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Academic Pursuits in Teleradiology: At the Crossroads of Technology, Radiology, and Implementation

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Abstract

Teleradiology is an essential part of modern radiology practice. It enhances efficiencies in image interpretation by improving availability and accessibility of radiologists. Being at the crossroads of technology, diagnostic radiology, and complex workflows, teleradiology provides abundant opportunities for academic engagement and innovative workflows, and allows for research and publication encompassing these multiple facets. This perspective provides an insight into the academic pursuits in teleradiology, highlighting the potential for contributions across these various domains, including core radiology, technological advancements, implementation challenges, innovative solutions, and lifestyle opportunities. By exploring these areas, we aim to provide a glimpse of the scope of a fulfilling academic career in teleradiology for radiologists, which extends beyond its primary attributes of convenience, lifestyle, and economics.

Keywords

- teleradiology
- academics in teleradiology
- research in teleradiology
- academic opportunities in teleradiology
- career in teleradiology

Introduction

Radiology has been at the forefront of technological innovation and early adoption in the relatively conservative field of health care. Fast internet, robust digital communications, and strong computing power have facilitated digitalized workflows in radiology departments within hospitals and stand-alone medium- to large-sized radiology organizations. The increasing demands for 24/7 imaging to aid diagnosis and decision-making in medicine could not be met by the scarce radiologist workforce and led to the genesis of teleradiology around the turn of the century.[1,2] By facilitating remote consultations and interpretation of medical images, teleradiology has helped provide access to expert opinion in a timely, efficient, and affordable manner, surmounting the widening gaps in demand and supply. With increasing need for diagnostic expertise across disparate geographic locations, and the need for social distancing during the recent COVID-19 pandemic, teleradiology took center stage and has become an integral part of many traditional radiology practices.[3,4] This technological disruption has transformed the career landscape in radiology. This way of practice of radiology, allowing for flexibility of physical location and work hours, is attractive to many radiologists with varied career goals, personal commitments, and other interests. While many radiologists engage in hybrid practice models with predominantly on-site radiology jobs and a fraction of their time in teleradiology to fill open hours or to supplement their incomes, an increasing number choose teleradiology as a full-time radiology career. For this segment of radiologists, who primarily work from home, or some from both home and office settings, career growth takes a

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different trajectory.[5] While such a work arrangement might seem far removed from academic scholarship, we observe that there is great potential in this space, which affords the practicing teleradiologist to reach beyond purely clinical contribution and participate in the research community.

A welcome trend is the exposure of radiology residents and fellows to teleradiology at the training stage, which may stimulate a spirit of enquiry and may encourage research efforts within the space of teleradiology. This is facilitated by three trends:

- Academic departments in teaching institutions/university hospitals are now embracing teleradiology, especially in the wake of the COVID pandemic.[6] This is a positive development as it brings teleradiology directly within the academic environment and allows residents to operate in a teleradiology-based environment from the very outset.
- Creation of training programs and fellowships with a teleradiology focus. For example, Teleradiology Solutions, an India-based global provider of teleradiology services has in collaboration with the Society for Emergency Radiology, India, established a Virtual Fellowship in Emergency Radiology, which has a focus on teleradiology and related technology and process.[7] This virtual training model has been validated in the recent literature.[8]
- Larger teleradiology practices recognize the importance of academics for a broader societal impact. There is a trend toward supporting academic pursuits of radiologists by providing academic time for presenting at conferences or writing manuscripts showcasing various aspects of a teleradiology practice including core radiology skills, operations, and practice quality improvement initiatives. Such activities may also be supported by financial incentives for time spent or productivity as assessed by number of publications or presentations. Incentives for research and academics in teleradiology are important given that the typical teleradiology reimbursement is related to clinical productivity, resulting in a decreased motivation to conduct research.

Further the vast amount of imaging data that teleradiology enterprises accumulate provides an opportunity for them to use this for educational or research purposes. While lack of access to clinical electronic medical record (EMR) data or patient outcomes might be a challenge for more traditional diagnostic performance studies, the large number of cases from multiple hospitals can provide a wide exposure to varied imaging manifestations of common diseases. The histopathological or surgical correlation can be obtained for these from the referring doctors in case of lack of access to the Hospital Information System (HIS), creating a rich repository for pictorial reviews, case reports, educational exhibits, or continuing medical education (CME) programs.[9–13] Equally compelling is the fact the digital technology and communication platforms that drive teleradiology lend themselves to distance education. As a result, various online radiology education initiatives have been launched by teleradiology platforms.[14] Large teleradiology databanks can be utilized to study discrepancy rates and patterns with regard to the level of radiologist training, time of day, shift length, and case volume.[15–19] Data from such studies can be used to guide practice improvement and planning.

This perspective aims to explore these vast and varied academic opportunities, particularly focusing on how teleradiologists can contribute to research, innovation and teaching in digital technologies, workflows, and operations, beyond core radiology. By examining specific areas of teleradiology practice and citing examples from established teleradiology practices, this article will highlight how academic pursuits can thrive at this intersection of technology and clinical implementation, and enhance the personal and professional lives of radiologists, despite a few intrinsic challenges.

Technology: The Foundation of Teleradiology

Necessity is the mother of invention and innovation. While the armed forces have utilized telehealth services for a long time to serve the sick personnel in hostile terrains with limited local resources, the demand for telehealth in civilian settings stems from a rising demand for access to medical expertise, convenience of the patient and the provider, and resource optimization while keeping the model economically viable. In 1967, horrendous traffic stimulated the beginnings of the initial teleradiology setup for civilians utilizing available technology, an interactive television system using direct microwave transmission from Boston's Logan Airport to Massachusetts General Hospital to transmit X-rays of travelers with respiratory issues to MGH physicians.[20] While poor image contrast and spatial resolution, cumbersome installation, and slow image transmission prevented closed-circuit television connections from gaining much traction for teleradiology, the foundation for civilian teleradiology was laid. With the advent of computers in the 1970s, computer- based approaches were explored. Digital or digitized data could now be collected and stored for transmission to the appropriate site. But not everything moves in tandem. Up to the 80s, the radiological images were primarily analog films. This piqued the interest of the community to explore technology at hand like camera systems, video grabbing, or laser for converting analog to digital images. Megapixel digital cameras were effectively utilized for conversion of analog to digital images in rural settings.[21] Picture Archiving and Communication System (PACS) was introduced in radiology practices with the promise of improving workflows and improved archival of imaging data. Over the next decade, universal adoption of digital imaging and the Digital Imaging and Communications in Medicine (DICOM) standard, increasing quality and decreasing cost of computers, and faster and affordable internet facilitated more widespread use of teleradiology. With such movement of patient data outside the conventional department or hospital building, privacy and data security concerns had to be addressed.

The field evolved in tandem with advancing technologies to bridge the increasing demand–supply gap. Staying abreast

with the health care market trends and technological developments was a fertile area for various academic activities in the development of new image transmission technologies, improvements in image quality, displays and interpretation, and efficient and effective communication pathways for radiology reports and critical findings. For instance, utilizing high-grade commercial monitors achieved the desired image quality for diagnosis for cross-sectional studies. Such research helped bring down the overall costs for teleradiology setups by eliminating the requirement for costly and bulky medical-grade monitors for most requirements barring mammography. With rapidly advancing mobile technologies providing high-resolution displays, several comparative studies explored the accuracy of image interpretation on mobile devices, further enhancing the reach, access, and ease of teleradiology.[22–27]

Above all, this became the genesis for innovative practice and business models. To meet the shortages of radiologists and lack of staff for after-hours radiology coverage, transcontinental teleradiology models were investigated, astutely utilizing day–nighttime time zone differences.[28–31] A proof-of-concept study was conducted in Bangalore for a university hospital in the United States demonstrating such models to be feasible, accurate, and effective, without compromising patient care. Various forms of image compression characteristics were studied to determine what can be acceptable,[32] to keep the transmitted data light and transmissible in a reasonable period over a mere 128 kbps internet connection. These academic endeavors formed the foundation of the largest teleradiology group in India, which also has a large global presence.

Today and going forward, there is and will be an abundance of opportunities for research, which is directed toward the role of technology in teleradiology. For radiologists with an interest in technology, this is an area of great promise.

These include the following:

- PACS–Radiology Information System (RIS) workflow: These technologies form the building blocks of teleradiology, and research into innovations and developments that enhance the field is necessary and important.[33,34]
- Reporting efficiencies: A keystone of teleradiology is the use of technology to enhance radiologist efficiency and productivity; therefore, the need for continuous research that drives this forward in the setting of continued radiologist shortages. Radiologist support systems, structured format reporting, and voice-to-text software are important areas of implementation research, improvement, and automation.[35,36]
- Artificial intelligence (AI) and large language models (LLMs): These will be discussed in greater detail in a subsequent section.

Emergency Radiology

Teleradiology has had a significant impact on the field of emergency radiology. The ability to provide 24/7 radiology services to emergency departments, especially in rural or underserved areas, is a major advancement. Round-the-clock radiology coverage can also be effectively provided via teleradiology without disturbing the normal sleep cycle of the local practice radiologists, by sending after-hours examinations for interpretation to dedicated night-shift teleradiology teams, in some cases relying on radiologists in different time zones compared with the site of origin of the examination. Such presumptions need to be supported by evidence, which requires an academic enquiry. This has been corroborated by data from studies evaluating the efficacy of teleradiology in emergency scenarios, comparing outcomes with traditional on-site radiology services. Emergency radiological services need to maintain accuracy in a high-pressure environment demanding prompt interpretations for acutely ill and traumatized patients. Studies could also explore the speed of service delivery, diagnostic accuracy, and the impact of real-time remote consultations during critical care situations. Studies have highlighted the contribution of teleradiology toward prevention of unnecessary patient transportation, improved quality of treatment, and efficient utilization of radiologist work hours by sending images to his or her geographic location. In specific acute conditions such as stroke, teleradiology has delivered significant benefit,[37] and additional research is needed to review both benefits and challenges to enable optimization of workflows in such acute settings.

Other Teleradiology Models

Apart from emergency radiology where there have been significant research efforts that have established its operational and clinical value and benefits, there are several other teleradiology models that also have significant potential impact on health care and where there is currently a dearth of and consequently opportunity for research. These include the following:

- **Teleradiology for remote areas:** There is a greater need for teleradiology services in remote parts of the world where radiologists are in particularly short supply or not available. An article by Char et al describes a basic model for the use of teleradiology in a remote part of northeastern India.[38] A more recent publication reviews the benefits of teleradiology in a tribal population in the state of Tripura.[8] Such case studies help describe and analyze models of success that can be replicated in other locations of need as well as highlight the challenges to be avoided by other groups. Similarly, multi-institutional studies that assess the role of teleradiology in specific geographies can be of value in reviewing the status of utilization of teleradiology in these regions.[39,40]
- **Teleradiology in specific clinical settings and for subspecialty imaging:** Each imaging modality or clinical practice setting lends itself to a specific use case analysis of the role of teleradiology. The use of teleradiology in the remote interpretation of ultrasound studies has been recently described in the literature.[41] Similarly, an article on the use of teleradiology in the intensive care unit (ICU) environment has been published, which highlights the

use case of teleradiology in the urgent scenario of intensive care medicine.[42] Another recent publication showcases the value of teleradiology in oncology, especially in the reporting of complex and subspecialized positron emission tomography with computed tomography (PET-CT) scans wherein it may be simpler to bring the images to suitably specialized radiologists.[43] Studies focusing on the use of teleradiology in child abuse[44] help in crystallizing workflows in these areas to benefit patient care. Additional work remains to be done on the role of teleradiology in several clinical areas.

- **Teleradiology in public health:** Teleradiology offers significant potential benefits in certain areas of public health importance, which include breast cancer.[45] Combined with the use of mobile radiology equipment, teleradiology may be used to address issues of access and scale, and studies that assess the potential benefits and challenges of teleradiology in this scenario are of importance in the public health realm, as they help in the creation of vision and policy in this important sector.

Implementation Challenges, Quality Assurance, Cost–Benefits, and Lifestyle Changes

While teleradiology offers many benefits, it also presents significant implementation challenges, particularly in terms of quality assurance and regulatory compliance. Academic research has focused and should continue to focus on developing standardized protocols for image transmission, interpretation, and reporting to ensure consistency and accuracy across different teleradiology platforms. Additionally, studies on the ethical and legal implications of remote diagnoses, including patient privacy concerns and data protection, are crucial. This research can lead to improved policies and practices that enhance the reliability and credibility of teleradiology services.

Quality assurance is key to the success of any enterprise. Teleradiology operations need to maintain high standards of service. While it is mandatory for radiologists to engage in CME programs for staying abreast with recent developments in core radiology, peer review is also standard of practice. Academic activities could include investigation of peer review data to identify knowledge gaps and preparation of suitable teaching modules for further training.[15] Various strategies can be used to minimize error rates with studies to validate their effectiveness. A study probing the efficacy of dual reads of selective studies was conducted in a teleradiology group as a possible way to improve accuracy.[46] The use of innovative approaches such as contemporaneous peer review by radiologist assistant models in the teleradiology environment serves as fertile ground for research in the space of quality innovation[47] and is a good example of the type of research question that may be addressed in a teleradiology environment.

The economic benefits of teleradiology have been discussed in the health care economics literature,[48] with models of implementation being shown to reduce costs of care, decrease the need for patient transportation, etc. Further research in this space, especially in rapidly evolving geographies and economies such as Asia and Africa, is necessary and welcome. Even within developed economies, there is an opportunity for research on billing practices and modules in teleradiology, which can help direct policy changes and evaluate best practices.[49]

Teleradiology has had a deep impact on the practicing radiologist's lifestyle by the promise of increased work–life balance, making it lucrative as a full-time career choice. However, this may not be universally true and possibly different for each person. The absent face-to-face interactions with referring physicians in a virtual environment and lack of real-time feedback for some may be more stressful and less fulfilling.[5] For many, the advantages of time savings by not commuting to the workplace can decrease stress, reduce burnout, increase productivity, and decrease attrition.[50,51] One must also ensure that patient care is not compromised in the slightest, and such a virtual practice is acceptable to the referring clinicians. Such practice must be supported by data and forms an interesting and useful subject for research and positive interventions.

Teleradiology: A Data-Rich Milieu for Artificial Intelligence Research

Teleradiology services are held to high standards by both the contracting radiology groups and the referring physicians. The need to meet stringent expectations for report quality and turnaround time, the prevalent radiologist shortages, and dwindling reimbursements have set the stage for innovations to make workflow and operations as efficient as possible without sacrificing quality. AI tools can be deployed at different steps of the teleradiology workflow to aid efficiency and accuracy. These can be easy to deploy in teleradiology settings as all available data are digital. AI tools are being used to predict case volume surges and balance the expected load with the staff schedule to ensure adequate coverage. Large teleradiology practices aggregate rich diverse data from multiple scanners and hospitals following different study protocols. This opens avenues for collaborative research with hospitals and AI companies for development of robust and generalizable AI tools using diverse and representative data for testing and validation. This large variety of image data from different locations, patient demographics, and scanners on a single teleradiology platform would be great resource for validation of AI tools for "real-world" performance. Academic work could focus on development of AI tools for triage, diagnosis, and quantification. AI tools working in the background at the image ingestion level can detect critical findings such as intracranial hemorrhage, fracture, pulmonary thromboembolism, and more, and appropriately triage busy worklists.[52,53] Automated quantification of abnormalities can save time for more complex cases or communication with the referring physicians. Publications could also explore real-time effects on accuracy and efficiency after integration of these automated technologies

into existing workflows. Voice-to-text software integration with RIS-PACS incorporating LLMs, has unparalleled speed compared with an average human transcriptionist. Smart reporting tools have been successfully deployed by a few teleradiology groups to expedite report generation while keeping error rates low. Such tools may incorporate various checks and feedback to the radiologist regarding discrepancies in study type or in the reported side or organ between the findings and impression, may aid in incorporation of relevant follow-up recommendations based on available expert guidelines, and may be used to identify dictated critical findings to prompt automated communication with the referring physician. Conversion of prose to structured reports or to the reporting styles or native language of the referring doctor can be done in real time without additional time burden for the radiologist[54,55] and can help lend uniformity to report outputs. Analysis of individual report quality based on essential data points or error types provides material for quality improvement research or personalized training modules curated by AI, without human intervention.

While the teleradiology setting is conducive to AI adoption, integration is not entirely trouble free. Tools developed on diverse data with good performance metrics may still fail in live work environments. An example is the AI tool developed in-house in a teleradiology group for detection and localization of acute intracranial hemorrhage on head CT examinations. In a controlled environment, the tool had a sensitivity of 97% and specificity of 85.3%, with a high false-positive rate of 15%. An occasional case of subtle intracranial hemorrhage detected by AI and missed by the radiologist was celebrated as a success.[56] By and large, it was only useful in triage of a long case list. Often, the false-positive alerts were distracting. The tool has undergone multiple iterations since then with improved results. This example highlights a frequent problem for most AI tools that underperform in live clinical environments, making stringent external validations and built-in feedback loops for continued improvements essential. Such forms of academic pursuits within one's practice lead to quality improvement and provide deeper understanding of what to enquire and test before implementing commercially available tools. Studies to assess the performance of AI tools in real clinical workflow can be undertaken as shown in a PICO format in ►**Table 1**. Pulmonary thromboembolism is another use case for an AI project with added measurements of ventricle diameters for detection of right heart strain, an important parameter guiding patient management. Teleradiology combined with AI is a strong step toward inclusive population screening in resource-limited settings. A pilot project was undertaken to provide teleradiology coverage to a mobile mammography unit and consumed in parallel by deep learning mammography algorithms, demonstrating comparable performance but in a significantly less average turnaround time of 5.5 versus 12.7 hours.[45] Such programs can be extended to other diseases beyond breast cancer without straining the already limited skilled radiologist workforce.

Ethics, Policy, and Legal Status: Logical Approach to Voice Concerns

Different people have different points of view. These points become widely accepted once published in a reputed journal. It is incumbent on teleradiologists to clarify perceptions of suboptimal quality of teleradiology reads. Any statements need to be backed by data, and therein lies the value of staying alert with regard to recent literature and archivable internal data to allay any misconceptions.

In its early days, teleradiology had a tumultuous course with backlash from proponents of more traditional radiology practices.[57–59], It is now much more widely accepted as a necessity for sustenance of a radiology practice. Optimal clinical service, stringent quality assurance, excellence in operations, focus on the latest technology trends, market needs, and radiologist education are all essential components of a successful teleradiology practice. Staying academic is what will keep one relevant and on top of one's field.

Challenges of Academics and Research in Teleradiology Practices and Possible Solutions

- **Limited access to clinical data:** History provided in a teleradiology setting is sometimes limited. Information regarding prior studies may not always be available in the emergency setting. This has the potential to limit the scope of outcomes-based clinical research. The follow-up details need to be specifically sought from the referring centers. However, specific cases can be investigated for the purpose of teaching, case reports, or pictorial essays. Operations and workflow improvement–related research can be effectively done for practice improvement as such data are digital and readily available with time stamps in PACS and RIS.

Table 1 Example of a study to assess the performance of an AI tool for intracranial hemorrhage detection in a P (Problem) I (Intervention) C (Comparison) O (Outcome) format

P	Does implementation of AI for intracranial hemorrhage detection in radiology workflow decrease report turnaround time (TAT)?
I	Implement AI tool for intracranial hemorrhage detection in live workflow
C	Compare the TATs for reports for head CTs before AI intervention with those after AI
O	TATs for the two groups of head CT studies. Do changes in TATs vary with radiologist experience?

Abbreviations: AI, artificial intelligence; CT, computed tomography.

- **Heterogeneous data from varied geolocations:** Even though teleradiology could be a "gold mine" for medical image data, heterogeneous data quality could pose problem in research studies. Ethical concerns will be a hurdle in conduction of prospective studies, as setting up a universal ethics review board or safety board will be difficult for multisite data. However, these hurdles could be overcome by appropriately made regulations and rules for a country. Legal know-how and in-depth review of precedents could help lay the foundations for policies and regulations commensurate with the current technology and health care landscape.
- **Virtual environment:** For some, a solitary workflow may limit access to clinical details or new ideas that may come about during an informal conversation over lunch or coffee. A full-time teleradiologist wanting to pursue academics would need to be self-motivated. Physical participation in CMEs, conferences, or clinical meets can help provide stimulation for scientific interrogation.[5]

Conclusion

In summary, the scope for research and academia in teleradiology adds another dimension to the field that transcends its somewhat mundane, albeit critical, role of providing an essential clinical service. It provides for intellectual stimulation, which improves the quality of experience and can potentially avert isolation and burnout for some. It allows for introspection and analysis that can enhance the quality of care. It can also provide a stimulus for new process development and acceptance and provide a leapfrog effect in catapulting new innovations to the forefront of clinical practice. This is also a powerful tool toward making the "invisible" radiologist "visible" by providing opportunities to reach a larger community through publications and collaborations.

As the philosopher Descartes postulated "cogito ergo sum," that is, I think therefore I am. In a similar vein, the thinking, researching, innovating teleradiologist is ultimately the catalyst for growth and evolution in the dynamic and rapidly evolving field of teleradiology. Long may he/she thrive!

Authors' Contributions

A.A. contributed to the concepts, design, definition of intellectual content, literature search, clinical studies, manuscript preparation, editing, and review. A.K. contributed to the concepts, literature search, clinical studies, manuscript preparation, and manuscript editing. A.D.S. contributed to literature search, manuscript editing, and review. A.A. takes responsibility of the integrity of the work as a whole from inception to the published article.

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Conflict of Interest

None declared.

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