

Impact of COVID-19 pandemic on radiology education, training, and practice: A narrative review

Md Anwarul Azim Majumder, Uma Gaur, Keerti Singh, Latha Kandamaran, Subir Gupta, Mainul Haque, Sayeeda Rahman, Bidyadhar Sa, Mizanur Rahman, Fidel Rampersad

ORCID number: Md Anwarul Azim Majumder 0000-0003-3398-8695; Uma Gaur 0000-0002-8017-6035; Keerti Singh 0000-0001-7532-1229; Latha Kandamaran 0000-0001-7207-1228; Subir Gupta 0000-0002-0512-6652; Mainul Haque 0000-0002-6124-7993; Sayeeda Rahman 0000-0002-7005-8801; Bidyadhar Sa 0000-0001-8702-7641; Mizanur Rahman 0000-0002-3827-4678; Fidel Rampersad 0000-0003-4354-9274.

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Md Anwarul Azim Majumder, Uma Gaur, Keerti Singh, Latha Kandamaran, Subir Gupta, Faculty of Medical Sciences, The University of the West Indies, Cave Hill Campus, Cave Hill BB23034, Barbados

Mainul Haque, Unit of Pharmacology, Faculty of Medicine and Defence Health, Universiti Pertahanan Nasional Malaysia (National Defence University of Malaysia), Kem Perdana Sugai Besi, Kuala Lumpur 57000, Malaysia

Sayeeda Rahman, School of Medicine, American University of Integrative Sciences (AUIS), Bridgetown BB11318, Barbados

Bidyadhar Sa, Fidel Rampersad, Faculty of Medical Sciences, The University of the West Indies, St Augustine Campus, St Augustine 33178, Trinidad and Tobago

Mizanur Rahman, Principal's Office, International Medical College, Dhaka 1207, Bangladesh

Corresponding author: Md Anwarul Azim Majumder, MBBS, PhD, Director of Medical Education, Faculty of Medical Sciences, The University of the West Indies, Cave Hill Campus, Cave Hill Road, Cave Hill BB23034, Barbados. azim.majumder@cavehill.uwi.edu

Abstract

Radiology education and training is of paramount clinical importance given the prominence of medical imaging utilization in effective clinical practice. The incorporation of basic radiology in the medical curriculum has continued to evolve, focusing on teaching image interpretation skills, the appropriate ordering of radiological investigations, judicious use of ionizing radiation, and providing exposure to interventional radiology. Advancements in radiology have been driven by the digital revolution, which has, in turn, had a positive impact on radiology education and training. Upon the advent of the corona virus disease 2019 (COVID-19) pandemic, many training institutions and hospitals adhered to directives which advised rescheduling of non-urgent outpatient appointments. This inevitably impacted the workflow of the radiology department, which resulted in the reduction of clinical in-person case reviews and consultations, as well as in-person teaching sessions. Several medical schools and research centers completely suspended face-to-face academic activity. This led to challenges for medical teachers to complete the radiology syllabus while ensuring that teaching activities continued safely and effectively. As a result, online teaching platforms have virtually replaced didactic face-to-face lectures. Radiology educators also

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sought other strategies to incorporate interactive teaching sessions while adopting the e-learning approach, as they were cognizant of the limitations that this may have on students' clinical expertise. Migration to online methods to review live cases, journal clubs, simulation-based training, clinical interaction, and radiology examination protocolling are a few examples of successfully addressing the limitations in reduced clinical exposure. In this review paper, we discuss (1) The impact of the COVID-19 pandemic on radiology education, training, and practice; (2) Challenges and strategies involved in delivering online radiology education for undergraduates and postgraduates during the COVID-19 pandemic; and (3) Difference between the implementation of radiology education during the COVID-19 pandemic and pre-COVID-19 era.

Key Words: Radiology; Education; Training; Practice; COVID-19 pandemic; Impact

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Core Tip: The COVID-19 pandemic has had a tremendous impact on radiology education. Even before the pandemic, educators often encountered many difficulties in delivering the radiology curriculum. During the pandemic, there was an almost complete transition of radiology education to a blended online platform. Many hiccups in implementing online teaching were reported, such as suitable hardware/software, reliable internet connection, innovative and interactive teaching methods and contents, and meaningful participation and interaction of the students. However, despite many challenges and restrictions, the current pandemic revealed opportunities for radiology educators and students to apply the technological acumen and wisdom they gained by teaching and learning remotely.

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INTRODUCTION

Recent surveys have explicitly stated the necessity of radiology education for undergraduate medical students[1,2]. Radiology education and training, over the last decade, has undergone a significant transformation from purely didactic lectures toward early clinical exposure and team-based learning, with an emphasis on hands-on workshops and case-based teaching[3]. Over the last decade, much before the corona virus disease 2019 (COVID-19) pandemic, e-learning has become a highly effective and valuable asset in the field of radiology education, just like many other areas of medical education[2,4]. In recent years, the majority of the medical teaching institutions throughout Europe were reportedly using e-learning extensively in radiology teaching and training[5]. Face-to-face learning, combined with online education, was found to be very successful in enhancing students' knowledge in basic radiology, clinical radiology skill application, and long-term retention of knowledge and basic skills in radiology[6].

The COVID-19 pandemic has resulted in an unprecedented worldwide disruption in medical education training and patient care[7-11]. Several medical schools and research centers suspended face-to-face academic activity and scientific research activities to maximize social distancing and minimize the spread of infection COVID-19 among staff and others[12-14]. Similarly, there has been a disruption in the activity of academic programs and research activities in radiology, with both short-term and long-term implications[1,15,16]. This disruption affected radiology practice and teaching of both undergraduate medical students and postgraduate trainees/fellows. It has now become important for medical teachers to deliver their lectures safely while ensuring the effectiveness and integrity of the process. Electronic or online teaching platforms have completely or almost completely replaced didactic lectures and all the

forms of face-to-face teaching. These online activities are structured to promote knowledge and skills defined in the curriculum while facilitating an individualized learning experience[17].

In the preclinical years, medical students have traditionally learned radiology through didactic lectures, case-based learnings, integrated anatomy laboratories, and clinical skill sessions, an example of which is hands-on ultrasound sessions. This fosters the student's ability to select the most appropriate imaging modality for the relevant clinical situation. Evidence-based selection of imaging tests, best suited for individual clinical scenarios, is a fundamental value in providing greater value to patient care[18]. The COVID-19 pandemic has posed significant challenges in utilizing these established formats of radiology education[19].

However, despite many challenges and restrictions, the current pandemic revealed opportunities for radiology educators to apply and expand the technological acumen and wisdom they gained by delivering content remotely[20]. In this review paper, we have discussed (1) The impact of the COVID-19 pandemic on radiology education, training and practice; (2) Challenges and strategies involved in delivering online radiology education for undergraduate and postgraduate students during the COVID-19 pandemic; and (3) Difference between the implementation of radiology education during the COVID-19 pandemic and pre-COVID-19 era.

LITERATURE SEARCH

We performed literature searches with PubMed, Scopus, and Google Scholar using specific keywords, *e.g.*, "Radiology," "Education," "Training," "practice," "COVID-19 pandemic," and "Impact." Original studies, reviews, editorials, commentaries, perspectives, short or unique communications, and policy papers on radiology education, training and practice were reviewed. Information from websites of different professional associations and national/international organizations was searched to retrieve relevant information.

RADIOLOGY TEACHING/TRAINING IN UNDER- AND POST-GRADUATE EDUCATION

Although the necessity of teaching radiology among undergraduate medical students has been continuously emphasized[1,5,21-23], medical students often receive inadequate teaching-learning input, and are, therefore, inadequately trained in basic radiology[22,24,25]. The usage and interpretation of medical images are very ubiquitous in clinical practice; therefore, basic radiology must be incorporated in the medical curriculum for interpretation of common abnormalities, such as those found in radiographs of the chest, abdomen, and limbs, as well as basic computed tomography (CT) scans of the head and abdomen. This exposure will allow medical students to become competent in basic medical image interpretation, and in recognizing the critical situations when expert radiological opinion should be sought [5,6]. Currently, the selection of the right imaging technique has become very challenging for the general practitioners, due to numerous medical imaging options which are becoming increasingly complex. Multiple studies reported that even in certain centers within the United States of America, radiology teaching among undergraduate medical students, including clinical clerkships, remains very "inadequate"[26-28]. Furthermore, British undergraduate medical students mentioned several limitations in their radiology teaching-learning program[22,29]. The aforesaid facts highlight the significance of radiology teaching in undergraduate medical education as an imperative building block. The central focus should be on teaching image interpretation skills and appropriate ordering of medical investigations, which should relate to prospective clinical practice. For radiology postgraduate programs (including residencies and fellowships), exposure and rotations through the various radiology subspecialties are mandatory, facilitating a wide exposure of the various imaging modalities, techniques, and clinical scenarios. Participation in multidisciplinary team meetings (MDTs) also facilitates a greater level of discourse with other specialists, such as surgeons, physicians, and pathologists.

Radiology instructional strategies should incorporate interactive teaching sessions and target all levels of medical education, at the undergraduate and postgraduate level as well as in the delivery of continuing medical education[28]. The current practice of

an e-learning approach has limitations in providing adequate clinical experience to the students and there has thus been an urgent call for more effective, modern teaching-learning methods to better train students in radiology[22,30]. Most teaching centers have a standardized core radiology curriculum that extensively covers general radiology experience supplemented by the subspecialty curricula, ensuring the equal status of radiologists in a multidisciplinary team. Further, with a growing number of clinicians acquiring interpretative skills in radiological imaging and diagnosis, radiologists are needed to prove mastery of their skills and knowledge to justify their inclusion in the team[31].

Pre-COVID-19 status of radiology education

Radiology teaching has undergone significant and continuous advancements during the pre-COVID-19 era. Fast-paced, expeditious technology-oriented innovations were introduced in clinical practice, which has transformed the specialty. This is highlighted by the change in the many radiology certification examinations from written and oral modes to computer-based testing. Although most universities have already embraced the new learning methods, some still find it difficult to administer these changes in the curriculum[32]. Radiology teaching in most of the European education centers was assembled and delivered as a part of the formal curriculum, mainly by the “classical approach” as an independent discipline, “modular approach” integrated with the clinical teaching modules, or by the “hybrid approach”-a combination of classical and the modular components. A growing need for more radiology education has been highlighted by the medical students, as radiology is frequently underrepresented in the medical curriculum and is usually taught by non-radiologists[26,33-35]. A study in the United States in Medical and Osteopathic schools reported that only 25% of United States medical schools required radiology clinical rotations, although students valued having radiology as a regular part of the medical school curriculum[36]. Medical students pursuing their clinical years have reported that radiology was being poorly taught, and highlighted a need for detailed teaching on topics such as radiation safety, magnetic resonance imaging (MRI) safety, and standardized requesting algorithms, such as the American College of Radiology appropriateness criteria (AC). The need to embrace the Alliance of Medical Student Educators in Radiology (ACR-AMSER) curriculum was recognized[28,35]. A United Kingdom study by Singh *et al*[36] established the core curriculum in the vital area of radiation protection (RP), thus formally establishing what medical students should be expected to know[36]. With the arrival and adoption of the latest imaging techniques and the growing demand for image-guided minimally invasive surgical procedures, interventional radiology (IR) has shown steady growth as a core element in medical and surgical therapeutics. However, a lacuna of teaching principles of IR, methods and techniques in the medical undergraduate curriculum was recognized[37]. Radiology has seen a digital revolution in the past decade having a notable impact on the education and training of radiologists. This includes the advent of handheld mini computer devices, virtual, online knowledge and skill assessments, enhancement of radiological procedural training with the use of simulations or virtual patients, high-quality videoconferencing tools, and the worldwide alliance of radiological resources *via* international databases [38]. Computer-assisted education or e-learning in radiology has become an important source of medical education especially for developing competencies in such areas as clinical X-ray interpretation. A study in Australia and New Zealand showed e-learning in combination with traditional learning can be more effective on radiological interpretation skills[39]. In 2014, following a detailed survey by the combined American College of Radiologists and the ACR-AMSER, recommendations and actionable interventions were proposed to allow measurable improvements to fulfill expectations surrounding medical imaging education[33]. Action plans were charted to meet the growing demands of radiology education and changes were adopted in the medical school curriculum by many teaching centers[33].

Radiology education: Issues and challenges

As radiology is not introduced as a separate discipline in the undergraduate curriculum, radiology tends to be marginalized in the examinations, a substantial reason for students to omit radiological anatomy and radiology topics[1,21,33]. Radiology educators often encounter challenges such as allocating adequate teaching time, education budgetary constraints, framing educational needs, professional development for facilitating radiology teaching-learning sessions, and difficulties in developing instruments to assess teaching quality. Radiology teaching-learning sessions in most institutions are frequently conducted by non-subject experts, although it is recognized that radiologists teach diagnostic imaging better than any other

specialty. Therefore, it was suggested as pertinent and timely for the development of a core curriculum and that radiologists should start playing a more active role in undergraduate medical education[21]. Severe competition due to encroachment of other clinical specialists in the field, lack of proper recognition, lack of recognized clinical training, inefficient management of the relationship of IR with diagnostic radiology and complexities of IR along with an obligation to the best clinical care for patients, cost escalation, workforce issues, and time constraints were seen as major threats and challenges of teaching IR techniques[40,41]. Cohen *et al*[42] reported that radiology faculty spent 72% of their time in clinical activities and only 19% on radiology education-related activities, revealing suboptimal time spent on educational activities. Faculty members usually spend more time teaching rather than asking questions to the students, which doesn't develop the cognitive and critical thinking skills, demanding a need for more "safe space" for students to learn by making mistakes[42]. There is a need for more apprenticeship training time for more active and stimulating interactions and more professional development time to facilitate radiology teaching-learning sessions. Another study among medical students revealed that a gap exists between theoretical input and clinical practice, inadequate exposure to specialized procedures (such as IR cases), and time allocated teaching-learning sessions[37]. Although IR is the most expanding field in radiology due to increased patient demand, regardless of the many accomplishments, public awareness of IR is however extremely limited[40,42].

Impact of technological innovation

As indicated before, the old style of medical education was enhanced by incorporating e-learning strategies[2]. A significant evolution from when teaching resources were limited to films developed in dark rooms and stored as archives or film museums[43]. Over the past several decades, the practice of radiology has undergone remarkable changes, accompanying the digital revolution and advances in imaging technology [22]. The digital modalities and extensive networking technology prompted the development of Digital Imaging and Communications in Medicine (DICOM) in 1993 [44]. In addition, wireless technologies, including smartphones and tablets were adopted by the radiologist for instant transmission or exchange of radiological images. We are moving into virtual machines, operated by one server as a host optimizing the processing power of that single device instead of multi-single servers. Artificial intelligence (AI) is capable of learning without explicit instruction and has emerging radiology applications[45]. Radiology informatics system and picture archiving and communication system (PACS), included several advanced technologies taught to radiologists. Many simple and advanced software options are now widely available on our desktops and portable devices. An example of such widely used technology is computer-assisted diagnosis[46]. Other emerging tools include online search tools and point of service tools, integrated into the radiology reporting process. A dictation/transcription vendor has incorporated a semi-automatic search wizard. Another highly advanced tool currently in development involves "watching" the radiology dictation in real-time and employing natural language processing to identify key trigger words, search the internet resources in the background, and display relevant information on another window. Healthcare data exchange of radiology images using "cloud services" is fundamental to maintaining the integrity of the patient's longitudinal medical record and for communication amongst conditions on the managing team[47]. Similar advancements including digital and model-based simulations allow the undergraduate and postgraduate students to have a greater practical experience with simple and advanced IR techniques. Across the board, these technological advancements which assist in better radiology workflow, also ultimately contribute to a more streamlined radiology teaching process, as these advanced softwares are usually integrated into didactic and hands-on sessions.

E-learning in radiology teaching and training

Research revealed that the continuous development of computer-related information technology, multimedia, online publishing, and increased Internet availability offer cherished opportunities for medical instruction strategy and continuing medical education, explicitly for radiology[48]. Additionally, the disposition of digital imaging networks, the PACS, teleradiology, and Internet services stalwartly advocates that e-learning will contribute an essential basis of education in radiology, principally among young medical graduates and students, as they are more contented in utilizing the Internet and computers[48]. Furthermore, medical students recognize the need to embrace computer-supported collaborative learning educational programs to embark on radiology training in order to be qualified and competent medical doctors[1]. It has

been reported that the choice of the teaching-learning approach has a superior impact on learning consequences, which is an important learning point for competent medical educators[49]. There are quite a few areas in teaching-learning sessions of radiology in theoretical and practical clinical teaching sessions where mobile electronic devices (MEDs) could pose an advantage for both pupils and teachers. In particular, these gadgets increase the possibility of improving efficiency in data acquisition and clinical interpretation and are therefore highly prized as an information delivery instrument [50,51]. Another study reported that implementation of an e-learning strategy regarding RP education is achievable and practicable, which resulted in a better-quality acquaintance among medical students regarding RP[52]. This study concluded that coalescing e-learning with traditional instructional strategy resulted in a definite improvement in acquiring radiology competence. Additionally, utilizing MEDs is a cost-effective educational instrument that has augmented practicing competencies, improved access to study resources, facilitate increased interactivity in educational meetings, and promotes interactions with the use of audience response software. As such, a preconfigured tablet effusively holds the technology transference into movable computing and characterizes a new effective approach in radiology education[53].

E-learning is a growing phenomenon in education that supports students learning in flexible environments, self-paced or instructor-led learning and that can include media in the form of text, images, animation, video, and audio[54,55]. E-learning can help address some of the challenges in healthcare education by allowing on-demand access, control of standardized content, quality assurance, and learning analytics. E-learning and blended learning have been particularly exploited in radiology because the field is rich in digital images and is thus suited for online access and viewing. Various e-learning methods used are Web-based software/platforms[56], interactive modules with multiple-choice questions (MCQs), self-assessment tests/quizzes/matching questions[57], interactive animations with videos[58], and online word documents/notes[59]. E-mails can also be used containing MCQ questions, and an additional follow-up email including the correct answers can also be an effective strategy[60]. Radiology teaching is being revolutionized by emerging tools such as Audience Response Systems, Web-based video tools, and interactive educational games. These tools are uniquely suited to radiology given the intense imaging nature of radiology education[2]. Virtual training methods have been well perceived by the student as there is better engagement, increased attendance and increased imaging confidence in trainees, and a significantly higher overall number of students performing radiology rotations[61]. E-learning can be considered more than suitable for “knowledge” including procedural performance knowledge but has limited utilization in actual patient care.

RADIOLOGY EDUCATION, TRAINING AND PRACTICE: IMPACT OF COVID-19 PANDEMIC

Radiology education, training and service underwent a significant transformation during the COVID-19 pandemic, primarily as a result of a temporarily reduced radiology workload and social distancing guidelines (Table 1)[62-74]. The alterations in case volume and teaching schedule resulted in significant changes to undergraduate and postgraduate trainee education[66]. Many teaching and research activities were limited, with some training programs even being suspended. Many certification examinations were canceled, with consequent effects on the mental health of both students and teachers alike. There was a complete transformation of the previously primarily didactic experience to embracing internet-based educational activities involving online content and virtual interactions, thus providing a blended learning environment[19]. These strategies, however, were not easily incorporated, as there were many challenges in their implementation. Innovative solutions were required, considering the psychological impact on the trainee and teacher. Institutions involved in radiology education require considerable investment and retooling to incorporate appropriate digital technologies to simulate a clinical type learning environment[75]. To survive and meet these challenges, we must continue to embrace varying strategies to maintain undergraduate and postgraduate radiology education in a safe environment, particularly with COVID-19 surging around us.

Radiology education: Impact of the COVID-19 pandemic

Radiology departments worldwide instituted policies and procedures designed to continue efficient operation, facilitating COVID-19 patients, all the while attending to

Table 1 Impact of COVID-19 on radiology education, training, and service

Ref.	Country	Institute	Study population, n (%)	Time of the study	Survey tools	Findings
Alamer and Alharbi[62], 2021	Saudi Arabia	Department of Radiology, College of Medicine, Qassim University	Medical student (n = 145)	2019-2020 Academic session	On-line questionnaire	<p>The sudden transition to completely distance learning was well received</p> <p>Synchronous learning was the preferred mode of delivery</p> <p>Student attendance in the synchronous sessions was high</p> <p>Synchronous interaction was found to be as effective as on-campus face-to-face learning</p> <p>The use of recorded sessions proved to be a source for knowledge gain and a solution for technical difficulties</p>
Durfee <i>et al</i> [63], 2020	United States	Department of Radiology, Brigham and Women’s Hospital, Harvard Medical School	Medical student (n = 111)	April 2020	Online final exam. On-line questionnaire	<p>Virtual radiology clerkship was a successful educational experience</p> <p>Final exam scores were similar to the in-person clerkship</p> <p>Students expressed their satisfaction with small group homerooms learning activities</p> <p>Lack of personal connections between faculty and students</p>
McRoy <i>et al</i> [64], 2020	United States	Department of Diagnostic Radiology and Nuclear Medicine, University of Maryland School of Medicine	Radiology residents (n = 16)	March 15-May 15, 2020	Novel cloud-based Distance Learning Workstation	<p>The model improved residents’ confidence and knowledge to take the independent call.</p>
Veerasuri <i>et al</i> [65], 2020	United Kingdom	A regional United Kingdom radiology school	All specialty trainees	May 5-May 19, 2020	On-line questionnaire	<p>Overall radiology workload had decreased in response to COVID-19</p> <p>Decreased subspecialty experience</p> <p>Complete lack of subspecialty training</p> <p>Decrease well-being compared to before the pandemic</p>
Odedra <i>et al</i> [66], 2020	Canada	Canadian Association of Radiologists	Resident members of the Canadian Association of Radiologists (n = 96)	May 1-May 15, 2020	On-line questionnaire	<p>COVID-19 pandemic has had a significant impact on radiology residency programs</p> <p>Experienced an overall higher disruption in daytime schedules and case volumes</p> <p>Teaching rounds were moderately affected</p> <p>Virtual interviews for fellowship have been proposed</p> <p>Internal and external assessments were heavily affected</p> <p>Impact on the psychological well-being of the trainees</p>
Rainford <i>et al</i> [67], 2021	12 countries	Selected Radiography training institutions (n = 14)	Student radiographer, including final year students (n = 592)	Mid-June-Mid-July 2020	On-line questionnaire	<p>Highlighted challenges related to clinical placements <i>e.g.</i>, accommodation, travel, childcare, finance</p>
Shanahan and Akudjedu [68], 2021	Australia	Members of the Australian Society of Medical Imaging and Radiation Therapy	Radiographers and radiation therapists (n = 218)	June 24-July 15, 2020	On-line questionnaire	<p>Changes in work hours and workload were experienced due to COVID-19</p> <p>PPE was in short supply</p> <p>Increased personal stress and anxiety</p>

						at work In addition, their work caused increased stress to their family, partners, or friends
Hoegger <i>et al</i> [69], 2021	North America	86 institutions	Radiology chief residents (<i>n</i> = 140)	March 20-May 15, 2020	On-line questionnaire	59% of residents reported increased stress 93% of programs had fewer residents on service
Robbins <i>et al</i> [70], 2020	United States	Members of Association of Program Directors in Radiology	Program directors, Associate program directors, department chairs, Education vice-chair, and Faculty (<i>n</i> = 108)	April 16-May 14, 2020	On-line questionnaire	Educational mission-moderate/ marked negative impact (70.1%) Resident morale-moderate/ marked negative impact (44.8%) Adequate resident access to mental health resources during the acute phase of the pandemic (88.8%) The morale of program directors-mild or marked decreased (61%)
Foley <i>et al</i> [71], 2020	Ireland	All six Irish healthcare regions	Radiographers (<i>n</i> = 370 first survey, and 266 second survey)	March 2020 (first survey). Late May 2020 (second survey)	On-line questionnaire	Almost 50% of the radiographers were exposed to COVID-19-positive patients without appropriate PPE Anxiety levels reduced substantially 6 weeks into the crisis period 40% of the radiographers reported burnout symptoms 30% reported considering changing jobs or retiring since the pandemic
Alhasan <i>et al</i> [72], 2021	Saudi Arabia	National survey	Radiology residents (<i>n</i> = 109)	Academic year 2019-2020	On-line questionnaire	Most residents reported a negative impact of the pandemic on their educational and clinical activities, and personal well-being
Coppola <i>et al</i> [73], 2021	Italy	National survey	Members of the Italian Society of Medical and Interventional Radiology (<i>n</i> = 2150)	2020	On-line questionnaire	Working and personal life of the respondents was impacted by the pandemic
Patel <i>et al</i> [74], 2021	Canada	National survey	Interventional radiologists (<i>n</i> = 142)	May 5-28, 2020	On-line questionnaire	Pandemic had a profound impact on IR services, particularly for elective cases Considerable percentage of trainees would have a delay in starting their careers

PPE: Personal protective equipment.

all other emergent/non-emergent patients[76]. Additionally, to protect both patients and healthcare workers from COVID-19 exposure, many healthcare departments temporarily postponed all non-emergency imaging examinations and interventions [77]. To minimize person-to-person virus transmission among radiology staff, many social distancing strategies were implemented, reporting stations were spaced apart, shift systems were developed, and radiology staff were staggered and were advised to work remotely by using online platforms[78]. Traditional in-person meetings were canceled, and the normal face-to-face training and interactions were minimized or eliminated. This led to a tremendous impact on undergraduate and postgraduate exposure to radiology training, as there was less interaction with colleagues and seniors in the radiology department, a vital component of training[79]. The number of hours of exposure to practical radiology was significantly decreased, and some radiology residents were even temporarily redeployed to other clinical disciplines. Similarly, many medical schools even suspended all clinical rotations of medical students, even to the radiology department. Didactic sessions for medical students became virtual and clinical teaching had been suspended or limited. Traditional case-based learning had been hampered and medical students can no longer shadow radiologists and radiology residents as they once did[19].

The COVID-19 pandemic even led to many extraordinary challenges in continuing to offer Radiology Residency and Fellowship programs, some being temporarily suspended[77]. One United States study regarding the educational impact of COVID-19 revealed that 70.1% and 2.8% reported moderate/marked negative impact and cessation of educational activities, respectively[70]. In Canada, COVID-19 has intensely altered the radiology resident training program. Virtual learning replaced face-to-face teaching-learning sessions. Consequently, it resulted in canceling rotations and clerkships, which resulted in case volumes affecting practical learning and staff-resident interaction[80]. Another Canadian study identified that the COVID-19 pandemic heavily affected four teaching-learning domains of radiology. Those were daylight hours' case volumes, daytime timetables, internal and external evaluations, and vacation/travel[66]. One more study reported that there has been a total halt in mammography after the inception of the COVID-19 pandemic and thereby affecting the radiology training program regarding breast cancer assessment. This study also demonstrated that mental stress and burnout have significantly increased among radiologists[81]. Overall breast cancer mammographic screening reduced nationally by 22.2% in Taiwan, more so in hospitals (37.2%) than in community settings (12.9%)[82]. Another United States study reported that the total mean weekly volume of imaging cases in 2020 post-COVID-19 was statistically significantly reduced compared with 2019[83]. The highest reduction was observed at week-16 of 2020 for all types of procedures, such as mammography (94%), nuclear medicine (85%), MRI (74%), ultrasound (64%), interventional (56%), CT (46%), and X-ray (22%). Additionally, "economic recessions generally tend to result in decreased health care expenditures, radiology groups have never experienced an economic shock that is simultaneously exacerbated by the need to restrict the availability of imaging" that occurred during this COVID-19 pandemic[84].

Following the World Health Organization directives for the COVID-19 pandemic, the workflow of the radiology department was restructured with minimal physical presence at work, preventing in-person case reviews and teaching sessions, in order to maintain physical distancing and safety precautions[79]. All non-urgent diagnostic and IR procedures were shifted to outpatient settings, elective surgeries were rescheduled, and only cancer-related appointments and therapies were categorized as urgent or semi-urgent and were followed. Traditional trainee-faculty member workstation teaching was sidestepped putting the year 1 and 2 residents at a disadvantage, although teleconferencing and remote readout screen sharing sessions were put in place as an alternate replacement, feelings of low motivation, abandonment and demoralization were more likely[85]. Important didactic teaching conferences offering lectures, case reviews, and discussions were either canceled or replaced by recorded conferences[86]. The majority of the radiology society meetings and interviews for fellowships and jobs were canceled which reduced networking and collaborative opportunities for trainees. Research activities were interrupted due to laboratory closures and mandates served by the institutional review boards[79]. Delay and rescheduling of the Diagnostic Radiology Core Exam by the American Board of Radiology has delayed graduation and certification, thereby impacting the commencement of radiology residencies and fellowships[87]. A significant decrease in the overall caseload in diagnostic imaging and IR procedures may impede the ability of residents to fulfill the graduation requirements. Consequently, this poses challenges for postgraduates in the Early Specialization in IR programme and increases the predicament of senior residents in meeting training requirements of the Mammography Quality Standards Act or Nuclear Regulatory Commission[88]. Many radiation oncology centers observed a decline in patients undergoing treatment due to patients' fear of getting infected with COVID-19 while traveling for radiotherapy. There is anticipated concern regarding these patients presenting with more advanced stages of disease in the future[89].

Innovative approaches to education and training

The reality of the COVID-19 pandemic requires the traditional undergraduate radiology curriculum to almost complete transition to online materials and interactive virtual teaching sessions, providing an effective blended learning environment, with a combination of didactic lectures, virtual case-based learning, and exposure to virtual clinical discussions[19].

Practical and innovative solutions are needed to compensate for the reduced variety and volume of patients presenting for routine radiological imaging during the pandemic. The development of a local repository of navigable interesting cases for radiology residents to access may compensate for the suboptimal clinical workload. Appropriate cases can be anonymized and collated for cloud-based teaching activities,

including viva practice or long case reporting[90]. To facilitate this, specially purposed integrative software (e.g. “Pacsbin”-Orion Medical Technologies) can allow for seamless transfer of hospital cases into the bank of interesting cases, which can then be reviewed by residents at their leisure or as part of sessional teaching activities[64]. Additionally, case collections may also be reviewed as part of group activity by maximizing video conferencing tools such as “Zoom” (Zoom Video Communications), since social distancing protocols prohibit such face-to-face interactions in the Radiology Department. This has been shown to suitably replicate teaching and learning activities at the Radiology reporting station[64].

Virtual learning environments using digital solutions and innovative approaches have proven to be helpful in radiology teaching during the COVID-19 pandemic. They impart knowledge and skills to medical students and trainees in reviewing radiological anatomy *via* online intelligent tutorial systems that provide a personalized, active, and interactive e-learning experience[32]. Learning anatomy from radiology studies has a myriad of pedagogical advances, as it displays “living anatomy”. Apart from depicting normal anatomy and pathology, radiology images when transferred and incorporated in virtual/augmented reality and 3-D printing potentiates anatomy teaching by making it a most authentic learning experience[19]. Customized applications/modules/tools provide many benefits of self-directed learning and are widely used e.g. student response systems, learning management systems (LMS) and customized LMS, RP modules (improved radiation protection knowledge), radiological ordering module (improved quality of radiological examination orders), CaseTrain software (significantly increased knowledge level); case-based e-learning tool VetsDataWeb (increased identification and accurate diagnosis of key radiological structures)[2]. Simulated mannequins with PACS simulator and Sectional-Anatomy™ software were used as effective online alternatives to face-to-face teaching[91]. Practicing physicians concordantly declared radiology teaching as a priority for medical students[92]. Virtual dissection tools used on near-life-size touchscreens, using “cut and dissect” commands on volumetric CT data help understanding and clinically correlate anatomical visuospatial relationships. 3D cinematic rendered images in absence of virtual dissection software have also been successfully used[93]. Videoconferencing platforms are also useful in the demonstration of radiological anatomy, Srinivasan *et al*[94] 2020. used “Zoom” which includes a screen annotation tool to teach anatomy to Singaporean medical students during COVID-19 and 89% of students were satisfied with this mode of content delivery[94]. De Ponti *et al*[95] surveyed online training sessions using Body Interact™, with 21 patient-based simulated clinical case scenarios for undergraduate medical students, while O’Connor *et al*[96] used a 3D virtual simulation tool in combination with radiology images of a virtual patient in the VR suite using HTC vive Pro™ headsets and hand controllers. These studies reported that simulated clinical scenarios can be incorporated in curricula as useful learning resources, as they avoided training interruption and met student expectations, with only a minority experiencing online access challenges to the virtual platform[95,96].

Radiological examination protocolling, clinical interaction (with radiographers, radiologists, clinicians, and trainees) and MDTs can be made more effective using existing technologies and online platforms for trainees in remote locations. Recorded/live cases, online lectures providing live and on-demand screening, virtual journal clubs, digital repositories for educational cases, simulation-based training as assessments with wider adoption on online tools can also be utilized[79]. Appropriate cases can be anonymized and collated for cloud-based teaching activities, “simulated” or phone-based daily readout (SDR) can be used for viva practice or long case reporting[90,97]. “Pacsbin” can be used by residents at all levels of training, and it is also useful for peer-to-peer resident learning or as part of sessional teaching activities [64]. Additionally, suitably replicable teaching and learning activities such as reviewing case collections at the radiology reporting station as part of group activity can be maximized by video conferencing tools[64] Institutional libraries *via* WebEx supports a series of organized specialist presentations providing information about useful technology tools, applications and resources and services available for faculty, staff and students to facilitate more efficient working from home. Additionally, support is provided through Library portals, Interlibrary Loan Internet-accessible database requests and publication services[77].

Special strategies and tools should be utilized to maximize meaningful participation in a flipped learning environment, develop critical thinking and complex reasoning skills, effective time management and communication strategies, as well as the incorporation of more interactive tools such as audience response systems and other advanced practical based software (Alvin, 2020)[79]. Practical and innovative solutions

are needed to compensate for the reduced variety and volume of patients presenting for routine radiological imaging during the pandemic.

Technological and academic challenges

The upheaval of the COVID-19 pandemic, following economic turmoil and its far-flung social unrest caused tumultuous shifts in the way radiologists work and teach, even affecting their work life harmony. It should be noted that remote sessions for Radiology teaching may lead to difficulties for some participants, especially when there are hardware and software issues, poor internet connectivity, and suboptimal interactions/content[90]. The set-up cost for these remote viewing systems can also be prohibitive. Additionally, there may be logistical and legal hurdles in the sharing of sensitive patient data *via* online teaching platforms. Private practices, hospitals and educational institutions facing significant monetary constraints may resort to possible salary cuts, redeployment, furloughs, shift to part-time employment and remote works. Academic institutions face new challenges of modified resident schedules, transformation to virtual platforms for evaluating imaging studies, and teaching and assessing trainees due to remote readouts[89]. Newly appointed junior trainees may be more significantly affected by technical challenges of remote image interpretation and readouts, busier rotations, limited in-person communication, unfamiliarity with team, exams and workflow, and the advent of the second wave in most countries may further worsen all factors to two fold.

With reduced numbers of diagnostic imaging and interventions, radiology residents may face the dilemma of meeting the training requirements, such as those mandated by the Mammography Quality Standards Act or the Nuclear Regulatory Commission [98]. Significant reductions in hands-on training sessions for fellows in IR could have a negative impact. Although live virtual conferences and recorded lectures have replaced face-to-face senior supervision, feedback and pedagogy, unfortunately, gauging the effectiveness of studying diagnostic and IR by virtual mode still remains vague, especially without any substantial supporting evidence on validity of remote and simulated learning[2,99].

Review of the COVID-19 impact on academic output in medicine has recognized a gender gap in women's first authorships which reduced to 23%, last authorships to 16% and there was a 16% drop in the general representation of women *per* author group in COVID-19 publications compared to publications in same journals last year [100]. This is a clear indication that women's productivity has been exceedingly affected than of men. This gender disparity is a possible result of increased demands at home and family responsibilities, which may limit academic and research output. In the future, the anticipated increase in workload due to rescheduling, backlog lists and procedures after COVID-19 may further widen the gender gap[100]. Studies reviewing the impact of COVID-19 show women work 20 more hours/week than men. With the major responsibility of childcare and domestic work, cancellations of child-care facilities and schools may affect women in radiology and radiation oncology more than men[101].

The reality of social distancing and working remotely have been recognized as potential stressors that have the potential to cause a negative psychological impact on the trainee, as they struggle to cope with an altered work and teaching environment and postponement of assessments/examinations while dealing with the realities of the pandemic[102]. Dedicated online psychological support for both the trainee and trainer is needed, in order to cope with these challenges to radiology education, so that solutions can be found to shared concerns[103]. Human relations and interactions must be maintained so that the feeling of remoteness does not become overwhelming.

Future directions

Technological advances in the field of radiology training must rise to the challenge and be able to foster the remote or "off-site" radiology interpretive skills of the radiology residents, while promoting self-motivated study[104]. Radiology Educators should also continue to increasingly integrate the use of recorded cases, enhance online lectures, digital repositories of educational cases, virtual journal clubs, and also acquire simulator-based training equipment. Teaching institutions should invest in appropriate technology and incorporate the utilization of the dynamic capabilities of an actual Radiology viewing platform, which facilitates a better learning experience for the Radiology Resident, mimicking a real-life scenario[75]. This is preferred to viewing static cases in film libraries, textbooks, and online databases, and will be a suitable substitute for the workstation learning experience. During the challenging time of the COVID-19 pandemic, it is paramount to utilize these strategies to maintain undergraduate and postgraduate radiology education in a safe but effective

environment.

Educational institutions should adopt e-learning, acquire new tools for teaching and digital transformation. Flipped classroom is a preferred model in medical education with small group interactions and instant feedback during in-class sessions. Integration of problem-solving scenarios and team-based learning in undergraduate curricula with appropriate use of imaging studies: simulating diagnostic reasoning, in a community-based design can improve imaging decisions and provide high-value care. Simulator-training models using Virtual Reality can be applied to ultrasonography and IR for trainees and working teams to enhance knowledge, experience, and learning skills by deliberate practice without compromising patient safety. Proper documentation of dynamic modifications in the radiology department's daily practices and learning experiences is crucial for handling current circumstances and in preparation for the second wave.

CONCLUSION

The COVID-19 pandemic has had a tremendous impact on undergraduate and postgraduate radiology education. Implementation of social distancing strategies resulted in infrastructural and human resource changes to the radiology department, resulting in a decreased physical presence/interaction and consequent limitation in face-to-face consultations and teaching exposure. Even before the COVID-19 pandemic, radiology educators often encountered many difficulties in delivering the radiology curriculum to undergraduate and postgraduate trainees, including limited teaching times, radiology education budgetary constraints and limited support in assessing/developing professional quality teaching.

During the pandemic, there was an almost complete transition of radiology education to a blended online platform, with the incorporation of didactic lectures, online interactive sessions and online participation in MDTs and other radiology department-related activities. There were many hiccups in the implementation of online teaching activities, such as challenges with respect to the procurement of hardware/software and a reliable Internet connection. Finding suitable innovative and interactive radiology teaching content proved to be another major challenge. Encouraging meaningful participation and interaction, while simulating the clinical environment was also particularly difficult, but not insurmountable. Technological advances in radiology education and training must continue to rise to address the challenges and meet the educational requirements needed to aid in the development of the undergraduate and postgraduate radiology trainees. This is particularly important in the face of the trials COVID-19 has provided.

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