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The Impact of the COVID-19 Pandemic on Radiology Resident Education: Where Do We Go From Here?

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The Coronavirus Disease of 2019 (COVID-19) pandemic caused a dramatic shift in radiology resident education. Primarily, physical distancing prompted a general transition to virtual learning. Common changes made by radiology residency programs included virtual rounds and readouts, the use of simulation technology, and case-based learning which utilized pedagogical approaches such as the flipped classroom for teaching residents. Virtual learning appears to be a suitable alternative to traditional, in-person learning, and may have a place post-pandemic as part of a blended curriculum with in-person and virtual components. The extent of disruption to radiology resident education varied based on the local impact of COVID-19 and the prevalence of redeployment, as did residents' mental health and well-being. Accessibility of mental health resources for residents was highlighted as an issue that programs need to address during these difficult times. Moreover, the pandemic resulted in unavoidable reductions in procedural exposure which programs mitigated through the use of simulation technologies and virtual learning resources. Professional development activities such as mentorship and career planning were also dramatically impacted by the pandemic and remains a challenge that programs need to consider moving forward post-pandemic. The purpose of this review is to outline the changes made to radiology resident education as a result of the COVID-19 pandemic and suggest what changes may be worthwhile to continue.

Key Words: radiology education; residency; COVID-19; flipped classroom; virtual learning.

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Abbreviation: COVID-19; Coronavirus Disease of 2019.

INTRODUCTION

Since December 2019, the Coronavirus Disease of 2019 (COVID-19) pandemic has forced radiology departments across the world to adapt their resident training curriculum. With the need to physically distance, many programs moved their typically in-person teaching and daily readouts to web-based, virtual conferencing platforms. Radiology may have been uniquely positioned for this transition as a field that is intimately connected with technology. However, this move to the virtual setting has not been without its challenges. Closure of outpatient imaging facilities, cancellation of elective procedures, and limiting imaging to urgent and emergent cases caused a drastic reduction in the case volume

and diversity of studies to which residents were exposed. In some cases, programs had to deal with these circumstances twice due to different waves of the pandemic. This professional uncertainty, combined with the effect of the COVID-19 pandemic on residents' personal lives, resulted in a significant impact on resident mental health and well-being.

With vaccination programs picking up speed in many countries, there is the potential for some radiology programs to return to their traditional training methodologies. However, the timeline for the "return to normal" remains uncertain given the continuous emergence of COVID-19 variants. Some changes that were made out of necessity during the pandemic have proven fruitful, and could be incorporated into the curriculums of radiology residency programs post-pandemic. Many of these changes are founded in blended learning theory and the flipped classroom model.

The purpose of this review is to evaluate the educational changes made by radiology residency programs due to the COVID-19 pandemic, and using current learning theories, discuss which changes may be worthwhile to continue post-pandemic, which has not been previously explored in the literature. A secondary goal was to create a unified resource on

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radiology residency curricular changes that could be referenced in the event of future pandemics.

WHAT DATA IS AVAILABLE TO GUIDE EDUCATORS?

In this review, we included any publication that described changes made to their radiology residency programs during the COVID-19 pandemic. We searched PubMed, Embase and Google Scholar for articles published in 2020 or later. Studies were not excluded based on program size or location, with international studies included. Articles that documented virtual learning in radiology prior to the pandemic were excluded. Articles were also excluded if there was no available English translation or full text. Studies outlining resident or attending radiologist perspectives on changes during the pandemic were also included. In general, the vast majority of the selected studies were from larger, resource-rich radiology residency programs based in North America.

READOUTS

One of the most essential components of radiology residency teaching is the daily readout, which was traditionally done in person (1-3). The interactive nature of the readout promotes active learning and immediate feedback tailored for the resident's knowledge level (3). Unfortunately, the cancellation of non-urgent imaging examinations during the pandemic limited the volume and diversity of studies to which residents were exposed (4,5-7). Case volume reductions were most evident for mammography, magnetic resonance imaging, and non-positron emission tomography/computed tomography nuclear medicine, whereas ultrasound and radiographs showed the least reduction in volume (6-8). Some institutions combatted this by leveraging informatics through simulated readouts, which consisted of a mix of normal and abnormal studies (9-11). One institution found that both residents and faculty involved in the simulated daily readout believed it effectively mimicked a typical resident's workload (9). Resident autonomy seems to have increased as a result of the changes made during the COVID-19 pandemic (10,12), possibly as a result of case-based asynchronous readouts or peer-guided readouts. While the use of a simulated daily readout will not be necessary post-pandemic, the technology could be used moving forward for a number of purposes including assessment, supplementation for rare and challenging cases, as well as a resource for rotation and call preparation (9).

Virtual readouts, performed using video conferencing software or over the phone, were also implemented due to the need for social distancing (4). In general, virtual readouts appear to maintain a similar experience to that of an in-person readout, however, one limitation of this technology is that instructors are unable to gauge body language and visual cues from trainees (2,13). Virtual readouts in one study were shown to negatively impact workplace atmosphere, personal

relationship building, and were more negatively rated by attendings than by residents (12). Attendings placed specific emphasis on the shortcomings of asynchronous virtual readouts becoming evident for complex exams and poorly written drafts by residents (12). For some residents, virtual readouts without real cases on a picture archiving and communication system (PACS) were also felt to be a training weakness (14). Post-pandemic, virtual readouts may have a place in radiology training, but would likely exist in a hybrid model with in-person readouts (13-15) and would have to address the described disadvantages (Table 1). Specifically, it would likely be helpful to initially establish a resident's level of knowledge and competence in-person due to the advantages of increased rapport and gauging body language, prior to taking advantage of a blended model through the use of a virtual platform.

TEACHING ROUNDS

In many institutions, teaching rounds were canceled initially, but were shortly resumed in a virtual setting, taking advantage of platforms such as Zoom, Google Hangouts/Meet, Microsoft Teams, or Skype (4,16). Recorded grand rounds from previous years (1), participation in internal medicine rounds in preparation for redeployment (17), and weekly or daily didactic radiology teaching rounds continued virtually (4,18,19). One study that surveyed radiology residents showed the majority of residents were satisfied with the virtual delivery of teaching rounds (14). For residents, remote rounds promotes social distancing and also reduces travel requirements which could decrease their time away from their current rotation. However, technical difficulties may impede learning and in general. It is also more difficult for teachers to engage a group of online learners, which may force lecturers to resort to didactic lectures which are a form of passive learning and are not the most optimal teaching strategy (20). As described in the next section, the employment of virtual learning strategies can improve remote learner engagement. Similar to readouts, a hybrid model combining in-person and virtual elements, alongside asynchronous, recorded components may persist going forward.

VIRTUAL LEARNING AND FLIPPED CLASSROOM MODEL

As rounds and readouts were initially made virtual, some feared that resident engagement would be significantly reduced (21). However, as residents and faculty became more accustomed to technology and the virtual format, engagement improved (2,16). A number of virtual learning strategies were also employed including, gamification (11), digital polling (14,16,21), and case-based learning (17,18,22,23). For the most part, residents prefer the in-person experience for teaching and learning (24). A minority seem to prefer virtual learning.

TABLE 1. Summary of Changes Made to Radiology Residency Programs, Impact on Training, and What Could Persist Post-pandemic

Category	Changes Made	Effect on Training	Implementation Post-pandemic
Teaching rounds and readouts	Simulated readouts Recorded grand rounds Virtual didactic lecturing	Ensured education continued remotely during the pandemic.	Use hybrid approach for assessment, supplementation for challenging cases, and rotation/call preparation both in-person and virtually.
Virtual learning and flipped classroom model	Resident-led conferences Case-based lectures Virtual Journal clubs Individual learning and small group discussions	Provided more teaching and learning opportunity for residents.	Useful post-pandemic to make residents more confident in their abilities and knowledge base and reach a wider audience.
Procedural exposure and IR residency changes	Simulation training	Allowed for continued procedural education despite low case volumes.	Could be useful post-pandemic if case volumes remain low but does not replace real-world procedural training.
Mentorship, resident research, and career planning	Formal Peer-mentoring program	Valuable at fostering positive relationships with colleagues.	Useful to build morale and a collegial environment post-pandemic.
	Remote research work	Valuable for researchers living remotely to participate in research.	Can be used post-pandemic to improve research exposure, involvement, and financial burden.
	Virtual conferences	Reduces travel and accommodation costs associated with conferences.	
Psychosocial impact and resident perception on disruption to training	Morale building activities introduced	Increases overall morale of residents.	Builds collegial environment for residents and faculty and should be continued post-pandemic.
	Mental health services made more accessible	Provide support to residents experiencing barriers to training.	Should be promoted more effectively to ensure residents know what services are available.

IR, interventional radiology.

The transition to virtual platforms came with limitations. The need for reliable, stable, high-speed internet access, adequate Health Insurance Portability and Accountability Act (HIPAA) compliant technology, and navigating a household where others were also working from home added additional pressure to residents (1) and instructors (25). Additionally, technical proficiency of participants was another drawback that may have initially hindered virtual learning, however, this was typically not an issue following an initial adjustment period (2,12,16). While the virtual environment alleviated the logistical challenges of in-person attending meetings, virtual sessions raised concerns for some regarding intellectual property, to whom the session should be made available, and for how long recordings should be published (2).

Visiting rotations for residents were canceled at most institutions, but virtual sessions, recorded or live, allowed residents from distant geographic areas to convene and learn from faculty they otherwise would likely not have had the opportunity to interact with (2,18,26). Virtual platforms can promote the participation of underrepresented groups in medicine, such as women, persons of color, and residents from developing countries, to network and gain exposure

within the field of radiology (2,21). Many residents believed there was an overall increase in national teaching during the pandemic with a general increase in quality as well (6). However without recordings, it may be difficult for some residents to participate due to clinical workload, time differences, and other commitments (2). Regional and national conferences were largely hosted virtually (17,21,27,28), with some cancellations (5,22). Having conferences held virtually allows international attendees to participate more easily and keeping virtual options for conferences should be considered moving forward. Similarly, the vastly improved accessibility and increased diversity of attendance for virtual teaching sessions may make it worthwhile for some teaching sessions to remain virtual post-pandemic (Table 1).

The availability and promotion of asynchronous lecture recordings (21,29), and other online resources (16,17) has increased during the COVID-19 pandemic. While many online radiology resources are available, typically they are very diverse and not compiled in an easy-to-access format. The COVID-19 pandemic added pressure for many institutions to cultivate a list of useful radiology resources (2). Online educational resources include websites, question

TABLE 2. Advantages and Disadvantages of Online Educational Resources for Radiology Residents

Advantages	Disadvantages
<ul style="list-style-type: none"> • Ease of accessibility and increased flexibility • Learners can find resources they find more suitable for their learning style • Many are free for residents • Develop learner self-directed learning skills • Smaller-sized residency programs can use to supplement teaching 	<ul style="list-style-type: none"> • Requirement for reliable, high-speed internet • Reliability of online resource content may not be well established • Requires learners to avoid distractions • Learner must have insight on gaps in knowledge and be accountable for their own learning

banks, video lectures series, and virtual case databases (14). For abdominal and neuro-imaging training, some resources that were employed include the RadPrimer question bank and teaching modules, online lectures provided by the Radiological Society of North America (RSNA), American Roentgen Ray Society (ARRS), and Society of Abdominal Radiology (SAR), and virtual interdisciplinary rounds (14). These resources have advantages and disadvantages that are summarized in Table 2.

In general, these changes involving asynchronous individual preparation, lend themselves to a flipped classroom model. This model is structured around an individual learning prior to a guided small group discussion with peers and instructors (30), and has been suggested to be more effective than traditional didactic lectures (20). The flipped classroom model has gained popularity in recent years, and the pandemic prompted many radiology residency programs to adopt this effective teaching strategy (10,20). For example, McRoy et al. 2020 implemented a novel cloud-based education system that combined discussions based on supplemental online resources with instructor guided readouts (10). All participating first year radiology resident in this study reported improved confidence and knowledge to take independent

call (10). The advantages and drawbacks of virtual learning are described in Table 3.

PROCEDURAL EXPOSURE AND INTERVENTIONAL RADIOLOGY (IR) TRAINING

Residents' procedural exposure was negatively impacted by decreased procedure volumes due to the cancellation of non-emergent procedures at pandemic peaks, and the need for minimizing the number of proceduralists physically present. Some residents believed that missing certain rotations and procedural exposure limited their training (6,17). Decreases in case volumes were particularly impactful for interventional radiology residents who have accreditation case requirements (22,31). Many of these accreditation requirements were adjusted or postponed, which caused residents additional stress (24,31,32). Nonetheless, to mitigate this issue, simulation technologies were used to allow residents to continue to develop their procedural skills (19,33). For programs that are transitioning toward a competency-based curriculum, simulation technologies could be a valuable tool if procedural volume remain low post-pandemic (Table 1) (17,29).

TABLE 3. Benefits and Drawbacks of Virtual Learning in Radiology Residency Programs

Benefits	Drawbacks
<ul style="list-style-type: none"> • Increased resident autonomy • Ease of accessibility • Effectively mimics a resident's workload • Use of simulated readouts for exposure to a wider breadth of cases • Resident-led conferences, virtual journal clubs, and case-based lectures became more common • Allows distant learners to be more involved remotely • Promotion of underrepresented groups • Perceived increase in overall national teaching • Increased use of flipped classroom model and small group learning 	<ul style="list-style-type: none"> • Inability to read body language and visual cues • Reduced personal relationship building • Negative impact on workplace environment • Lack of real cases available on PACS • Asynchronous virtual readouts for complex cases leading to poorly written drafts by residents • Reduction in case volumes • Requirement for high-speed internet access and HIPAA compliant technology • More difficult to implement changes in larger programs

HIPAA, Health Insurance Portability and Accountability Act; PACS, picture archiving and communication system.

Many radiology residents were redeployed to general medicine wards, COVID-19 wards, and intensive care units where they were more engaged in direct clinical care and procedures than they would have been pre-pandemic (6,17). Interventional radiology residents redeployed to intensive care units were able to provide strong image interpretation leading to a clearer differential diagnosis, which allowed intensivists to better focus on addressing the patient's clinical deterioration (19,29). While this exposure augments radiology residents' exposure to procedures, it could have prevented them from developing and refining their diagnostic radiology skills. More research on the downstream impacts of residents who lost dedicated radiology training as a result of redeployment is needed (34).

Additionally, residents were worried of not only possibly contracting COVID-19, but also spreading it to their loved ones (31). The extent of redeployment varied between institutions, which was dependent on regional COVID-19 case rates (4,6,28,35,36). Although redeployment could limit refinement of diagnostic radiology skills, there may be a role for radiology resident exposure to direct patient care activities, as seen in residents redeployed to intensive care wards (37). These experiences with patients and their family members provides important clinical context for radiologists-in-training (37).

MENTORSHIP, CAREER PLANNING, AND RESIDENT RESEARCH

While teaching rounds and readouts are a vital component of radiology learning, they also play an important role in fostering personal connections and mentorship. Despite working and corresponding with staff virtually, virtual platforms do not lend themselves to the informal conversation between radiologists and trainees that builds personal relationships (1,14). To combat this, one program implemented a formal peer mentoring program which they found to be a valuable addition to their training and increased the sense of community for their residents (38). Despite virtual platforms theoretically allowing for similar interactions with potential mentors, most residents prefer the in-person setting to better foster personal connections (21,39). Resident mentorship has suffered as a result of the pandemic, and this suggests a role for program-established peer mentoring systems and a possible shift toward a hybrid model for mentorship that takes advantage of virtual platforms when convenient (Table 1). Specifically, as we suggest with readouts, an emphasis on in-person activities in the initial stages to establish rapport and build personal connections, followed by the use of virtual platforms would be an optimal approaching moving forward.

Pediatric and breast imaging case volumes were reduced during the pandemic and this was felt to potentially have an impact on the likelihood of residents pursuing these subspecialties (5,26,40). In one study, most trainees felt that the pandemic negatively impacted their education in these areas (5). Similar to IR case requirements, mammography credentialing

requirements added additional pressure to residents as a result of reduced volume (27,41). Many breast imaging rotations switched to virtual alternatives due to the need for physical distancing and reduced volume (42). Whether it be IR, breast imaging, or pediatric radiology, COVID-19 limited resident exposure to these sub-specialties, which consequently could negatively impact future application rates. This stresses the importance of providing consistent exposure, possibly with simulated technology where in-person exposure is not a viable option.

Resident involvement in research underwent changes to deal with the cancellation of many projects that depended on in-person activities (43). Remote projects, virtual meetings, and COVID-19 related projects gained popularity during this time (7,32). In addition to knowledge advancement, benefits for residents engaged in research is mentorship provided by the research supervisor and networking from presenting their work at local and national conferences. As described previously, given the limitations of fostering personal connections virtually, it is important for research supervisors to have a continuous dialogue with their trainees, and to encourage mentorship. Moreover, attendings can help with networking at national conference, for example during virtual social hours at conferences.

INTERVIEWS

Most medical student interviews for radiology residency positions shifted to an online format during the COVID-19 pandemic. This was a significant change from the traditional interview process where students previously had to travel to multiple different programs for on-site interviews. Interview preparation did not change significantly, with the exception of ensuring that the location from which students wished to do the interview was optimized for a virtual interview, including minimizing background noise, ensuring a stable internet connection, and avoiding backlighting (44). Medical students were also not as restricted in the programs to which they wished to apply since virtual interviews are far less costly than in-person interviews given that applicants no longer had to pay for travel and accommodation (45).

For programs, it was important to acknowledge the potential bias against applicants with limited access to reliable internet or web conferencing technology (44). One institution's reflection at their virtual interviews showed that the majority of applicants and interviewers were satisfied with the online platform (45). However, applicants tended to agree that the virtual setting limited their ability to assess a program's environment (45). Social events helped applicants meet residents and get a sense for the program's culture and this was emulated through alternatives such as "virtual happy hours" where breakout rooms could be used to speak in smaller groups (44). Many of the changes required to develop and implement a permanent online system for radiology residency applications will likely require substantial investment and may only be possible for larger programs (44). Post-pandemic,

programs may desire to offer hybrid interviews to mitigate the financial burden interviews impose on students. Optional in-person site visits may be offered to allow applicants to better understand and gain exposure to the program's facilities and atmosphere.

Similar changes were made for radiology residents interviewing for fellowship positions. To attract candidates during the pandemic, fellowship programs increased their outreach through web pages, social media, and virtual information sessions (46). For residents, advantages of virtual interviewing included the lower cost, reduced work missed, and the ability to attend more interviews, however, virtual interviews do not allow residents to assess the programs dynamic and training atmosphere (47). From the program's perspective, virtual interviewing is easier to accommodate interviewer schedules and locations. Disadvantages include the inability to determine personal compatibility of the interviewee with the group. Moreover, many programs have reported a significant increase in the number of applications during the pandemic, likely related to the increased number of interviews candidates can now attend virtually, which places an additional administrative burden on selection committee members (47).

PSYCHOSOCIAL IMPACT AND RESIDENT PERCEPTION ON DISRUPTION TO TRAINING

Some radiology residents felt that their radiology department and their education changed due to the COVID-19 pandemic (5), potentially more so than their medical and surgical resident colleagues (48). Despite undergoing changes, program directors and residents felt that learning standards were being adequately addressed for knowledge and interpretation, but case volumes and technical skills were lacking (14,49). Some institutions reported that residents felt their education was negatively impacted by the circumstances of the pandemic (35), but similar levels of competence (14) appeared to be displayed. However, there is currently very limited data on objective measures of radiology resident competence following education changes due to the pandemic.

The changes made to their program was associated with an increase in anxiety for residents (49). The disruption experienced by radiology residents appeared to differ between junior and senior residents, however, this appeared to vary between institutions and may have been related to the extent of redeployment (4,8,34,35,37,50). Specifically, the perceived negative impact of the COVID-19 pandemic on resident training appeared to differ based on the toll of COVID-19 in the region (50). Some residents felt it difficult to have the responsibility of covering multiple large hospitals during COVID-19 (18), although for some, on-call responsibilities did not appear to change very much during the pandemic (23). Also, the cancellation or postponement of certification exams led to a decrease in resident wellness due to the worry of increased stress and scheduling difficulties in their upper years of residency (24), and these results could be extrapolated to the candidates who wrote a 2020 diagnostic radiology certification

exam who had to navigate the challenges of a postponed exam. Permanently increasing the flexibility of administration of these exams to a more accessible, possibly online, format should be considered going forward (24). However, invigilation of online formats may motivate exam administrators to return to proctored, in-person examinations.

Some residents felt that their training was delivered on an "ad-hoc" basis, but most believed their program was delivering coordinated training (6). Furthermore, reduced onsite capacity displaced many residents to their homes to participate in virtual learning (14,24,51). For some, the allocation of unused PACS workstations allowed residents to work remotely (1,10). Many program directors felt that the pandemic negatively impacted their residents' education and morale, with redeployment decreasing morale further (23). Access to mental health resources appeared to be plentiful, but some residents were not aware of the resources available and how to access them (19,23,35,36). The circumstances of the pandemic have highlighted a shortcoming in awareness of available mental health resources and residency programs in the future should promote the existence of these resources for residents (Table 1).

Some residents felt that the circumstances of the pandemic led to an increase in willingness to cooperate with colleagues (28). Centralizing virtual platforms for meeting and communication including Zoom, Webex, Microsoft Teams, Gotomeeting, and Google Meet proved to be effective (17-19,36,52). Combatting social isolation and offering a platform for peer support suggests a role for virtual meetings, phone calls, and social media such as Twitter, Instagram, or Slack (41).

The impact of COVID-19 on residents' personal lives was one of the most common concerns (5,19,28,53). Many residents reported increased stress related to the pandemic, a part of which may be attributed to redeployment (19,24,54). Residents experiencing barriers such as technical difficulties, childcare, or a lack of an office space, were less likely to adhere to virtual learning and felt more likely to fall behind in comparison with their peers (14). Strategies implemented to lower exposure such as scheduling changes to allow working from home, and virtual readouts decreased resident stress levels (4). Some programs explored other virtual team activities to build morale including workout challenges, happy hours, and game nights (52).

Generally, the impact of the COVID-19 pandemic was quite significant on residents' lives. Programs that actively foster an interactive and collegial environment through virtual or in-person activities may be more likely to have increased resident morale (Table 1).

SMALLER PROGRAMS' UNIQUE SITUATION

Many of the curricular interventions we discuss in this paper are in the context of large, resource-rich, radiology residency programs. The capacity to make these changes is different for large programs with many faculty, fellows, and residents in comparison to smaller programs (1).

For smaller programs who do not have the resources to implement simulated readouts, there is a plethora of online case banks that can be used, many of which are free to trainees. For example, the RSNA Case Collection has a large collection of cases from every radiology sub-specialty and attendings could create quizzes that mimic a simulated readout. Alternatively, attendings could collect a log of interesting cases and have residents interpret them as unknowns.

Simulation is still a viable option for smaller programs. Although access to expensive cadavers may not be realistic, common image guided procedures such as image guided biopsy can still be taught using homemade biopsy phantoms (55). Finally, smaller programs could also partner with a nearby larger institution to take advantage of virtual rounds and teaching.

LIMITATIONS AND FUTURE DIRECTIONS

Our paper is limited by the lack of literature outside of North America, as well as from smaller programs that have limited financial resources and fewer residents. Further reporting in these areas may offer a valuable resource for educators in similar educational contexts. There is also a lack of literature assessing objective measures of radiology resident performance for those training during the pandemic. Analysis of exam performance, staff evaluations, and call performance before and after the pandemic would be a worthwhile avenue to explore to better understand the impact of curricular changes.

CONCLUSION

Despite vaccination programs advancing rapidly in many countries, the pandemic is very much ongoing. As a result, the long-term impact of the changes made by residency programs are yet to be understood. While the COVID-19 pandemic has undoubtedly put radiology programs in a difficult position to adapt their programs, several effective changes have been implemented at an impressive pace. A shift to a partial hybrid model with intermittent use of simulated technologies, virtual readouts, virtual teaching sessions, and remote work could improve on the traditional model of purely in-person training by increasing flexibility, convenience, and exposure for residents. The circumstances of the pandemic also emphasized the importance for programs to facilitate opportunities for residents to interact with each other in a non-work capacity and ensure that the mental health resources available to residents are made clear. Iteratively improving these new radiology residency teaching and learning elements will be essential to permanently establishing them within radiology education.

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