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Combined Radiology Residency/PhD Program for Education of Academic Radiologists: A Response to Revitalizing the Radiology Research Enterprise

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In a 1999 *RadioGraphics* article (1) entitled “Revitalizing the Radiology Research Enterprise,” Staab and Brady announced an initiative of the same name by the Radiological Society of North America (RSNA). The Revitalizing the Radiology Research Enterprise (RRRE) is designed to help academic radiology departments strengthen their research infrastructure and clarify their research strategy (2). Our department was one of six elected in 2000 to be surveyed and assisted by the RSNA's RRRE committee. A site visit that year provided a review of our research facilities and programs. In 2001, as a response to the challenge of the RRRE, we established a fully integrated 6-year residency/PhD program. The program combines radiology residency, under the guidelines of the B. Leonard Holman Research Pathway of the American Board of Radiology (ABR), with pursuit of a doctorate degree in radiological sciences.

Our program is designed to produce academic radiologists who are proficient in research and competitive for national funding. Herein, we describe the educational structure of the program and its results during its first several years.

Background

Current Standing of Research in Academic Radiology

Academic radiology faces two major challenges. First, the vitality of our specialty depends on continuing innovation and discovery by research-oriented radiologists. Second, faculty recruitment by academic departments is hampered by limited resources and competition from private practice. These challenges have been attributed to several factors, including the economic restructuring of academic departments (3), the severe salary discrepancy between academic and private practice, increasing barriers to national funding (4), and the lack of research training of most physicians (4–6).

Historically, most radiology research has been descriptive (4,7,8). While valid, useful observations have been made, today's increasingly complex imaging technologies necessitate more sophisticated research methods. Only a limited number of government-funded projects are credited to radiologist investigators (4,9). Our specialty's lack of

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competitiveness in this arena is tied in part to the nature of our residency programs, in which there is little research training (4,7,10–12).

Most radiologists in academic departments devote time to an escalating volume of clinical responsibilities, as well as to resident education, and have little time for research (4,5,13). Nonetheless, they face research requirements in university tenure tracks to achieve promotion (4,5,9). Many productive academicians sacrifice their free time for writing and research activities, and, if academicians are not located in large academic centers, they have little aid from statisticians, research associates, or scientist collaborators (4,5,7).

These circumstances call attention to the crucial need to sustain the growth of radiology, to compete for national funding, and to maintain scientific standards in research.

National Efforts to Strengthen Radiology Research

The current movement to strengthen radiology research began more than a decade ago. In 1994, a special National Institutes of Health (NIH)–cosponsored conference was held to address priorities for more than 30 areas of imaging research (14). In 1995, the Academy of Radiology Research was founded, with a goal of establishing an NIH institute for radiologic sciences (15,16). Creation of the National Institute of Biomedical Imaging and Bioengineering (NIBIB) (17) in 2000 fulfilled this goal and secured a prominent place within NIH for radiology. It boosted the visibility of the discipline and represented an acknowledgment of the importance of imaging research (18). NIBIB currently provides training and funding opportunities for investigators (19,20).

The nation's major radiology organizations also have made efforts to revitalize research. The ABR recognized the shortage of physician-investigators in radiology and radiation oncology and created the B. Leonard Holman Research Pathway for residents planning a career in basic or clinical research (21). The RSNA approved the RRRE in 1999 to increase the quality and quantity of research in academic radiology (22). The ACR organized the National Cancer Institute–funded American College of Radiology Imaging Network for clinical trials concerning cancer-related imaging and image-guided therapy (23,24).

Additionally, the Accreditation Council for Graduate Medical Education has a research requirement for residents of all specialties. In radiology programs, this requirement has been variably enforced. However, the existence of this requirement highlights the alliance between residents, medical students, and faculty as an important source of research (10,11,25).

Source of Research-oriented Radiologists: MD/PhD versus Resident/PhD Training

Despite these beneficial national efforts, problems within academic radiology remain. The number of research-oriented radiologists continues to be low. Difficulties persist in competing with private practice for faculty. A necessary component of the solution is to have more radiologists who are trained in research methods and are interested in research. This description matches the concept of the physician-scientist. Specifically, “the term *physician-scientist* represents the entire species of [physicians] who devote all or a majority of their professional effort to seeking new knowledge about health and disease through research” (26).

Physician-scientists are natural candidates for academic positions. However, they are uncommon in radiology. For this reason, it is worthwhile to examine the system for training new physician-scientists and how it relates to our specialty.

Currently, an established training pathway is the MD/PhD program, which is offered through medical schools. The MD/PhD avenue is made possible by the Medical Scientist Training Program (MSTP), which was created by the National Institute of General Medical Sciences in 1964. It is reported that 80% of MSTP graduates ultimately hold academic appointments, and researchers with a MD/PhD receive 30% of all NIH awards given to physician-scientists (27). The yearly crop of MD/PhD graduates would seem an ideal source of research-oriented radiologists. However, less than 2% of MD/PhD graduates specialize in radiology. Most pursue careers in internal medicine or pathology (28–31).

Several factors likely contribute to the disinclination of MD/PhD graduates to specialize in radiology. One important reason may be a lack of training and skills appropriate for radiology research. MD/PhD training is based on a general or nonspecific biomedical sciences curriculum, which reflects its origins in the preimaging era of medicine and medical science. However, today's world of radiology, in both the clinical and research spheres, is too specialized to accommodate such a generalized approach. Radiology and imaging science now encompass a vast body of knowledge, enough to justify a dedicated curriculum for training radiology physician-scientists. This necessity for specialized training is a major driving force behind our residency/PhD program. The program's aim is to optimize the conditions for research training in radiology and radiologic sciences—to provide a relevant, focused experience for the resident/PhD trainee.

Inasmuch as training conditions must be optimized, any barriers must also be eliminated. Any reasons for potential physician-scientists to avoid radiology as a specialty must be removed or at least minimized. Such reasons generally fall into three categories (27):

Time—Potential candidates may believe that after medical school, neither time nor resources for research training are available. They may also question whether the time commitment would be worthwhile. Would it contribute substantially to their career development? Would it require falling behind peers in clinical radiology?

Debt—Residents, having just finished medical school, may have a large debt burden, which has been cited as a disincentive to additional research training (32). Because of ever-rising tuition, traditional medical school graduates are likely to have taken out substantial loans. This is in contrast to MD/PhD trainees, because the MSTP pays medical school tuition and provides a yearly stipend.

Uncertainty of success—Radiology residents who are interested in academic careers may be concerned about their future competitiveness for financial support. This becomes particularly important when one considers the relatively low level of NIH funding for radiology research.

These three concerns are all addressed by specific features of our residency/PhD program, which will be detailed after we describe the general structure of the program.

Radiology Residency/PhD Program

The radiology residency/PhD program has been designed to provide instruction and foster critical research skills not present in traditional radiology residency training. Moreover, it is intended to provide specific, focused training for research-oriented radiologists that is not present in traditional MD/PhD curricula. We believe this approach can facilitate the development of successful academic research-oriented radiologists (Fig 1).

Structure of Residency/PhD Program

The program enrolls one resident per year to participate in an integrated 6-year curriculum that fulfills requirements of diagnostic radiology residency and PhD training. Upon completion of the program, graduates are eligible to sit for the ABR oral examination and receive a PhD in radiological sciences. Participation in the B. Leonard Holman Research Pathway allows the clinical internship (9 months), diagnostic radiology residency (27 months), and PhD program (3 years) to be condensed into 6 years. The 1st year consists entirely of clinical radiology rotations. The 2nd year contains the bulk of the PhD coursework, as well as the planning and initiation of the primary research project. In the 3rd year, most of the experiments and data collection are performed. Years 4–6 consist of a balanced mix of research time, clinical internship, and radiology rotations (Figs 2, 3). Residents are able to tailor their schedules to suit their specific research and educational needs. The clinical internship months are delayed until the latter half of the program so that the time may be focused in areas relevant to the resident's planned subspecialty, as recently advocated by Jost (33). After completion of the program, the trainee is encouraged to pursue a clinical or research fellowship and a mentored NIH K series career development award.

Features of Residency/PhD Program

The program incorporates several features that function to eliminate barriers that might deter prospective research-oriented radiologists from participating in further postgraduate training.

Dedicated time and resources—The resident participates in 3 years of research, including three semesters of formal PhD coursework. Furthermore, during clinical rotations, 1 day per week is allotted for research time, and, during research rotations, 1 day per week is spent on clinical duties. All three semesters of coursework (Table 1) include instruction in research skills, including study design, biostatistics, and writing. Another part of the resident's coursework is shared with students in the department's Graduate Program in Radiological Sciences—the second largest in the nation—which allows in-depth learning of imaging physics and technology. To develop the research plan, the resident works closely with one or several MD and PhD mentors. This results in the student's eventually selecting a primary research mentor and a supervising committee for the completion of the dissertation. Financial resources are also available, because the department will fund pilot projects to gather data in support of subsequent grant funding.

Furthermore, the program is designed to ensure that the time commitment is worthwhile and contributes substantially to career development. All the components of the program, including PhD training, are integrated into six postgraduate years. This structure means that the research resident commits to only one more postgraduate year than a radiology resident not in the program. The PhD dissertation itself consists of a compilation of scientific papers written during the course of the program, which are submitted to peer-reviewed journals for publication. The program also includes grant-seeking experience. Residents are expected to apply for grant support, including the RSNA Research Resident/Fellow Grant. Other sponsors of research grants for the residents include professional societies, industrial enterprises, and private foundations. Therefore, during the program, the resident builds experience and necessary skills for a future academic research career, as well as building a robust research portfolio and curriculum vitae.

Because the clinical radiology experience is reduced, the concern that research residents may fall behind their peers deserves attention. The shortened schedule is in accordance with the B. Leonard Holman Research Pathway, which requires 27 months of clinical radiology compared with 48 for other residents. However, several features of the program help mitigate clinical deficiencies.

1. The residency program director must attest to the resident's clinical progress to the ABR every year.
2. The entire first postgraduate year is spent in clinical radiology, rotating in all major subspecialties, providing a solid clinical foundation.
3. Subsequently, during research rotations, 1 day per week is spent in clinical duties.
4. Clinical internship rotations can be designed to focus on the imaging aspects of particular fields (eg, obstetric imaging while rotating in obstetrics/gynecology or cardiac imaging while rotating in cardiology), similar to other programs with integrated clinical experiences (35,36).
5. Daily noon lectures and case conferences supply almost 6 years of didactic material.

Debt relief—Several debt relief mechanisms are built into the program. Research residents are enrolled full time as graduate students in radiologic sciences until completion of the PhD in the final year. Student status affords a loan deferment (ie, postponement of repayment) for the duration of this period. In addition, the radiology department pays all tuition and fees. There is also a bonus of \$10 000 in salary support per year to lighten the economic burden of an extra year of training. Another debt relief mechanism exists for residents who participate in clinical research; namely, they may qualify for loan repayment programs (37,38).

Competitiveness for future funding—It is the intent of the program that graduates be competitive for grant funding at the national level. As described above, participation in the program provides experience in writing for scientific publication and grant seeking. In like measure, it results in a track record of publications and entry-level grant funding. To provide residents with important skills, scientific writing and grant-writing courses are included in the PhD curriculum. Furthermore, awarding of the PhD at the end of the program confers official recognition as a researcher in radiology.

Increased Efficiency

One of the major advantages of the resident/PhD program is its efficiency. This can be illustrated in contrast to MD/PhD training. MD/PhD trainees do not formally begin their research career until their first assistant professorship, on average (in 2005) at age 40 (39). Conversely, typical resident/PhD trainees begin their research career soon after 4 years of medical school, usually at age 26. By age 32, they have completed clinical and research training in radiology. They have a publication track record in their field, not in an unrelated area, as is often the case with MD/PhD graduates. They will join academic departments as research-oriented radiologists at an earlier age, and their careers as physician-scientists will be longer, thereby increasing the productivity for the per-student investment.

Benefits of the Program to the Department

The residency/PhD program is also an integral component of the development process of the department's research program, in line with recent calls for such progress (40,41). Funding of research residents forms a cost-effective method of fostering research, thus expanding both the quality and quantity of research. Moreover, it is designed to stimulate a cultural change in the department's academic environment. Research residents bridge the clinical and scientific staff and work in groups that include both. These multidisciplinary "mentorship cores" consist of faculty members, postdoctoral trainees, and graduate students who focus on a specific area of research. Creation of such mentorship cores is intended to encourage an atmosphere of team-work instrumental to development of the department's research

enterprise. Furthermore, the program promotes collaboration with other departments and institutions. A number of ongoing projects involve such collaboration. The resident's dissertation supervising committee by its nature is a multidisciplinary group, requiring one member from another department within the institution, as well as one expert in the field from outside the institution.

Integration with B. Leonard Holman Research Pathway

The B. Leonard Holman Research Pathway is the framework around which the residency/PhD program is built. As described by the ABR, "the purpose of this pathway is to allow certification in diagnostic radiology or radiation oncology for individuals interested in pursuing academic careers. It offers ABR-approved trainees the opportunity to more actively pursue research experience during their training" (42).

Residents apply for the B. Leonard Holman Research Pathway in their second postgraduate year and must be accepted to continue in the program. The program is designed so that the research resident fulfills the requirements of the Pathway during 6 years. In fact, the program expands on and exceeds those requirements, in three ways. First, formal research training is provided as PhD coursework. Second, including that coursework, the amount of research time is increased compared with the B. Leonard Holman Research Pathway requirement (3 years instead of 21 months). Third, under formal mentorship and supervision, an established sequence of research milestones culminates in the PhD degree.

Recruitment and Funding of Research Residents

Our main targets for recruitment are 4th-year medical students applying for radiology residency who have a demonstrated commitment to research. Thus far, most of the research residents have been recruited from the regular resident applicant pool or by word of mouth. Information is available on the department's Web site (43). Entrance requirements are stringent, because we are seeking excellent candidates with a high probability of success in academia. The salary for the one research resident per year is funded partially by the department and partially by hospital graduate medical education funds. Some of the research residents are eligible to compete for funding through a NIBIB-sponsored NIH National Research Service Award Institutional Research Training Grant (T32). So far, the training grant has funded three research residents.

Program Growth and Research Productivity

The program has grown from one to six residents in 6 years. Since the program's inception, research residents have presented their research results on numerous occasions at national meetings, have published a number of scientific papers, and have garnered substantial grant funding (Table 2, Fig 4). The number of active research projects in the department has also grown, along with the number of faculty members involved in these projects (Fig 5). The first resident to complete the program graduated in 2007 and has joined the department as a member of the faculty. Currently, we are continuing recruitment to ensure the program's sustained growth, and we are continuing to look for ways to improve the program to maximize its probability of success.

Conclusion

As a response to the RRRE, we have introduced the radiology residency/PhD program, a new model designed to address serious challenges facing academic radiology. One purpose of the program is to educate new academic radiologists. By efficiently integrating clinical training and a full PhD curriculum, the program offers an opportunity for capable residents to train as physician-scientists in radiology. It is our hope that graduates, armed with

experience and critical skills, will develop successful careers as research-oriented radiologists. Another purpose of the program is to strengthen research in the department in general. Thus, in itself, the program stands as an internal challenge to increase research quality and quantity.

Results of the first years of the program are promising. Future assessment of the accomplishments and career outcomes of the program's graduates, as well as its long-term benefits to the department itself, will prove the ultimate test of its success.

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Key Aspects of the Residency-PhD Program

1. Efficient curriculum combines radiology residency and PhD training, condensing a typical 1-year internship, 4-year residency, and 3-5-year PhD into 6 postgraduate years
2. Medical school coursework counts for one year of credit toward graduate degree
3. B. Leonard Holman Pathway enables reduction of clinical radiology to 27 months
4. Curriculum provides integrated clinical and research training early in professional career
5. Integrated training prevents reorientation necessitated by transitions in MD-PhD programs
6. Papers submitted for publication in peer-reviewed journals assemble to form dissertation
7. Publications and grant applications provide head start on academic career development

Figure 1.

Key aspects of combined residency/PhD program.

Figure 2. Pie chart shows distribution of time in residency/PhD program in months. Three years are spent in clinical training, and 3 years are spent in research.

Block	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
1	Chest	ER radiology	ER radiology	Mammography	Research	Research
2	Abdominal	Research	Research/Courses	Clinical internship	Abdominal	Clinical internship
3	Neuroradiology	PhD coursework	Research/Courses	Research	Research	Research
4	Special procedures	PhD coursework	Research/Courses	Research	Clinical internship	Clinical internship
5	Nuclear medicine	PhD coursework	Research/Courses	Nuclear medicine	Neuroradiology	Research
6	Neuroradiology	PhD coursework	Research/Courses	Research	Clinical internship	Clinical internship
7	Mammography	PhD coursework	Research	Clinical internship	Research	Research
8	Musculoskeletal	PhD coursework	Research	Research	Musculoskeletal	Neuroradiology
9	Fluoroscopy	PhD coursework	Nuclear medicine	Special procedures	AFIP	Chest
10	Pediatric radiology	PhD coursework	ER radiology	Research	Research	Mammography
11	Chest	PhD coursework	Research	Clinical internship	Clinical internship	Pediatric radiology
12	Abdominal	PhD coursework	Research	Research	Research	Nuclear medicine
13	Neuroradiology	Research	Research	Research	Research	Abdominal

Figure 3.

Typical schedule of rotations during residency/PhD training in 4-week blocks. Shaded areas = clinical rotations, unshaded areas = research rotations.

Grant Funding of Program Participants

1. 2004-08 NIBIB/NIH T32 "Multidisciplinary Human Imaging Training Grant"
2. 2005-07 NCI San Antonio Cancer Institute Image Guided Intervention Supplemental Award "Radiofrequency Ablation and Rhenium Liposomes for Solid Tumor Therapy"
3. 2006 Society of Uroradiology Research Award "3.0T MRI and Spectroscopic imaging of prostate cancer in a 'watchful waiting' patient cohort"
4. 2005-06 Philips/RSNA B. Leonard Holman Pathway Research Resident Seed Grant "Improved MRI Diagnosis of Collagenous Lesions in Tendon"
5. 2005-06 Society of Gastrointestinal Radiologists Phillip H. Meyers, M.D., Research Grant "Thermal Ablation of the Liver: Design of Effective Composite Ablations for the Treatment of Large Liver Tumors"

Figure 4.

Grant funding of program participants. *NCI*= National Cancer Institute.

Figure 5.

Current research projects, as labeled. *Tumor ablation*: Left: Illustration of overlapping ablation technique used to ablate large tumors. Right: Photograph of intraoperative in vivo porcine liver ablation study procedure. *Small animal imaging*: Two three-dimensional reconstructed single photon emission computed tomographic images of rat demonstrate increased uptake of radiolabeled liposomes in tumor after radiofrequency ablation compared with that in unablated control tumor. *3T prostate MRI*: High-spatial-resolution transverse (bottom) and coronal (top) 3.0-T endorectal coil magnetic resonance images demonstrate central gland benign prostatic hyperplasia nodules. *MRI of tendon lesions*: Evaluation of tendon crosslinking after glycation in vitro; short-echo-time MR images illustrate significant change in signal intensity over time after incubation in glucose (top line of graph) versus that in control tissue incubated without glucose (bottom line of graph). *AU*= arbitrary units.

Table 1**Combined Residency and PhD Coursework**

Course Name	No. Of Credit Hours
Patient Oriented Clinical Research Methods	4
Biostatistics for Medical Research	4
Seminars in Radiological Sciences	4
Physics of Diagnostic Imaging	3
Physics of Nuclear Medicine	3
Basic Radiation Biology	3
Introduction to MRI	2
Critical Skills in Writing Research Papers and Grants	2
Supervised Teaching	2
Physics Measurements in Imaging	1
NIH/NCI Human Participant Protections Education for Research Teams (34) (online course)	NA
Total	28

Note.—NA = not applicable, NCI = National Cancer Institute.

Table 2

Resident and PhD Research Productivity, 2002–2006

Achievement	Research Residents					Total
	A	B	C	D	E	
Scientific presentations and educational exhibits	8	5	3	1	8	25
Published peer-reviewed papers	3	2	1	0	4	10
Papers submitted for review	1	0	0	0	1	2
Papers in preparation	3	3	1	0	3	10
Ongoing research projects	4	4	2	2	1	13
Funded grant proposals	1	2	2	1	0	6