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Institutional strategies to maintain and grow imaging research during the COVID-19 pandemic

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Abstract

Understanding imaging research experiences, challenges, and strategies for academic radiology departments during and after COVID-19 is critical to prepare for future disruptive events. We summarize key insights and programmatic initiatives at major academic hospitals across the world, based on literature review and meetings of the Radiological Society of North America Vice Chairs of Research (RSNA VCR) group. Through expert discussion and case studies, we provide suggested guidelines to maintain and grow radiology research in the post-pandemic era.

Keywords

Academic radiology; COVID-19; pandemic; research; vice chair

Abbreviations

3DP = 3D printing; AI = artificial intelligence; COVID-19 = coronavirus disease of 2019; RSNA = Radiological Society of North America, VCR = vice chair of research

Introduction

The COVID-19 pandemic drastically impacted patient care, medical education, and biomedical research worldwide. In the United States, radiology departments were forced to adapt rapidly with initial shutdowns in early 2020, followed by multiple cycles of adaptation and gradual reopening continuing to the present day. In the early stages of the pandemic, the prioritization of essential work and social distancing severely reduced most research activities other than those directly related to COVID-19. This created an involuntary hiatus for many MD, DO, and PhD imaging researchers, many of whom pivoted into new avenues of investigation as the pandemic continued with unpredictable implications for research. Finally, the late pandemic rebound in both clinical and research imaging volumes has created ongoing issues for hospital operations and the future of radiology work.

To help address challenges in imaging research at the national level, the Radiological Society of North America Vice Chairs of Research (RSNA VCR) group began hosting quarterly videoconference discussions, along with a virtual retreat in September 2020, hybrid meeting in October 2021, and yearly discussions at the RSNA Annual Meetings. These activities resulted in

multicenter publications on COVID-era research operations and sustainability; strategies to address administrative setbacks, researcher burnout, and diversity, equity, and inclusion; and action plans to increase funding from industry and government sources. (1) In addition, an expert panel consisting of interested leaders from the RSNA VCR group was convened to discuss experiences, challenges, and strategies for COVID-19 in academic radiology departments. This panel consisted of vice chairs of research from the following radiology departments: Corey W. Arnold, PhD, University of California, Los Angeles; David A. Mankoff, MD, PhD, University of Pennsylvania; Elizabeth A. Krupinski, PhD, Emory University; John D. Hazle, PhD, The University of Texas MD Anderson Cancer Center; and Summer J. Decker, PhD, University of South Florida. The objectives of the panel discussion and subsequent literature review were to develop coherent themes regarding the state of radiology research during and after COVID-19, with a focus on disaster planning, response, and recovery.

In this article, we summarize key insights and programmatic initiatives across the United States in response to COVID-19. First, we discuss departmental processes and their impact on VCRs and principal investigators (PIs) during the early, middle, and late stages of the pandemic. Next, we examine the effects of COVID-19 on research grant funding. Subsequently, we highlight emerging research areas of excellence with high potential for future growth. Utilizing expert discussion and literature review, we provide suggested guidelines to maintain and grow radiology research in the postpandemic era.

Departmental Processes

Early Pandemic

In the early stages of COVID-19 (early to mid-2020), many radiology departments rapidly downsized with a focus on essential work. Imaging was largely restricted to high-acuity, high-severity emergency cases and inpatients. (2-8) Attempting to offset losses in clinical revenue, many hospitals furloughed or laid off workers perceived to be less essential, sometimes leading to a disproportionate impact on research employees. Depending on the rigor of disaster response, hospitals either scaled down or suspended research and grant spending, negatively impacting the research enterprise overall. Some hospitals offered stop-gap funding for researchers, though declining profits prompted employee furloughs and/or downsizing. Staff changes and absences broadly impacted research administrative activities (e.g. radiology research cores, IRB, IACUC, grants management) at the department, hospital, and university levels. (9-10)

To maximize social distancing, most hospitals encouraged employees to work remotely if possible. Radiology informatics infrastructure facilitated the shift to off-campus work, particularly for teleradiology and dry labs. Equipment such as computers, PACS systems, and books were transitioned to home offices. Researchers largely spent their offsite time analyzing existing data, writing papers, and submitting grants. However, connectivity issues and travel restrictions at the national and international levels presented logistical challenges for collaborators. Additional complications arose for wet labs requiring in-person bench work. Pre-clinical research was severely impacted as animal care facilities restricted access and often downsized to bare-necessity breeding animals to minimize veterinary support staffing. Smaller

in-person meetings had to be conducted with social distancing and personal protective equipment (PPE), while medium and large group meetings were canceled or conducted virtually. (9-10)

Over the initial months of the pandemic, radiology departments worked with hospital and medical school leaders to develop concrete definitions and standard operating procedures for essential research. Key examples include but were not limited to the following. Onsite radiology staff were often restricted to those supporting essential in-person activities, such as technology operation (cyclotron, radiochemistry labs, imaging scanners) and procedural care. Special exemption and approval pathways were developed for researchers needing to enter the hospital, requiring the combined efforts of VCRs, PIs, and health care administrators. For human subjects research, the most important studies (e.g. COVID-related) were prioritized, and appropriate patient groups for recruitment were determined. Research subject visits were allowed only if deemed essential to the health and well-being of subjects, and when the benefits of study participation outweighed the risks of potential COVID-19 exposure. (9-10) For example, ongoing oncologic trials were continued with inclusion of longitudinal imaging studies for clinical decision-making. Non-cancer trials took longer to be reinstated, and clinical trials not yet initiated were put on hold. Some studies with designs not requiring prospective access to human or animal subjects (e.g. retrospective, observational, computational) continued remotely, albeit hampered by reduced team communication and the overhead of establishing resource connectivity. (11-12)

At the same time, high priority was placed on new COVID-19-related research, which in radiology centered around clinical imaging manifestations, new technology assessment, and

computational image analysis. New grant programs and initiatives sprang up to encourage multicenter data sharing, artificial intelligence (AI)-powered decision support, 3D printing and visualization, workflow quality improvement, and employee wellness. (13-17)

Mid-Pandemic

The middle of the pandemic (mid-2020 to mid-2021) was a time of continual adaptation, given our evolving understanding of COVID-19 pathogenesis and transmission with rapidly changing geographic distributions. Radiology departments worked to balance essential and elective procedures, depending on institutional needs and real-time disease prevalence. The use of physician-assigned examination priority scores helped improve operational scheduling and efficiency. Periods of relative infection control served as opportunities to catch up on the backlog of lower-priority studies, including outpatient scans and non-cancer clinical trials. Physicians turned to telehealth appointments for non-essential patient visits and remote consultations. At the same time, many research protocols were modified to permit virtual recruitment outside of clinical visits. This approach facilitated contact of large numbers of potential research subjects via email, text messaging, and patient portals. (11-12, 18-26)

Computational research continued during the pandemic and progressed more successfully than other basic science areas. Informatics support was the major rate-limiting step, requiring scale-up and optimization of high-performance computing (HPC) and virtual private networking (VPN) solutions for large-scale remote data access and processing. With regard to wet lab reopening, chemistry and radiochemistry research ramped up more rapidly than other radiologic areas—

likely due to the non-reliance on biologic systems, workers' standard practice of working in separate areas and wearing protective gear, and clinical need for radiopharmaceuticals. (9-10)

Remote lab meetings worked well for many research groups, but depended greatly on individual PI leadership skills, personality, and ability to keep team members engaged. Nearly all employees became more skilled at videoconferencing and teleconferencing; this in turn enabled higher departmental attendance at grand rounds, huddles and other activities from individuals on clinical service, working at off-campus sites, or traveling for meetings and vacations. Despite visitor restrictions, off-campus students and international scholars were able to engage in research opportunities at different sites or through virtual work. On the other hand, onsite research trainees experienced disproportionate stresses when transitioning to home, since many lived in multi-person housing without adequate individual space and resources for remote work. In-person researchers utilized rotation schedules to utilize laboratory equipment and space efficiently, while respecting social distancing policies. The widespread use of videoconferencing encouraged new national and international collaborations with a major shift toward multicenter data/image sharing, manuscript writing, and visiting professorships. (1, 9-10)

COVID-19 vaccines started to become available in December 2020, first under emergency use authorization and subsequently full approval by the Food and Drug Administration (FDA). This enabled a gradual return to the workplace throughout 2021, with small in-person and hybrid gatherings replacing fully virtual interactions. Returning to work was important for many researchers, especially students and trainees who had been living in relative isolation without face-to-face PI mentorship or strong social support systems. During the course of the pandemic,

increasing employee dissatisfaction and burnout resulted in people changing and quitting jobs, leading to an unprecedented workforce shortage in healthcare. New resources and programs to increase well-being and work-life balance became a major focus for radiology departments, hospitals, and universities. (1, 9-10, 18-25)

One of the most significant challenges for PIs during and after this public health emergency has been recruitment of qualified graduate students and postdoctoral fellows, especially international candidates. Several factors have contributed to the paucity of research talent in academic radiology over the last several years, which were further exacerbated by the pandemic. Key issues include disincentivization of research in the face of declining clinical reimbursements; rapidly changing employment and travel policies; higher wages offered in industry; and opportunities for fully virtual employment with better work-life balance. (1, 9-10, 24-25)

Late Pandemic

By the late pandemic (mid-2021 to present), mandatory vaccinations for health care workers and a plateau in community vaccination rates prompted progressive hospital reopening. There was a rebound of both clinical and research volumes, due to long-backlogged cases and delayed care with more severe or complex disease presentations. Radiology stood out as a leader in the pandemic response, with strong technical and informatics programs to prioritize and coordinate studies, thereby supporting clinical and research colleagues across the enterprise. Radiology's central role in organizational response and recovery completely transformed how hospital leaders and colleagues in other specialties view our field. (27-32)

Many employers initially advocated for a complete return to the office, but increasingly came to accept more flexible work options. This strategy helped to retain skilled workers, many of whom had already changed jobs during the pandemic for personal and/or professional reasons. Example considerations included commuting time and costs, continued health risks, limited office space, distance to and time with family, childcare options, travel opportunities, and alternative work setups. Particularly on the research side, these hybrid setups had minimal impact on overall operations, and furthermore allowed for innovative strategies such as shared laboratory facilities and hoteling of office space. (1, 10, 33)

In the late pandemic world, virtual meetings help to connect people across different locations during a busy workday, while periodic in-person meetings help to maintain social contact and overall well-being. Resumption of in-person work has been gradual and uneven across labs, with many PIs and radiologists continuing to leverage remote tools that were developed during the pandemic. To encourage greater physical interaction and invoke the collaborative culture of the pre-pandemic era, many leaders are establishing research engagement and wellness programs. (1, 10, 34-35)

The adoption of alternative work setups creates new challenges and questions including optimal care for patients, hospital space utilization and reallocation, informatics infrastructure and connectivity, equity between in-person and remote workers, student/trainee experience, performance tracking, recruitment and retention, and differential salary/cost considerations. Given our society's ever-increasing connectivity and trends toward digital health, it is crucial to

develop new strategies to optimize employee, patient, and student interactions and experiences. With robust systems and platforms for communicating science and data, radiology teams can now make direct clinical impact locally, nationally, and internationally. Expanding global infrastructure for videoconferencing and data sharing will continue to facilitate research collaborations. (33, 36)

In the near term, special attention should be given to recovery of radiology core facilities, which provide a variety of imaging services to clinical and pre-clinical researchers. Prolonged reduction of core use during COVID-19, with fixed operating costs for imaging equipment service and maintenance, has resulted in substantial deficits for many radiology departments. Furthermore, imaging cores require specialized and highly trained staff, who are difficult to replace once lost. To optimize future crisis response, radiology departments should maintain contingencies for offsite work, including: continuing technology and infrastructure development; developing informatics solutions for remote data collection and analysis; maintaining a hybrid approach to clinical and research activities; training/upskilling personnel to build redundancy and avoid workforce gaps; and introducing flexibility clauses for grants, promotion and tenure timelines. (1, 10, 37-39) [Table 1]

Based on discussions with hospital administrators and radiology leaders, clinical limitations are a key barrier to ongoing research. In many hospitals with shared or non-dedicated research equipment, the clinical and research operations are inextricably linked. Even in centers with separate research facilities, clinical trials and inpatient studies remain dependent on the hospital service. In addition, clinical revenue directly impacts business strategy and institutional

capability to invest in research. Over time, research will hopefully return to pre-pandemic levels, aided by new opportunities in COVID research and the ease of virtual collaboration. (1, 10, 37)

Grant Funding

Flexible Timelines

The COVID-19 pandemic adversely impacted health care research at multiple levels. With the majority of radiology research deemed nonessential, research activities were the first to shut down and the last to reopen. During this period, human/animal studies and grants spending were either stopped completely or severely restricted. As a result, most funding agencies offered more flexible timelines on a case-by-case basis, including: delayed deadlines for grant submission, longer eligibility windows for early-career investigators, no-cost extensions of active grants, and more flexibility in grant milestones and funds carryover. Many universities also added flexibility clauses and COVID-specific considerations into promotion/tenure paperwork and timelines. In most cases, extensions of up to 1 year were offered, similar to birth or adoption of a child. (1, 9-10, 40-42)

Flexible grant and promotion timelines helped researchers to sustain existing grants and analyze preliminary data toward new submissions. However, new data outside of COVID-19 projects was difficult to obtain, limiting clinical trials not yet started and restricting new grant applications to trailblazer/pilot mechanisms. Lingering challenges include recovery of researcher momentum, particularly for junior faculty and new investigators; and inefficient usage of funds

during the pandemic without full research productivity, especially for clinical and wet lab grants. Some institutions have created interdisciplinary programs to bring researcher engagement and cross-pollination back to pre-pandemic levels. (1, 10, 37) The National Institutes of Health (NIH) has published multiple guidelines and resources for PIs regarding research during COVID-19, including: grant policies, human subjects and clinical trials, animal welfare, and survey results. (40-42)

New Initiatives

COVID-19 funding opportunities and programs arose rapidly during the pandemic and continue to grow. Some of these initiatives interfaced naturally with existing radiology work, such as that performed by chest radiologists and data scientists. Other researchers lacking the requisite expertise had time during the pandemic to integrate COVID-19 into their current research, or start new research directions and apply for grants that they would not have considered under normal circumstances. (1, 9-10, 37) At the time of writing, a PubMed search indicates that 3.7% of total radiology publications (4908/132626) created between 2019-20 (early pandemic), 6.6% (9314/141166) between 2020-21 (mid-pandemic), and 5.5% (7312/131886) between 2021-22 (late pandemic) contained the keyword “COVID.” (43) In other words, COVID radiology publications rapidly emerged in the early pandemic, nearly doubled mid-pandemic, and showed a slight decline during the late pandemic.

With regard to NIH funding, Congress and the President approved increases in total awards from \$39.3B in fiscal year 2019 to \$41.7B in 2020, \$43.0B in 2021, and \$46.2B in 2022, with a

projection of \$62.5B for 2023. (44) Biomedical imaging grants were estimated at \$2.35B in 2019, increasing to \$2.54B in 2020, \$2.77B in 2021, and \$2.90B in 2022, with a projection of \$2.94B for 2023. Coronavirus research projects were funded at \$2.36B in 2020 (emergency supplemental appropriations), peaked at \$4.23B in 2021, then decreased to \$3.68B in 2022, with a further projected decline to \$3.03B for 2023. (45) From this, we can conclude that total government funding for research including radiology has steadily increased over time. Monies available for COVID have declined slightly, as we pass the worst of the pandemic and various vaccines and therapies have become available. From the PI perspective, total applications continue to increase, while the percentage of applications funded remains relatively stable. Success rates were 20% (11035/54903) in 2019, 21% (11332/55038) in 2020, and 19% (11229/58872) in 2021. (46)

The NIH and National Institute of Biomedical Imaging and Bioengineering (NIBIB) sponsor several COVID-19-specific federal grants and programs. The Rapid Acceleration of Diagnostics (RADx) Tech and Advanced Technology Platforms (ATP) innovation funnel accelerates development, commercialization, and implementation of new technologies for COVID-19 testing with a focus on performance, accessibility, and ease of use. Overarching themes for funding announcement and projects include cellular/molecular mechanisms, comorbid disease processes, socioeconomic disparities, and digital health platforms. Radiology-specific opportunities include technology development, imaging approaches, quantitative biomarkers, and informatics tools. (47-50)

Major North American radiology organizations including the RSNA, American College of Radiology (ACR), and American Association of Physicists in Medicine (AAPM) have created various collaborative initiatives and grants for researchers to augment imaging databases and elevate the role of radiology in COVID care. Funded programs include international imaging research registries, data science and reporting tools, longitudinal effectiveness of COVID practices, characteristics of long COVID, and health services research. (51-58) [Table 2]

Radiology Focus Areas

Artificial Intelligence

Radiology AI development was a major focus of COVID-19 research that was facilitated by widely available pilot data, grant funding from multiple agencies, and expedited journal publications. However, many initial AI studies were clinically irrelevant with little consideration given to practical research questions, realistic data wrangling and bias, algorithm development and performance reporting, and testing timelines relative to long-term needs. For example, most radiology AI publications investigated diagnosis of COVID-19 based on chest radiography, but the majority of imaging trials utilize computed tomography (CT) to evaluate disease severity or prognosis. (59-61)

To support AI algorithm development, there was a universal push to share anonymized health care data across institutions. Multiple North American radiology organizations have supported and funded the creation of large, high-quality, and diverse COVID-19 imaging datasets. These

efforts helped to establish national/international consortiums and advance big data science. (51-56) However, multicenter data sharing is still relatively uncommon and has drawn increasing scrutiny from institutional leadership, due to patient confidentiality and intellectual property concerns. (59-62)

A vast array of publications have emerged in the fields of machine learning and deep learning for COVID-19 detection, diagnosis, screening, classification, drug repurposing, prediction, and forecasting. Federated learning paradigms have allowed multiple centers to contribute to a centralized model while keeping protected health information within institutional firewalls, thus minimizing administrative overhead and accelerating algorithm development/testing. (63-64)

Comprehensive reviews and meta-analyses of COVID-19 literature indicate that AI approaches are maturing with better peer review processes, data quality and scale, model quality, experimental rigor, and clinical deployment. There is also an increasing focus on interpretable, explainable, and transparent AI methods, characterized by multimodal data input, biologic relevance, and scientific reproducibility in order to optimize clinical translation. Sustained interdisciplinary collaboration between medical physicians and data scientists is critical to develop relevant computational tools that can impact medical decision-making. (59-61, 65-74)

Team science will hopefully advance translation and implementation across a variety of medical specialties.

3D Printing

COVID-19 caused global supply chain shortages, especially in the United States where supplies were primarily imported from other countries. Many hospitals leveraged their existing 3D printing (3DP) and visualization facilities, which were already being used clinically for patient counseling, medical simulation, and surgical planning with medical reimbursement. During the pandemic, 3DP provided local stop-gap measures as well as cost savings in designing and printing replacement parts for clinical procedures and equipment. Examples included 3DP respiratory swabs for COVID testing, as well as PPE: masks, goggles, face shields, respiratory devices, ventilator connectors, gloves, gowns, and even isolation wards. (75-81)

In addition, novel opportunities arose with regard to alternative designs, materials, and new device development. Radiology 3D labs worked alongside clinical physicians and industry partners using rapid iterative design to develop prototypes, conduct bench lab testing, design clinical trials, and patent new technologies. Open-source electronic model sharing via websites, social media, and file repositories saved a great deal of design time for end users. (82) For example, the RSNA-ACR 3D printing registry stores anonymized data including patient information, clinical indication and use, radiology source images, model construction, printing techniques, and clinical impact. (83) Many print farms, universities, and companies also came forward to offer resources to the global community. These activities broadened the international reach of 3DP, with prioritization of low-cost printers and accessible stocks of surgical-grade materials enabling distributed manufacturing. Ongoing investigations in 3DP include next-generation laboratory tests, drug manufacturing, biomaterials, sustainability, and virtual/augmented clinical trials. (84-91)

Other Topics

COVID-19 invoked a practice shift to teleradiology and remote work, which broadly impacted radiologists' personal and professional lives with emotional and physical stressors; introduced quality issues with home viewing environments; and revealed service gaps related to rapidly changing staffing and workload volumes. These issues prompted several research projects in the realms of virtual/hybrid education (92-95), quality improvement (96-98), health care disparities (99-101), and radiologist well-being (102-104).

New diagnostic imaging technologies may enable higher patient throughput while minimizing exposure to health care providers. Examples of novel imaging innovations include multicontrast imaging to interrogate various tissue properties, advanced tomosynthesis for low-dose and high-information scanning, microscale/nanoscale technologies to assess viral-level pathology, and portable or remote-controlled scanning of infectious or critically ill patients. (105-109) There is also a role for interventional radiology using image-guided interventions for combined diagnosis and therapeutic delivery via intranasal, intravascular, or intrapulmonary routes (theranostics). (110-112) Radiology informatics has played a major role in COVID-19 mitigation, planning, response, and recovery. (113-115) Artificial intelligence approaches will mine increasingly large and diverse multiplex databases of radiology, genomics, radiology, electronic health records, survey results, laboratory values, and physical data, enabling precision medicine approaches with individualized risk assessment, diagnosis, prognosis, and treatment. (116-120) Real-time digital health monitoring and point-of-care treatment are becoming possible with the advent of smart

devices, wearable sensors, robotics, and unprecedented connectivity of the Internet of Things (IoT). (121-126) [Table 3]

Conclusions

Understanding of imaging research challenges and solutions during and after COVID-19 is critical to prepare for future disruptive events. Agility and effective communication among research PIs, VCRs, and health care administrators is critical for successful leadership of academic radiology departments. Insights from the RSNA VCR group and literature review provides strategic direction for new radiology research opportunities including AI, 3D printing, technology, and informatics. Interdisciplinary collaboration among radiologists, referring clinicians, physicists, and data scientists across the world is critical to understand data sources and quality, develop clinically relevant questions and decision support tools, and ensure practical impact and generalizability. [Table 4]

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Tables.

Table 1. Key departmental challenges and responses for radiology research during each stage of the COVID-19 pandemic.

<i>Early Pandemic</i>	
Challenges	Responses
Essential work mandate	Imaging limited to high-acuity, high-severity cases
Loss of clinical revenue	Research employee downsizing
Research shutdown	Decreased research activities and spending
Dry lab closure	Remote work with analysis of existing data
Wet lab restriction	Administrative guidelines for exemption and approval of in-person work
Animal care facilities	Downsizing to bare-necessity breeding animals
Human subjects research	Study prioritization and criteria for subject enrollment
COVID-19 understanding	High-priority research studies

<i>Mid-Pandemic</i>	
Challenges	Responses
Varying disease understanding and prevalence	Titrate essential and elective procedures based on institutional needs
Backlog of non-essential studies	Telehealth and virtual recruitment strategies
Remote informatics support for computational studies	High-performance computing and virtual private networking solutions
Wet lab reopening	Scale-up of resources and personnel
Limited in-person interactions	Virtual/hybrid meetings and conferences
Workforce shortage	Recruitment/retention initiatives and wellness programs
<i>Late Pandemic</i>	
Challenges	Responses
Hospital reopening	Technology and informatics tools to prioritize and coordinate examinations
Work-life balance	Flexible and hybrid work options
Limited collaborations	Research engagement and wellness
Reduced core use	Recovery of clinical and pre-clinical services and personnel
Future crises	Contingency planning for offsite work

Table 2. Effects of COVID-19 on radiology grant funding.

<i>Flexible Timelines</i>

Issue	Programs
Restriction of new projects	Delayed grant deadlines Longer eligibility windows New COVID-19 funding opportunities Trailblazer/pilot mechanisms
Suspension of active research	No-cost extensions More flexibility in grant milestones and funds carryover Flexibility clauses for promotion/tenure
Resumption of pre-pandemic momentum	Interdisciplinary engagement programs Published guidelines for researchers
<i>New Initiatives</i>	
Issue	Programs
Imaging characteristics of COVID-19	Quantitative disease biomarkers New imaging technologies Informatics and digital platforms
Imaging registries for COVID-19	International database development Reporting and data science tools Long-term outcomes

Table 3. Radiology research areas related to COVID-19.

Topic	Projects
Artificial intelligence	Multicenter data sharing

	<p>Machine learning</p> <p>Deep learning</p> <p>Clinical decision support</p> <p>Precision medicine</p>
3D printing	<p>Personal protective equipment</p> <p>Testing devices</p> <p>Replacement parts</p> <p>Clinical trials support</p>
Teleradiology	<p>Virtual education</p> <p>Quality improvement</p> <p>Health care disparities</p> <p>Radiologist well-being</p>
Imaging technology	<p>Multicontrast imaging</p> <p>Advanced tomosynthesis</p> <p>Microscale/nanoscale technologies</p> <p>Portable or remote scanning</p> <p>Image-guided interventions</p> <p>Digital health</p>

Table 4. Summary of strategies to maintain and grow radiology research in the post-pandemic era.

Topic	Strategies
Staff shortages	Flexible work, engagement and wellness

	programs, training and recruitment pipelines
Researcher support	Infrastructure building, programs to incentivize research, internal and external funding, protected time, startup packages
Technology and informatics	Radiologic technology, informatics systems, multicenter data sharing, artificial intelligence, digital health
Shifting focus	COVID research, computational projects, interdisciplinary collaboration, implementation science, international relations