Proposals for new topic areas include imaging informatics and electronic imaging technology specialists.^{91,92} There are arguments about the degree to which specialization should occur^{93–96} and topics that should or should not be included in the curriculum.^{97–99} Articles of this nature can be found dating back to the 1960s. Some authors demand that a standardized national curriculum for radiology residencies be defined¹⁰⁰; that the institutions be required to follow the guidelines¹⁰¹; and that the radiology board exams test from the curriculum.^{102,103}

Authors also describe radiology education in its current manifestation, how it was developed, or how it was historically taught in their area of the world.^{104–113} Many European medical schools offer master's degrees in conjunction with their residency programs.¹¹⁴ This is also a trend in the chiropractic radiology residency programs with master's programs currently offered at National University of Health Sciences and New York Chiropractic College.¹¹⁵ The University of Glamorgan Welsh Institute of Chiropractic and Life University are currently developing similar master's programs.¹¹⁶

A subsection of curriculum discussion focuses upon non-interpretive skills^{117–119} that radiologists will need during their professional lives, such as job search and contracting skills,¹²⁰ business savvy, professional standards, ethics,^{121–124} accreditation programs, critical thinking skills, interpersonal skills, communication skills,^{125,126} research skills,¹²⁷ teaching skills,^{11,128–131} and medical organizational politics.¹³² One article describes a collaborative effort undertaken by the American College of Radiology and the Association of Program Directors in Radiology to meet this curricular need within residency programs. This effort entailed designing a set of videotapes to teach residents these skills.¹³³ This study found that significant resident learning occurred as a result of viewing the videotapes. Feedback from residents and residency directors was very positive. Additional skills requiring mastery by radiology residents include effective communication and an understanding of guidelines for making the most appropriate imaging or treatment decision for a specific clinical condition.¹³⁴ Accordingly, the Accreditation Council for Graduate Medical Education mandates that radiology residency programs teach residents communication skills.¹³⁵

Discussions exist of the importance of radiology training for residents in other medical specialties such as orthopedics,¹³⁶ pediatrics, internal medicine,¹³⁷ family practice,¹³⁸ and emergency medicine.¹³⁹ One article, examining the use of the morning report to provide radiological education to pediatric residents, found that during 388 case presentations over a 10-month period, 559 radiological studies were shown. However, the morning reports were generally done by non-radiologists which resulted in questions participants could not adequately answer. Common unanswered questions included radiological study indications and techniques and the radiological appearance of diseases. The article concluded it was important for radiologists to take part in morning reports to enhance primary care residents' education.¹⁴⁰ Several schools are integrating radiology resident training with emergency medicine residents¹³⁹ and other specialties, and some are requiring a clinical year in addition to the 4 years of radiology residency.¹⁴¹

Limitations

This study was limited to articles available in the English language and therefore is not comprehensive of all literature world-wide. The search did not include the grey-literature or other potentially relevant sources. It is possible that the search terms did not identify all relevant articles.

Conclusions

This literature review identified that the only similarity found in literature relating to radiology curricula is that radiology education is perceived to be important in both undergraduate and residency medical education programs. However, formal radiology education is not taught at all undergraduate medical programs and, in most undergraduate programs, it is only offered as an elective. Similarly, little radiology training is incorporated into non-radiology residencies. This insufficient amount of radiology education has resulted in about one-half of new medical graduates not learning the contraindications and indications for ordering diagnostic imaging tests, and not given the opportunity to learn how to read and interpret basic radiology images in the event that a radiologist is unavailable. The remaining literature on radiology education curricula consists of debates and suggestions for curricular content, descriptions of existing programs, and proposals for methods incorporating radiology into

various programs and other related ideas. No agreement exists in these areas, and it does not appear that there will be in the near future.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

References

- Collins J. Curriculum in radiology for residents: what, why, how, when, and where. *Acad Radiol* 2000;7(2):108–13.
- Croy BA, Dobson H. Radiology as a tool for teaching veterinary anatomy. *J Vet Med Educ* 2003;30:264–9.
- Subramaniam RM, Gibson RN. Radiology teaching: essentials of a quality teaching programme. *Australas Radiol* 2007;51(1):42–5.
- Subramaniam RM, Kim C, Scally P, Tress B. Medical student radiology training: What are the objectives for contemporary medical practice? *Acad Radiol* 2003;10:295–300.
- Gunderman RB, Williamson KB, Frank M, Heitkamp DE, Kipfer HD. Learner-centered education. *Radiology* 2003;227(1):15–7, <http://dx.doi.org/10.1148/radiol.2271021124>.
- Williamson KB, Gunderman RB, Cohen MD, Frank MS. Editorial—learning theory in radiology education. *Radiology* 2004;233(1):15–8, <http://dx.doi.org/10.1148/radiol.2331040198>.
- Barlev DM, Lautin EM, Amis ESJ, Lerner ME. A survey of radiology clerkships at teaching hospitals in the United States. *Invest Radiol* 1994;29:105–8.
- Subramaniam RM, Kim C, Scally P. Medical student radiology teaching in Australia and New Zealand. *Australas Radiol* 2007;51(4):358–61, <http://dx.doi.org/10.1111/j.1440-1673.2007.01750.x>.
- Tay K, Kamei R, Tan B. Developing a radiology curriculum for a new medical school in Singapore. In: Chhem R, Hibbert KM, VanDeven T, editors. *Radiology education: the scholarship of teaching and learning*. Berlin: Springer; 2009. p. 169–96. [Vol].
- Collins J, Riebe JD, Albanese MA, et al. Medical students and radiology residents: Can they learn as effectively with the same educational materials? *Acad Radiol* 1999;6(11):691–5.
- Shaffer S, Kitt S. Profile of medical student teaching in radiology: teaching methods, staff participation, and rewards. *Acad Radiol* 2000;7(10):868–74.
- Ell PJ. Undergraduate teaching of radiology and nuclear medicine. *Eur J Nucl Med* 1997;24(9):1081–2.
- Du Cret RP, Weinberg EJ, Sellers TA, Seybolt LM, Kuni CC, Thompson WM. Role of radiology in medical education: perspective of nonradiologists. *Acad Radiol* 1994;1(1):70–4.
- Shepherd SM, Dudewicz DM, Hindo WA. Immediate and long-term effects of a sophomore radiology elective. *Acad Radiol* 2003;10(7):786–93.
- Linaker KL. Shades of grey: An exploration of the student learning experience in diagnostic imaging education (doctoral dissertation). Chicago: Loyola University of Chicago; 2012 [Available from: http://ecommons.luc.edu/cgi/viewcontent.cgi?article=1307&context=luc_diss].
- National Board of Chiropractic Examiners. NBCE Part IV Examination November 2012 Brochure. https://www.nbce.org/pdfs/partiv_broch.pdf 2012.
- Afaq A, McCall J. Improving undergraduate education in radiology. *Acad Radiol* 2002;9:221–3.
- Cassumbhoy R, Lau WFE. Challenges in medical imaging teaching. *Australas Radiol* 2007;51(4):307–8.
- Lee JS, Aldrich JE, Eftekhari A, Nicolaou S, Müller NL. Implementation of a new undergraduate radiology curriculum: experience at the University of British Columbia. *Can Assoc Radiol J* 2007;58(5):272–8 [<http://www.ncbi.nlm.nih.gov/pubmed/18286902>].
- Scheiner JD, Noto RB, McCarten KM. Importance of radiology clerkships in teaching medical students life-threatening abnormalities on conventional chest radiographs. *Acad Radiol* 2002;9(2):217–20.
- Subramaniam RM, Sherriff J, Holmes K, Chan MC, Shadbolt B. Radiology curriculum for medical students: Clinicians' perspectives. *Australas Radiol* 2006;50(5):442–6.
- Lewis PJ, Shaffer K. Developing a national medical student curriculum in radiology. *J Am Coll Radiol* 2005;2(1):8–11.
- Mullins ME, Lieberman G, Shaffer K, Novelline RA. Factors to consider in the revision of educational objectives for medical students in radiology clerkships. *J Am Coll Radiol* 2005;2(1):55–60.
- Subramaniam R, Gibson R. Radiology teaching: essentials of a quality teaching programme. *Australas Radiol* 2007;51:42–5.
- Branstetter BF, Faix LE, Humphrey AL, Schumann JB. Preclinical medical student training in radiology: the effect of early exposure. *AJR Am J Roentgenol* 2007;188(1):W9–W14, <http://dx.doi.org/10.2214/AJR.05.2139>.
- Branstetter BF, Humphrey AL, Schumann JB. The long-term impact of preclinical education on medical Students' opinions about radiology. *Acad Radiol* 2008;15(10):1331–9.
- Ekelund L, Elzubeir M. Diagnostic radiology in an integrated curriculum: evaluation of student appraisal. *Acad Radiol* 2000;7(11):965–70.
- Ekelund L, Lanphear J. Diagnostic radiology in an integrated curriculum: experience from the United Arab Emirates. *Acad Radiol* 1997;4(9):653–6.
- Ekelund L, Langer R. Radiology is a perfect tool for problem based learning. *Acad Radiol* 2004;11(4):480.
- Anderson DJ, Jost RG. The senior radiology clerkship. Disparate goals of students and faculty. *Invest Radiol* 1988;23(8):632–3.
- Collins J, Reddy GP, Mullan BF, et al. A curriculum in cardiothoracic radiology for medical students, with goals and objectives. *Acad Radiol* 2001;8(12):1247–51.
- Relyea-Chew A, Chew FS. Dedicated core clerkship in radiology for medical students: development, implementation, evaluation, and comparison with distributed clerkship. *Acad Radiol* 2007;14(9):1127–36.
- Robinson AE, Voci S. On teaching radiology to medical students: a commentary. *Acad Radiol* 2002;9(2):224–5.
- Vydareny KH. The community hospital radiology clerkship: how should it be structured? Opinions of clinical and university faculty. *Invest Radiol* 1985;20(5):540–2.

35. Buckenham T. Teaching imaging to undergraduates: strategies and expectations. *N Z Med J* 2005;118(1224):U1698 [<http://www.ncbi.nlm.nih.gov/pubmed/16258574>].
36. Chapman AH. Report on the Kodak travelling scholarship section I: interventional radiology. Section II: undergraduate radiology training in North America. *Clin Radiol* 1982;33(3):241–51.
37. Anderson DJ, Jost RG. Student analysis of imaging studies. A radiology clerkship exercise. *Invest Radiol* 1988;23(10):776–7.
38. Subramaniam RM, Beckley V, Chan M, Chou T, Scally P. Radiology curriculum topics for medical students: Students' perspectives. *Acad Radiol* 2006;13(7):880–4.
39. Gunderman RB. Education and the art of uncertainty. *Radiology* 2005;237(3):801–2, <http://dx.doi.org/10.1148/radiol.2373050278>.
40. Cohen MD, Gunderman RB, Frank MS, Williamson KB. Challenges facing radiology educators. *J Am Coll Radiol* 2005;2(8):681–7.
41. Subramaniam RM, Scally P, Gibson R. Problem-based learning and medical student radiology teaching. *Australas Radiol* 2004;48(3):335–8, <http://dx.doi.org/10.1111/j.0004-8461.2004.01317.x>.
42. Bull JWD. What is diagnostic Radiology's place in medicine? *Br Med J* 1974;3(5927):394–400.
43. Clark GA. Radiology in the curriculum. *Lancet* 1936;227(5881):1143.
44. Freimanis AK. Successful teaching of radiology to medical students and interns. With emphasis on third and fourth-year programs. *Radiology* 1970;97(3):669–80.
45. Hood JH. The role of a university department of radiology. *Med J Aust* 1966;2(21):983–6.
46. Syme J. More about education in radiology. *Australas Radiol* 1971;15(2):111–2.
47. Syme J, Bloomfield JA. Radiology in the undergraduate curriculum: 1984 update. *Med J Aust* 1985;142(12):652–3.
48. Marchiori DM. Chiropractic student attitudes toward radiology. *J Manipulative Physiol Ther* 1996;19(9):583–6.
49. Robinson AE, Voci S. On teaching radiology to medical students. *Acad Radiol* 2002;9(1):224–5.
50. Holt NF. Medical students need more radiology education. *Acad Med* 2001;76(1):1.
51. Jeffrey DR, Goddard PR, Callaway MP, Greenwood R. Chest radiograph interpretation by medical students. *Clin Radiol* 2003;58(6):478–81.
52. Marchiori DM, Henderson CNR, Adams TL. Developing a clinical competency examination in radiology: part II — test results. *J Manipulative Physiol Ther* 1999;22(2):63–74.
53. Subramaniam R, Hall T, Chou T, Sheehan D. Radiology knowledge in new medical graduates in New Zealand. *N Z Med J* 2005;118(1224):U1699.
54. Subramaniam R. Response to editorial—teaching imaging to medical students: strategies and expectations'. *N Z Med J* 2005;118(1226):U1766.
55. Bloomfield JA. A radiology teaching programme for undergraduates. *Australas Radiol* 1977;21(2):184–8.
56. Bloomfield JA. Undergraduate training in radiology. *Australas Radiol* 1987;31(1):14–5.
57. Bloomfield JA. Radiology: focus of the medical curriculum? *AJR Am J Roentgenol* 1982;138(5):980–1.
58. Albertyn LE, Davies GT, Newble DI, Tucker WG. The fifth year undergraduate radiology teaching programme at the Queen Elizabeth Hospital. *Australas Radiol* 1987;31(3):232–5.
59. Whitehouse G, Sorrow G, Evans A. Initial experiences with a formalized teaching programme in diagnostic radiology during the clinical undergraduate course. *Clin Radiol* 1979;30:233–7.
60. American Association of Dental Schools. Curricular guidelines for oral radiology. *J Dent Educ* 1980;44:674–9.
61. Collins J, Dottl S, Albanese MA. Teaching radiology to medical students: an integrated approach. *Acad Radiol* 2002;9(9):1046–53.
62. Burkill G, Francis I. Trends in radiological anatomy teaching in the UK and Ireland. *Clin Radiol* 2003;58(7):570, [http://dx.doi.org/10.1016/S0009-9260\(03\)00139-9](http://dx.doi.org/10.1016/S0009-9260(03)00139-9).
63. Chowdhury R, Wilson ID, Oeppen RS. The departments of radiology and anatomy: new symbiotic relations? *Clin Radiol* 2008;63(8):918–20.
64. Chowdhury R, Wilson IDC. Re: The departments of radiology and anatomy: new symbiotic relations? A reply. *YCRAD Clin Radiol* 2009;64(6):651.
65. Erkonen WE, Albanese MA, Smith WL, Pantazis NJ. Gross anatomy instruction with diagnostic images. *Invest Radiol* 1990;25(3):292–4.
66. Erkonen WE, Albanese MA, Smith WL, Pantazis NJ. Effectiveness of teaching radiologic image interpretation in gross anatomy. A long-term follow-up. *Invest Radiol* 1992;27(3):264–6.
67. Erkonen WE, Vydareny KH, Sandra A, Ferguson KA, Kreiter CD. Interinstitutional study to compare the effectiveness of a radiology–anatomy module of instruction. *Acad Radiol* 2000;7(9):700–4.
68. Erkonen WE, Pantazis NJ, Smith WL, Albanese M. Gross anatomy and diagnostic imaging. *Invest Radiol* 1989;24(12).
69. Bohl M, Francois W, Gest T. Self-guided clinical cases for medical students based on postmortem CT scans of cadavers. *Surg Radiol Anat* 2011;29:173–80 [<http://hdl.handle.net/2027.42/87056>].
70. Miles KA. Diagnostic imaging in undergraduate medical education: an expanding role. *Clin Radiol* 2005;60(7):742–5.
71. Lowitt NR. Assessment of an integrated curriculum in radiology. *Acad Med* 2002;77(9):933.
72. Allen SS, Roberts K. An integrated structure-function module for first year medical students: correlating anatomy, clinical medicine and radiology. *Med Educ* 2002;36:1006–110.
73. Chew FS, Relyea-Chew A. Distributed Web-supported radiology clerkship for the required clinical clerkship year of medical school: development, implementation, and evaluation. *Acad Radiol* 2002;9(6):713–20.
74. Chew FS. Distributed radiology clerkship for the core clinical year of medical school. *Acad Med* 2002;77(11):1162–3.
75. Keats TE, Cochran DQ, Sweeny TP. Cinefluorography as a teaching instrument in the undergraduate course in medical pharmacology. *Am J Roentgenol* 1966;96(4):845–53.
76. Singh RK, McCoubrie P, Burney K, Miles JA. Teaching medical students about radiation protection—what do they need to know? *Clin Radiol* 2008;63(12):1344–9.
77. Angtuaco TL, Hopkins RH, DuBose TJ, Bursac Z, Angtuaco MJ, Ferris EJ. Sonographic physical diagnosis 101: teaching senior medical students basic ultrasound scanning skills using a compact ultrasound system. *Ultrasound Q* 2007;23(2):157–60.

78. Novelline RA, Scheiner JD, Mehta A, Mullins M. Preparing medical students for a filmless environment: instruction on the preparation of electronic case presentations from PACS. *Acad Radiol* 2001;8(3):266–8.
79. Chew FS. Educational infrastructure for radiology residency programs. *Acad Radiol* 2003;10:92–6.
80. Mundy WM, Binet E. A comprehensive objective-based curriculum for radiology residents. *Acad Radiol* 1995;2(2):173–8, [http://dx.doi.org/10.1016/S1076-6332\(05\)80155-2](http://dx.doi.org/10.1016/S1076-6332(05)80155-2).
81. Collins J, Abbott GF, Holbert JM, et al. Revised curriculum on cardiothoracic radiology for diagnostic radiology residency with goals and objectives related to general competencies 1. *Acad Radiol* 2005;12(2):210–23.
82. Babcock DS. Meeting ACGME requirements for a pediatric radiology training program. *Pediatr Radiol* 2002;32(8):545–8.
83. Bakshi R, Alexandrov AV, Gomez CR, Masdeu JC. Neuroimaging curriculum for neurology trainees: report from the neuroimaging section of the AAN. *J Neuroimaging* 2003;13(3):215–7.
84. Bassett LW, Cassady CI, Gold RH. Present status of residency training in mammography. *AJR Am J Roentgenol* 1991;156(1):59–62.
85. Kazerooni EA, Collins J, Reddy GP, et al. A curriculum in chest radiology for diagnostic radiology residency, with goals and objectives. *Acad Radiol* 2000;7(9):730–43 [<http://www.ncbi.nlm.nih.gov/pubmed/10987336>].
86. Collins J, Abbott GF, Holbert JM, et al. Revised curriculum on cardiothoracic radiology for diagnostic radiology residency with goals and objectives related to general competencies. *Acad Radiol* 2005;12(2):210–23, <http://dx.doi.org/10.1016/j.acra.2004.12.013>.
87. Flemming D, Davis KW, Dinauer PA, et al. Musculoskeletal radiology curriculum for radiology residents. *J Am Coll Radiol* 2007;4(9):636–9.
88. Resnik CS, De Smet AA, Chew FS, Kathol MH, Kransdorf MJ, Steinbach LS. Musculoskeletal radiology curriculum guide. The Education Committee of the American Society of Musculoskeletal Radiology. *Acad Radiol* 1999;6(6):360–7.
89. Resnik CS. The making of a curriculum. *Acad Radiol* 1999;6(6):325–6.
90. Smith WL, Schlesinger AE. A curriculum in pediatric radiology for diagnostic radiology residents. Education and Training Committee, Society for Pediatric Radiology. *Pediatr Radiol* 1995;25(5):403–7.
91. Bartholmai BJ, Erickson BJ, Hartman TE, et al. The electronic imaging technology specialist: the role of a new radiology subspecialty for the 21st century. *J Digit Imaging Off J Soc Comput Appl Radiol* 2002;15(Suppl 1):184–8, <http://dx.doi.org/10.1007/s10278-002-5024-y>.
92. Siddiqui KM, Weiss DL, Dunne AP, Branstetter BF. Integrating imaging informatics into the radiology residency curriculum: rationale and example curriculum. *J Am Coll Radiol* 2006;3(1):52–7.
93. Alderson PO. A balanced subspecialization strategy for radiology in the new millennium. *AJR Am J Roentgenol* 2000;175(1):7–8.
94. Arenson R, Dunnick NR. Training a better radiologist. *J Am Coll Radiol* 2006;3(6):389–93.
95. Bacon JF. Separation of programs in radiology training a general radiologist's evaluation. *Radiology* 1972;102:463–5.
96. Dunnick NR, Applegate K, Arenson R, Levin D. Training for the future of radiology: a report of the 2005 Intersociety Conference. *J Am Coll Radiol* 2006;3(5):319–24.
97. Collins J. Evaluation of an introductory course in chest radiology. *Acad Radiol* 1996;3(12):994–9.
98. Cuttino JT, Scatliff JH. First year radiology residents: PGI vs. PGII. *AJR Am J Roentgenol* 1979;132(5):855–6 [<http://www.ncbi.nlm.nih.gov/pubmed/20439076>].
99. Theros EG. The value of radiologic-pathologic correlation in the education of the radiologist. *Am J Roentgenol Radium Ther Nucl Med* 1969;107(2):235–57.
100. Chew FS. Standardization of the curriculum for resident education in diagnostic radiology. *Invest Radiol* 1990;25(11):1258–60.
101. Brummett DP, Brummett DM, Robinson AE. A 3CR 2 Problem-Solving Session 2000: The Teaching Curriculum and the Problem Attending Radiologist. *Acad Radiol* 2001;8(1):86–7.
102. Goske MJ, Reid JR. Define a national curriculum for radiology residents and test from it. *Acad Radiol* 2004;11(5):596–9, <http://dx.doi.org/10.1016/j.acra.2003.12.010> [discussion 600–601].
103. Goske MJ, Reid JR. Point/counterpoint define a national curriculum for radiology residents and test from It 1. 2004; 44195:596–9, <http://dx.doi.org/10.1016/j.acra.2003.12.010>.
104. Baddeley H, Middlemiss H. Radiology from the department of radiodiagnosis. University of Bristol; 1973:12–7.
105. Baddeley H, Middlemiss H. Training in Diagnostic Radiology. *Clin Radiol* 1973;24:12–7.
106. Berquist TH. Changes in radiology training and New examination format. *Am J Roentgenol* 2008;191(6):1641–8.
107. Felix R. Technology and radiologic education in Germany. *Invest Radiol* 1993;28:106–7.
108. Isherwood I. Radiologic education in Europe. New challenges and new opportunities. *Invest Radiol* 1993;28:94–5.
109. Moncada RM. Postgraduate radiologic education in Latin America. An international model for combining the resources of radiology societies and a United States university. *Invest Radiol* 1993;28:92–3.
110. Moncada RM, Cardoso JM, Gimenez CR, Secaf F, Martinez S, Palacios E. Postgraduate radiologic education in Latin America: an international model for combining the resources of organized radiology and a U.S. university. *Radiology* 1993;186(1):49A–53A.
111. Rubin P. Changing trends in radiologic education. American versus English and European programs. *J Med Educ* 1969;44(4):249–62.
112. Thomsen HS. Trends in European radiologic education in 1993. *Invest Radiol* 1994;29(1):109–12.
113. Young KJ, Siordia L. The legacy of the radiology residency of the Los Angeles College of chiropractic since 1978. *Chiropr Hist* 2000;20(1):33–7.
114. Flodmark O. Master in medical science with major in neuroradiology. *Neuroradiology* 2003;45(8):505–6, <http://dx.doi.org/10.1007/s00234-003-1083-0>.
115. Mestan MA, Taylor JA, Blackshaw GL, McDonald JC. Commentary: establishing an accredited master of science in diagnostic imaging degree at a chiropractic college. *J Manipulative Physiol Ther* 2006;29(5):410–3, <http://dx.doi.org/10.1016/j.jmpt.2006.04.008>.

116. American College of Chiropractic Radiology. Minutes of the ACCR Academics Committee Meeting 2005. 2005 American College of Chiropractic Radiology Workshop; 2005. [Vol].
117. Alderson PO. Noninterpretive skills for radiology residents. Introduction to series. *AJR Am J Roentgenol* 1999;173(6):1451.
118. Alderson PO. Customer service and satisfaction in radiology. *AJR Am J Roentgenol* 2000;175(2):319–23.
119. Gunderman RB. A vital skill for radiologic education. *Acad Radiol* 2001;8(7):651–5 [<http://www.ncbi.nlm.nih.gov/pubmed/11450967>].
120. Collins J. Noninterpretive skills for radiology residents. Job search and contracting issues. *AJR Am J Roentgenol* 1999;173(6):1453–7.
121. Chertoff J, Pisano E, Gert B. Core curriculum: research ethics for radiology residents. *XACRA Acad Radiol* 2009;16(1):108–16.
122. Gunderman RB. Why is ethics needed in the radiology curriculum? *Acad Radiol* 2001;8(1):82–5.
123. Oljeski SA, Homer MJ, Krackov WS. Incorporating ethics education into the radiology residency curriculum: a model. *AJR Am J Roentgenol* 2004;183(3):569–72.
124. Vydareny KH. Ethics education in the radiology residency curriculum. *AJR Am J Roentgenol* 2004;183(3):573 [<http://www.ncbi.nlm.nih.gov/pubmed/15333337>].
125. Goske MJ, Reid JR, Yaldoo-Poltorak D, Hewson M. RADPED: an approach to teaching communication skills to radiology residents. *Pediatr Radiol* 2005;35(4):381–6, <http://dx.doi.org/10.1007/s00247-004-1356-8>.
126. Ouellette H, Kassarian A, McLoud TC. Teaching the art of verbal consultation. *J Am Coll Radiol* 2006;3(1):9–10.
127. Baum S. Training for our future. *Acad Radiol* 2000;7(11):909–10.
128. Donovan A. Views of radiology program directors on the role of mentorship in the training of radiology residents. *Am J Roentgenol* 2010;194(3):704–8, <http://dx.doi.org/10.2214/AJR.09.3403>.
129. Gunderman RB, Heitkamp DE, Kipfer HD, Frank MS, Jackson VP, Williamson KB. Developing Tomorrow's academic radiologists: a 3-month residency elective in education. *Acad Radiol* 2003;10(6):650–6.
130. Donovan A. Radiology resident teaching skills improvement: impact of a resident teacher training program. *Acad Radiol* 2011;18(4):518–24.
131. Naeger DM, Phelps A, Shah V, Avrin D, Qayyum A. Clinician-educator pathway for radiology residents. *Acad Radiol* 2011;18(5):640–4.
132. Wood J, Collins J, Burnside ES, et al. Patient, faculty, and self-assessment of radiology resident performance: a 360-degree method of measuring professionalism and interpersonal/communication skills. *Acad Radiol* 2004;11(8):931–9.
133. Collins J, Amsel S, Alderson PO. Teaching Noninterpretive Skills to Radiology Residents: A Collaborative Effort between the American College of Radiology and the Association of Program Directors in Radiology. *Acad Radiol* 2001;8(9):903–7.
134. Vydareny KH. New tools from the ACR (American College of Radiology): appropriateness criteria and utilization analysis. *Radiol Manage* 1997;19(2):40–5.
135. Contemporary issues in medicine—medical informatics and population health: report II of the Medical School Objectives Project. *Acad Med* 1999;74(2):130–41.
136. Chew FS, Smirniotopoulos JG. Teaching skeletal radiology with use of computer-assisted instruction with interactive videodisc. *J Bone Joint Surg Am* 1995;77(7):1080–6.
137. Bingley LJ, Messaros J, Anderson JL. A radiology elective for internal medicine residents. *J Med Educ* 1988;63(7):571–2 [<http://www.ncbi.nlm.nih.gov/pubmed/3385760>].
138. Thompson BH, Berbaum KS, George MJ, Ely JW. Identifying left lower lobe pneumonia at chest radiography: Performance of family practice residents before and after a didactic session. *Acad Radiol* 1998;5(5):324–8.
139. Stubbs DM, Mundy WM. A joint course in emergency radiology for residents in radiology and in emergency medicine. *Invest Radiol* 1990;25(11):1261–4.
140. D'Alessandro DM, D'Alessandro MP. Radiologic Education of Pediatric Residents during Morning Report. 1997;1:534–8.
141. Wiest PW, Locken JA, Mettler Jr FA, LoRusso AP, Romero MV. The integrated clinical year: a unique approach to training radiology residents at the University of New Mexico. *Acad Radiol* 2002;9:343–5.