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Building for Tomorrow Today: Opportunities and Directions in Radiology Resident Research

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Medical imaging—comprising computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET) techniques, among others—has become an indispensable clinical tool (1). With the advent and introduction of these new imaging technologies over the past 30 years, much of radiology research was focused on the modality-specific imaging features of disease. While the importance of this descriptive research was critical to the development and maturation of these new imaging modalities, imaging and our understanding of the underlying pathophysiology of disease has since become much more nuanced and sophisticated. In recognition of this, there has been a concerted effort by academic departments as well as the Radiological Society of North America (RSNA) and the Association of University Radiologists (AUR) to promote early research training to develop researchers that are capable of tackling the hypothesis-driven research that is typically funded by the National Institutes of Health (NIH) (1).

To this end, the late 1990s and early 2000s saw the development of several measures to spur the participation and development of radiologists in radiologic and imaging-based research including the formation of the American Board of Radiology (ABR) Holman Pathway for training radiologists as basic and clinical research scientists, the launching of the Revitalizing the Radiology Research Enterprise (RRRE) by the RSNA, and capped by the

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establishment of the National Institute of Biomedical Imaging and Bioengineering (NIBIB) at the NIH in 2000. Despite these and ongoing efforts of academic radiology departments, academic radiology leadership (through the Society of Chairmen of Academic Radiology Departments [SCARD]), and clinical educators, resident participation has not significantly increased in the intervening time (2-5) even with research and scholarly activity comprising an important component of the Accreditation Council of Graduate Medical Education (ACMGE) Next Accreditation System (NAS) Milestone Project (6). To address this disconnect, it is imperative that radiology residents and fellows are made better aware of what contemporary research questions and directions exist in radiology research and the tools available to starting tackling these questions today.

A measured first step towards recruiting and training radiologic researchers is ensuring that trainees are aware of the abundant research opportunities available to them. Efforts to engage residents in contemporary research efforts range from programmatic approaches that incorporate formal research tracks or NIH research training programs (e.g. T32 programs) into residency programs to less structured and informal research opportunities scattered throughout training. Numerous funding opportunities to provide residents the resources to pursue radiologic research are also widely available. These range from institutional seed grants, research grants from the RSNA (including both basic science and educational grants), grants and research sponsorship from the Association of University Radiologists (AUR) to grants from the industrial sector (General Electric, Siemens and other) and other allied academic societies (e.g. American Heart Association and American College of Medical Quality). As the accessibility and application of medical imaging grows, the importance of nourishing physician-investigators trained in the radiologic sciences is increasingly important and highlights how critical opportunities and funding for radiology research, especially at the resident level, are towards realizing that today's research is tomorrow's practice (7).

This manuscript aims to serve as an introduction to the breadth and depth of ongoing research at academic radiology departments across the country and to highlight both subject matter and opportunities available to radiology residents eager to engage in radiologic research. Radiology research is not so narrowly defined as laboratory investigations or descriptive studies; in this article we hope to dispel any misconceptions about radiology research and to familiarize trainees to the wide spectrum of radiological research opportunities available to them.

Basic Science Research

Basic scientific research typically includes fundamental theoretical or experimental investigation designed to advance knowledge in its own right, without specific need for practical application or outcome (8). Broadly speaking, basic science research in biomedical imaging can be divided into categories of core scientific disciplines: the biological, chemical, and physical sciences. While it is not possible to be comprehensive in reviewing all possible opportunities in these disciplines, a brief introduction is offered, with a focus on research that is best suited to resident involvement.

Research Opportunities

Basic biological research in the imaging sciences is typically conducted under the umbrella of ‘biomarker’ development. In a very general sense, a biomarker can be described as any measurable diagnostic indicator that may be used to assess the risk or presence of disease (9). Imaging biomarkers are more specifically defined as anatomic, physiologic, biochemical, or molecular parameters detectable with imaging methods used to establish the presence or severity of disease (10). Traditionally, biomarkers have been divided into three categories—prognostic, predictive, and pharmacodynamics—with the first two categories being most relevant for biomedical imaging (11). Prognostic biomarkers aid in determining the natural course of a disease process; for example, distinguishing “good outcome” tumors from “poor outcome” tumors. Predictive (or response) biomarkers differ in that they assess the probability that a patient will benefit from a particular treatment. A common example of a predictive biomarker is the HER2/neu receptor in breast cancer. Unlike biochemical or histological markers, imaging biomarkers have the advantage of being noninvasive and being spatially and temporally resolved.

The initial steps of biomarker development, namely receptor (or target) identification and validation, remain a significant and active area of molecular biology research. Rapid advances in genomics and proteomics have propelled efforts in this area, most often outside of radiology departments. Opportunities for radiology residents are greater in the secondary stages of biomarker development, which include identification and optimization of novel compounds which image (and potentially act upon) established target receptors: i.e. *molecular* imaging. While imaging molecular targets is highly attractive, the more target-specific a molecular imaging probe is, the more restricted is its use, and the higher the risks are with its development (12). Furthermore, extensive toxicological studies must be performed for each new probe, likely limiting the use of molecular imaging as a biomarker to animal studies as a first step. Due to the complexity of the biology in tumors and other diseases, imaging science often endeavors to assess downstream changes of molecular/genetic pathways with *functional* imaging. The rationale of this approach is that many disease processes (especially tumors) acquire the same functional capabilities in their progression, albeit through various mechanisms. These capabilities may include up-regulation of numerous metabolic markers, unbounded proliferation, extensive angiogenesis, resistance to apoptosis, and metastasis formation (13). These general hallmarks of cancer are already imaged with existing imaging modalities, including PET, CT, MRI and MR spectroscopy. Examples of these functional imaging biomarkers include: increased glycolytic turnover as measured with 18F-fluorodeoxyglucose (FDG) PET; increased proliferation as assessed with 18F-thymidine PET, a marker of DNA synthesis; increased angiogenesis with perfusion MRI or 18F-RGD peptides targeting the $\alpha_v\beta_3$ integrins; and increased cellularity/apoptosis which can be assessed with diffusion-weighted MRI and 18F-annexin PET (12).

There is inherent overlap in basic imaging research between biological and chemical sciences; however, the latter is often focused on the design and optimization of injectable imaging agents. The basic problem of designing imaging agents is to achieve high target-to-background ratios, where the ideal agent contributes minimally to background signal (e.g.,

minimal nonspecific tissue extravasation, internalization by macrophages, or renal or hepatic elimination) but yields high concentrations at the intended sites (14). Chemical strategies are often employed in the solution of this problem when considering the design of radiopharmaceutical, magnetic resonance, and ultrasound contrast agents. Specifically, Weissleder, *et al.* describe chemical amplification strategies such as: using multiple copies of a label in a single molecule (multivalency), pairing of deactivators and fluorochromes (quenching), using covalent target binders (active-site binding), inducing magnetic changes on target interaction (relaxivity changes and magnetic switches), releasing caged compounds by photolysis (uncaging), and using distance-dependent interaction between excited states of dyes (FRET) (14).

Challenges and Solutions

The pursuit of basic science research as a radiology resident is inherently challenging. Most radiology residencies offer limited built-in research time due to increasing clinical demands. Prior surveys have shown that less than a quarter of residents are provided with dedicated research time, even upon request (15). The nature of basic science investigation requires not only protected longitudinal research time, but appropriate and early faculty mentorship. For radiology to be successful in training clinically excellent physicians with basic science expertise, departments must make a conscious investment. Recruitment of medical students with PhDs and “year-off” research experiences should be increased, as well as retaining qualified students who plan to continue basic research at their home institution. Training should be flexible to accommodate longitudinal research endeavors, particularly in the final year of training, in the context of recent changes by the ABR. Given the significant resources required to conduct basic research, radiology departments and their trainees should consider collaboration with other clinical and non-clinical departments. Trainees seeking to undertake basic science research should plan early, finding timely mentors who guide mentees with short- and long- term goals. Trainees should also exercise efficiency and foresight in obtaining funding, institutional research approval, and collaborators—especially graduate and medical students. Basic science research remains the bedrock upon which our specialty is built, and investing in its future will pay returns in the continued innovation and sustainability of biomedical imaging.

Clinical and Translational Research

Clinical and translational research (C&TR) applies discovered knowledge to advance diagnostic or therapeutic medical science, and is often less resource intensive and more accessible than basic science research. Specifically, translational research brings novel techniques, developed through basic science research, to the clinic in order to translate its use for contemporary medical diagnosis and therapy. Clinical research is broadly defined to encompass a variety of activities that involve direct interaction with human subjects and/or samples of their tissue.

Research Opportunities

There are a wide variety of research topics that fall under the rubric of C&TR and are appropriate for radiology resident involvement. These include, but are not limited to: clinical

validation of novel imaging techniques and modalities, product and medication safety and aftermarket surveillance, and imaging hardware and software development. Current research efforts are particularly robust in the clinical validation of new diagnostic agents being developed for MR and ultrasound, CT dose reduction methodologies, and quantitative MR imaging, quantitative PET imaging, analysis, and elastography. Aftermarket surveillance of newly introduced medications and products following Food and Drug Administration (FDA) approval is important clinical research and is well suited for radiology residents. For example, the first therapeutic alpha-emitting radiopharmaceutical (Xofigo – Radium-223 dichloride) was recently approved for the treatment of prostate cancer and bone metastases. Close post-marketing surveillance will help to establish its clinical safety and efficacy. Dose reduction, in both CT and fluoroscopic procedures, is an attractive clinical research area due to recent widespread publicity of high radiation doses associated with increasing radiologic procedures. Novel translational research may also involve medical device technology, such as novel methods for biopsy guidance, or new software applications, such as iPhone apps, which aid in decision support or scheduling.

Finally, imaging-related engineering and technical research should also be briefly considered. Radiology has a rich history of innovation in the development and optimization of novel imaging technologies, from the technical developments that laid the groundwork for magnetic resonance imaging, to the continued optimization of MRI utilizing novel pulse sequences. Examples of research opportunities in magnetic resonance technology include areas such as: receiver coil design, which impacts image signal-to-noise ratio (SNR); novel pulse sequence design, which increase desirable signal and/or reduce undesirable signal; varied data sampling techniques, such as Partial Fourier acquisition, which can decrease scan time; contrast-enhanced and time-of-flight techniques for vascular imaging; perfusion- and diffusion- weighted imaging techniques; diffusion tensor imaging (DTI), which measures and maps the orientation of myelin fibers in the brain; blood oxygenation level dependent (BOLD) techniques for assessing tissue function; proton spectroscopy techniques for noninvasive biochemical measurements; and new techniques in cardiac MRI for assessing morphology, function, viability, and anatomy (16). Similarly, opportunities for research in instrumentation and novel data analysis exist for other imaging modalities, namely nuclear medicine and ultrasound.

Challenges and Solutions

Many of the challenges residents may encounter in their clinical research efforts are similar to those encountered in basic research, including time constraints from a clinically demanding schedule, limited availability of protected research time, and poor mentorship. The lack of physical and administrative infrastructure may also hinder efforts towards a residents' involvement in clinical research. The formation of close clinical collaborations with allied medical and surgical colleagues can be highly productive and provide resources that might not be available in a resident's home department. Additionally, interdisciplinary research teams strengthen both ongoing research and applications for future grant funding. By developing manageable and realistic projects in partnership with faculty and clinical colleagues, residents can reduce the resources that a project might need. Non-traditional funding, such as a Small Business Innovation Research (SBIR) grant might be considered

for research projects with commercial potential. Existing intellectual property and patents should be investigated before proceeding with research that might be commercialized. Finally, institutional restrictions that limit the research participation of drug and device companies should be reviewed to ensure that institutional policies maintain academic integrity while exploring available research opportunities.

Information Technology and Informatics Research

Healthcare information technology (IT) and informatics tools—comprising the whole spectrum of computer hardware and software available in the clinical setting—have completely revolutionized modern radiology practice (17, 18), and in recent years have started to make their way into the broader healthcare enterprise (19). These efforts have been spurred in part by legislation such as the Health Information Technology and for Economic and Clinical Health (HITECH) Act, “meaningful use” mandates by the Centers for Medicare and Medicaid Services, and creation of the Office of the National Coordinator for Health Information Technology (20-23). Given this widespread interest in promoting the use of IT in healthcare delivery and ongoing improvements in the underlying technologies, there are enormous opportunities for residents to contribute to research and innovation in this field.

Research Opportunities

Research opportunities in healthcare IT can be classified into three broad categories: development of informatics tools, evaluation of informatics tools, and improvement of national standards and infrastructure.

Development of informatics tools often involves improvements to existing radiology workflow (24-26). Tools that enable improved computerized decision support and high fidelity protocol selection can improve the quality and efficiency of the pre-imaging workflow. Software to aggregate patient information from electronic health records or “just-in-time” knowledge databases that provide radiologists with pertinent knowledge at the moment it is needed can enhance the data-gathering phase of the radiologist's workflow. Tools that facilitate computer-aided detection and visualization can improve visualization of CT colonography and enterography datasets and permit enhanced detection of lung nodules and breast masses, thereby improving the interpretative phase of workflow. Software to simplify the generation of structured reports of results, and to enable efficient transmission of results to other providers, can greatly improve reporting. Lastly, opportunities to improve the post-imaging phase of workflow may take the form of software to streamline peer review, permit continuous quality improvement, enable sharing of images with geographically distinct sites, and facilitate clinical follow-up. Notably, some areas of opportunity do not strictly involve improvements in routine workflow. New and improved image display and storage technologies, such as cloud-based PACS, vendor neutral archives, and mobile display can address infrastructure needs, while case-based teaching files and interactive case-taking software can offer didactic improvements.

Important research opportunities also exist for residents interested in evaluating rather than developing informatics tools. In its most basic form, this may involve utilization research, looking at utilization rates and satisfaction scores for a variety of informatics tools. As an

example of this sort of research, one could ascertain the number of cases submitted for peer review, or the fraction of dictated reports that contain radiation dose information. Beyond simply assessing utilization, one could take inspiration from clinical outcomes research by assessing the actual impact of these tools on clinical practice, or alternatively, using these tools to measure the quality and efficiency of clinical practice (24-28). For example, one could attempt to quantify cost-savings associated with the use of computerized decision support systems or image sharing networks, or assess the likelihood of imaging follow up in outpatients for whom radiological results are securely transmitted using a computerized system.

Finally, there are research opportunities in the development of national standards and infrastructure. Interested residents could get involved in the development and deployment of new information sharing infrastructure, such as the RSNA Image Share network or various projects of Integrating the Healthcare Enterprise (29, 30). Alternatively, residents could participate in the establishment of national standards such as the RSNA-developed RadLex or various other lexical systems such as BI-RADS or LI-RADS (24, 31, 32), which are essential for the development of the next generation of data mining and information processing tools used in clinical radiology.

Challenges and Solutions

Compared to other forms of research, there are fewer funding opportunities in informatics and IT, except for a few grant-offering organizations such as the Society for Imaging Informatics in Medicine (SIIM) and the RSNA. Fortunately, many forms of informatics research do not require large capital expenditures and can be successfully performed with institutional seed funds.

Clinical informatics research requires a skills set and knowledge base that is not developed in traditional medical school and residency training. As such, the intellectual barrier to entry may be relatively high. Further, subject-matter expertise in this area is not available at all institutions. Fortunately, public educational resources are widely available for residents interested in developing skills such as computer programming. Further, if local expertise is unavailable, there are numerous opportunities for residents to engage in cross-institutional research through national radiology organizations such as SIIM, RSNA, and the AUR.

A unique challenge of informatics research is the blurred line between research and commercialization. Specifically, research into the development of informatics tools is largely synonymous with product development. While this feature may be advantageous for physicians looking to bridge the gap between clinical practice and entrepreneurship, research of this sort may run into institutional barriers against industrial partnerships as well as conflict over intellectual property.

Quality Improvement and Health Care Economics Research

Radiology continues to rapidly evolve and incorporate new paradigms into practice. Among these is a renewed focus on quality improvement (QI), which encompasses encompasses

programs/procedures for quality assurance and continuous important, improved patient and staff safety, and improved clinical, technical, and diagnostic performance (33).

While the most important and overarching goal of QI is to improve patient care, there are additional practical reasons to emphasize QI. For example, as the Accountable Care Act (ACA) begins to implement its various regulatory aims, the Centers for Medicare and Medicaid Services have begun to shift from a fee-for-service based compensation model, to a pay-for-performance model. This new model emphasizes reimbursement based upon various performance metrics, and thus a focus on QI allows a radiology department to simultaneously optimize the chances of financial solvency. An ongoing emphasis on QI also helps to mitigate potential malpractice exposure allowed by the absence of a tort reform component in the ACA. In addition, given the expanding role of QI across all medical specialties, emphasis and expertise in QI creates a natural opportunity for radiologists to be visible and active within hospital administration, particularly within the framework of various QI committees.

QI is now a mandated component of the ABR's Maintenance of Certification (MOC) program, which is required for radiologists to maintain board certification. In particular, MOC is composed of four distinct aspects: (1) evidence of professional standing, (2) lifelong learning self-assessment (via CME), (3) cognitive expertise (via an examination), and (4) practice quality improvement (PQI). Examples of QI projects delineated by the ABR include: fluoroscopy dose recording, universal procedural pause, techniques to reduce breath-hold artifacts on abdominal imaging studies, and many others.

Research Opportunities in QI

Having explained the importance of QI, we can now review specific mechanisms through which residents can become involved in QI research. In this section, we consider specific QI research opportunities in order of proximity to individual residents: program-specific opportunities, followed by those offered by academic institutions, and lastly those offered by professional societies.

Radiology residencies have started to recognize the importance of QI as a part of the educational mission of a radiology residency and have taken measured steps to incorporate QI into the radiology residency curriculum. At Beth Israel Deaconess Medical Center (BIDMC), for example, one of the requirements for graduation from the residency is that the resident has completed a Quality Assurance rotation. This rotation itself lasts two weeks and takes place in the second year of residency. During this time, the resident is linked with a mentor of their choosing and formulates a QI project to be completed by the end of residency. While the two-week rotation is given as dedicated time, remaining data collection, analysis, and subsequent presentation of the work often occurs for several months following the protected rotation. Ultimately, the results from QI projects are presented annually to the entire department, and often submitted for publication and/or presentation at national meetings.

In addition to structured QI activities and curricula established by radiology departments, residents with a deeper interest in QI may become engaged in research and educational

opportunities sponsored by the larger academic institution. These areas of QI involvement may be sponsored by a specific department (e.g. Medicine), or by a QI-focused research institute such as the Stoneham Center for Quality Improvement (BIDMC) or the Armstrong Institute for Patient Safety and Quality (Johns Hopkins). While these types of opportunities may be more general in nature, there is often room for radiology residents to bring their own unique perspectives and areas of academic interest together with other clinical services to create projects that examine the interface between referring services and consultant radiologists.

Many of radiology's professional societies offer research grants, awards, and opportunities for residents who wish to pursue QI research. The RSNA, for example, offers Research and Education Grants for radiology residents or fellows pursuing original research in QI. These grants often require 6-12 months of part-time or fulltime research and offer both a stipend and the opportunity to present at a national meeting. Additional funding or recognition opportunities may exist locally, and vary between state-specific radiology professional societies.

Research Opportunities in Health Care Economics

Beyond quality improvement, residents may also consider the often-overlooked area of health care economics (HCE), which is important to the health and longevity of radiology as a field. In the constantly changing landscape of medicine and radiology, professional societies such as the American College of Radiology (ACR) are increasingly directing resources at the interface between radiology and economics. Specific examples of the ACR's more recent efforts include: the Imaging 3.0 campaign, Medicare Payment Systems reform, and the creation and implementation of Clinical Decision Support. The importance of continued education, research, and advocacy for the value of radiology in the context of healthcare reform cannot be overstated. The 2005 Deficit Reduction Act, as an example, had drastic and painful effects on the field of radiology. Its swift congressional passage along with many other healthcare reforms stand as stark reminders that radiologists must strongly advocate for the future of their specialty. Residents skilled in HCE research will be well positioned to have a meaningful voice in these discussions.

Fortunately, many of the same research opportunities afforded to radiology residents pursuing QI research can be extended to HCE research. For instance, programs may offer residents the opportunity to pursue HCE-related research during residency. In some cases, there may even be an option to work affiliated business schools to obtain a formal degree, adding further value and credibility to the experience.

Furthermore, national opportunities for radiology advocacy also exist. As one example, the ACR's Annual Meeting and Chapter Leadership Conference (AMCLC) affords residents the chance to attend lectures relating to health care economics and radiology, and to meet with current leaders of the ACR. At this unique annual venue, residents even have the opportunity to sit with United States Senators and Representatives to discuss legislative issues affecting the field and advocate for positive change.

Comparative effectiveness research (CER) has also emerged as a vibrant field of study within both radiology and in medicine at large. CER, as recently defined by the Institute of Medicine, is defined as the generation and synthesis of evidence that compares the benefits and harms of alternative methods to prevent, diagnose, treat, and monitor a clinical condition or to improve the delivery of care (34-36). The passage of the American Recovery and Reinvestment Act of 2009 (ARRA) and the Patient Protection and Affordable Care Act (PPACA) in 2010 codified and made necessary resources available for the development and dissemination of CER with commensurate funding to support research in comparative effectiveness (36). Within radiology, numerous prospectively driven CER studies have been recently published including the evaluation of emergency department patients with acute coronary syndrome with and without CT angiography (37), comparing digital versus film-screen mammography (38), and the inclusion of MRI in the evaluation of women prior to wide local excision (39), all of which can serve as templates for future investigations in CER (40). The passage of the PPACA also created the Patient-Centered Outcomes Research Institute (PCORI) to conduct research to provide information about the best available evidence to help patients and their health care providers make more informed decisions (40). Radiology as a discipline is uniquely positioned to make substantial contributions to both CER and research affiliated with PCORI; largely due to our close integration in contemporary patient management from initial diagnosis, to disease surveillance, to therapeutic intervention, there is tremendous potential for imaging to improve patient outcomes and reduce costs to the overall health system (40).

Challenges and Solutions

Radiology residents performing research in QI/HCE face many of the challenges similarly encountered by residents pursuing basic science and clinical research as detailed previously. QI and HCE radiology-specific investigations are also relatively novel research domains within most radiology departments and thus may not be beneficiaries of departmental support and resources as other better-established departmental research endeavors. Similarly, there may be a lack of mentors available within the department who are performing QI/HCE research. Looking beyond the radiology department, residents can expand their network and collaborate with other clinician colleagues and health care economists to pursue their interests.

As with the other forms of research discussed here, attracting funding and support for QI/HCE research is no less challenging. Especially given the relatively new nature of this type of research, formal grant support and funding opportunities are especially scarce and may pose a significant obstacle, especially if the research involves the acquisition and maintenance of large public health databases. To address these shortcomings, collaborations with other well-established researchers and mentors, both within and outside of radiology, provide the easiest entry point to introduce interested residents to the methodologies, databases, and intellectual support and expertise that is not universally found in radiology departments today. Additionally, active engagement with ongoing departmental QI and continuous quality improvement efforts will provide radiology-specific exposure within these domains and can help inform and shape future research interests and efforts.

There are also numerous challenges to performing robust comparative effectiveness research, not the least of which is demonstrating a direct link between imaging test results and patient outcomes (40-42). Also stymieing efforts to perform CER are the long lead-times associated with prospective studies, which may hamper efforts to rapidly integrate changes in an iterative fashion into clinical care, the comparison of interventions across departments leading to 'turf wars', and limited resources and access to clinical databases, especially national repositories (41, 42). To circumvent some of these challenges, residents interested in CER can perform observational studies, which are less costly, find alternative sources of information that are available to them (institutional electronic medical records) and find collaboration with other clinical departments to share the costs and administrative burden of CER and to expand potential research opportunities available to them (40).

Mentorship and Radiology Resident Research

Mentorship is one of the most important – and often forgotten – components in developing a successful radiology resident research experience. A good mentor will demonstrate confidence in mentees, provide an outstanding academic environment for academic growth, provide frequent unvarnished feedback, protect mentees from institutional politics and distractions, and always consider mentees' welfare and growth as the goal of the mentor-mentee relationship. Effective mentors provide support and challenge with opportunities and high expectations to extend the growth of mentees in a positive way. The ultimate goal is that mentees reach academic and personal successes at levels higher than a mentor, in their lifetime.

Time, patience, empathy, communication skills and knowledge of the field are primary qualities to be an effective mentor (43) and go through three distinct phases of mentoring: recognition and development, emerging independence, and letting go. It is important to set directions by detailed goals, timelines, prospective achievements and then managing expectations for a successful mentor-mentee relationship. Involving residents in research projects and providing support and guidance for completion of projects, writing manuscripts, and submission are the essential components of mentoring residents in academic research.

The level of guidance and support required vary depending on the skill, motivation, prior research, and publication experiences of residents. Generally, junior residents will require more guidance and support than senior residents, but the level support and guidance is largely dependent on individual residents. The residents can be guided in selecting an appropriate topic of investigation, IRB application process, data collection, analysis, synthesis, writing and submitting manuscripts. In addition, motivated residents and fellows can be guided for grant preparation such as resident grant or fellow grant from the research and education foundation of the RSNA. Mentoring and guiding residents for winning awards for their research, from professional societies such as the AUR, the RSNA, the American Roentgen Ray Society (ARRS), and the American Society of Neuroradiology (ASNR), is considered a commendable achievement in a mentee-mentor relationship. Mentors also have a responsibility to instill honesty, integrity, and professionalism in their residents conducting imaging research and advancing new knowledge.

Over time, the mentoring relationship matures in a number of ways: residents may need someone with a different expertise to foster their academic advancement, may change institutions, graduate, or, in the best scenarios, continue to mature and forge a life long mentor-mentee relationship. As the relationship matures, both mentor and mentee should prepare themselves as the mentees' needs may take a different direction (44). Though on the surface these circumstances may feel awkward for mentor and mentee, these are times of positive development in the growth of mentees. Mentors need to be aware and guide the mentees to their next stage of advancement. Sometimes difficult situations occur in the mentor-mentee relationship. Failure to define appropriate professional and personal limits, taking credits for residents' work, disregarding residents' opinion, unethical behaviors such as exploitation, secrecy and dishonesty can lead to a failed mentor-mentee relationship (44). It is a responsibility of both a mentor and mentee to avoid pitfalls and unethical behaviors to sustain a healthy and positive mentor-mentee relationship. The opportunity to develop others is one of the most fulfilling professional satisfactions a radiologist can achieve. If we do this effectively with self-sacrifice and service, one day we will look back and be proud of what we did in our lifetime.

Conclusion

There is an incredible breadth and depth of ongoing research at academic radiology departments across the country and the material presented herein aspires to highlight both subject matter and opportunities available to radiology residents eager to engage in radiologic research. Investing in radiologic research is an investment in the future of our field, and the key is early and well grounded training. The opportunities for interested radiology residents are as numerous as they are broad, spanning the basic sciences to clinical research to informatics, with abundant opportunities to shape our future practice of radiology. Nourishing and fostering physician-investigators trained in the radiologic sciences is a critically important step towards realizing today's research as tomorrow's practice.

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