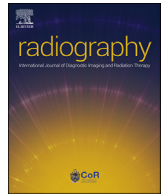




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Review article

How to safely and sustainably reorganise a large general radiography service facing the COVID-19 pandemic



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ABSTRACT

Objectives: This paper aims to share our experience in reorganising our general radiography service during the coronavirus disease (COVID-19) pandemic from the viewpoint of a large tertiary referral medical centre.

Key findings: Re-organization of the radiography workforce, patient segregation, and modification of routine radiographic practices are key measures to help radiographic services deal with the COVID-19 pandemic. Specific emphasis on deploying more mobile radiographic units, segregating equipment, developing consistent image acquisition workflows, and strict adherence to infection control protocols are paramount to minimize the possibility of in-hospital transmission and ensure a safe environment for both patients and staff. Streamlining communication channels between leadership and ground staff allows quick dissemination of information to ultimately facilitate safe provision of services.

Conclusion: COVID-19 has drastically altered the way general radiography teams provide services. The institution of several key measures will allow hospitals to safely and sustainably provide radiographic services. To date, there have been zero incidences of radiographer healthcare worker transmission within our institution during the course of work.

Implication for practice: Radiographers are facing the challenge of providing high-quality services while simultaneously minimizing pathogen exposure to staff and patients. Our experience may lend support to other radiographic services responding to the COVID-19 outbreak and serve as a blueprint for future infectious disease outbreak contingency plans.

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Introduction

The emergence of the coronavirus disease (COVID-19) has caused a global outbreak. On 11th March 2020, the World Health Organisation (WHO) officially changed the classification of COVID-19 from a public health emergency of international concern to a pandemic and has called on all nations to contain the spread of the virus. Despite rigorous global containment and quarantine efforts, the incidence of the virus continues to rise rapidly. Reports on management and practice preparation in different settings are therefore critical to prepare the community for the outbreak. In Singapore, since the first locally confirmed case of COVID-19 on 23rd of January, there have been a total of 5050 locally confirmed cases, inclusive of 11 deaths and 708 recovered patients (data obtained 17th April 2020) (Table 1).¹

Individuals infected with COVID-19 typically present with fever, dry cough, and dyspnoea.² The Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is highly contagious, transmitted between people through close contact, droplets and fomite.^{3,4} Although there is insufficient evidence to suggest that COVID-19 is largely transmitted via airborne particles, infection appears possible through aerosol-generating procedures such as bronchoscopy or open suctioning of the airway.^{5,6}

In Singapore, there are a total of 10 public and 8 private hospitals serving a population of 5.7 million. The hospital discussed in this paper is an acute tertiary referral medical centre and the largest hospital in Singapore. It has 1785 beds and staff strength of 10,000. The hospital caters to approximately 1 million patients a year, and is a major teaching and training institution for doctors, nurses and allied health professionals. The radiology department performs approximately 500,000 imaging exams a year. The general radiography section of the hospital has approximately 100 practising radiographers and is divided into three sections, namely: the

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Table 1
COVID-19 case overview in Singapore (Data collated on 17th April 2020).

	Total cases
Currently Active (Admitted)	2135
Clinically stable with COVID-19. Discharged to Isolation	2218
Deaths	11
Recovered	708
Total Confirmed Cases	5050

Outpatient Imaging Centre (OIC), Inpatient Imaging Centre (IIC) and Emergency Imaging Centre (EIC). From 23rd January to 17th of April 2020, the hospital has received a total of 319 confirmed COVID-19 cases with 141 patients currently admitted. Our institution has received up to 30 cases in a single day. At the time of writing, the department has performed over 6500 screening cases for COVID-19. Approximately 7% of Singapore's confirmed COVID-19 cases have been admitted to our hospital¹

The radiology department plays a vital role in the diagnosis and management of COVID-19. In Singapore, a chest radiograph (rather than chest CT) is the primary imaging method to identify any visible lung infection.^{7,8} Therefore, general radiographers are amongst the frontline healthcare workers with an increased risk of exposure to COVID-19 due to the close patient contact during image acquisition. We have developed a coordinated system to manage confirmed or suspected COVID-19 patients which we have found to be crucial to protect patients and staff while ensuring that the daily operations within the department can be adequately maintained. At the time of writing (26th April 2020), we have had zero instances of radiographer infection during the course of work.

This paper aims to describe how we have safely and sustainably reorganized our radiographic service during the COVID-19 era with emphasis on segregation measures and changes in radiography workflow.

Reorganisation of radiography workforce/safe distancing

One of our initial steps was to segregate our radiographer workforce into multiple independently functioning subunits, so we would be able to continue general radiography services in the event of a quarantine situation to any one team.⁹ The different teams are segregated based on clinical location. The emergency and inpatient locations are considered high-risk working areas where COVID-19 patients are more likely to aggregate, whereas outpatient areas are deemed lower risk. We therefore divided our manpower teams along these lines; staff are prohibited from moving between segregated teams or from high-risk areas to low-risk areas, and vice versa. Teams are not allowed to meet or swap shifts with one another. In this manner, our functional subunits are physically isolated from one another and allow continuity of services in the event of nosocomial spread of infection.

We divided our EIC and IIC general radiography workforce into four teams of eight radiographers (Fig. 1) to allow a sustainable schedule in the event of a prolonged outbreak. The four-team setup allows a rotating 12-h day shift, 12-h night shift, and two day consecutive rest period before repeating the cycle. This differs from the routine eight hour shifts prior to our COVID-19 manpower reorganization. The staffing needs for eight radiographers was decided based on the average workload of 10 cases per hour in the respective clinical areas. Each team consists of a team leader, a mobile radiography team of two radiographers for COVID-19 cases and five radiographers to cover the routine workload. Our roster pattern is fixed and is synchronised with the rosters of the nurses and radiologists in the department for ease of contact tracing.

Further, we have instituted additional safe distancing measures to protect staff.^{10,11} We have reorganised staff rest areas to facilitate physical distancing and rostered a smaller group of staff for staggered breaks at any one time. For example, seating facilities in the rest areas have been rearranged to provide gaps of one to two metre between tables with a maximum of one staff per table. During meal breaks, staff members are encouraged to leave immediately after meals and refrain from engaging in conversations with others.

Modification of hospital workload and radiographer workforce Re-allocation

To allow increased workforce capacity in the event of a surge in COVID-19 cases, there was a hospital level mandate to reduce elective clinical services by 50%. Routine non-urgent radiology examinations were reduced by 45%. Overall, total general radiography cases within the hospital were reduced by approximately 30% (Figs. 2 and 3). However, COVID-19 related chest requests increased from an average of 30 requests per day in January and February 2020 to an average of 140 per day in March and April 2020.¹

To cope with the excess chest radiography demand, our radiology department was able to draw resources from areas that were less stressed. We planned for the lower risk OIC area to act as the reserve pool to the higher risk emergency and inpatient stations (Fig. 1). From January until April 2020, there were five radiographers from the outpatient general radiography team who were placed on prolonged sick leave (more than five days) and told to self-isolate at home due to close contact with patients who were later found to be COVID-19 positive. All five staff were eventually ruled out for COVID-19. Our system of reallocating radiographers from our outpatient reserve team has allowed us to sufficiently staff higher risk areas. We have created a flexible and efficient workforce activation system, yet this organizational structure is more workforce intensive and is only possible with the reduction of routine clinical workload and introduction of radiographers from other subspecialties into the general radiography pool.

Our manpower status board (Table 2) allows us to monitor the daily workforce status of the entire department. Based on the different staffing levels, the department is able to promptly redeploy workers from areas of excess manpower to those areas in need to ensure the smooth operation of daily services. Currently, we have redeployed 10 radiographers from outpatient specialised modalities such as ultrasound and breast imaging to reinforce the current pool of the general radiographers.

Patient segregation

Emergency Imaging Centre

Patients are screened for relevant respiratory symptoms and epidemiological history to segregate them into COVID-19 and non-COVID-19 areas in the emergency department. Our existing fever isolation area was only able to cater up to 10 COVID-19 patients. Because of the large influx of suspected COVID-19 patients during the course of the outbreak, there was an urgent need to set up additional triage capacity. The radiology department collaborated with the Department of Emergency Medicine to free up additional bed space at the adjacent recovery area of a day surgery centre. The additional space was used to house suspected patients who were waiting for reverse transcription polymerase chain reaction (RT-PCR) swab tests, chest radiograph or admission to the isolation ward (Fig. 4). The newly converted fever isolation area is able to house up to 38 patients. In order to provide immediate imaging services, we deployed two mobile radiography units to each fever isolation area.

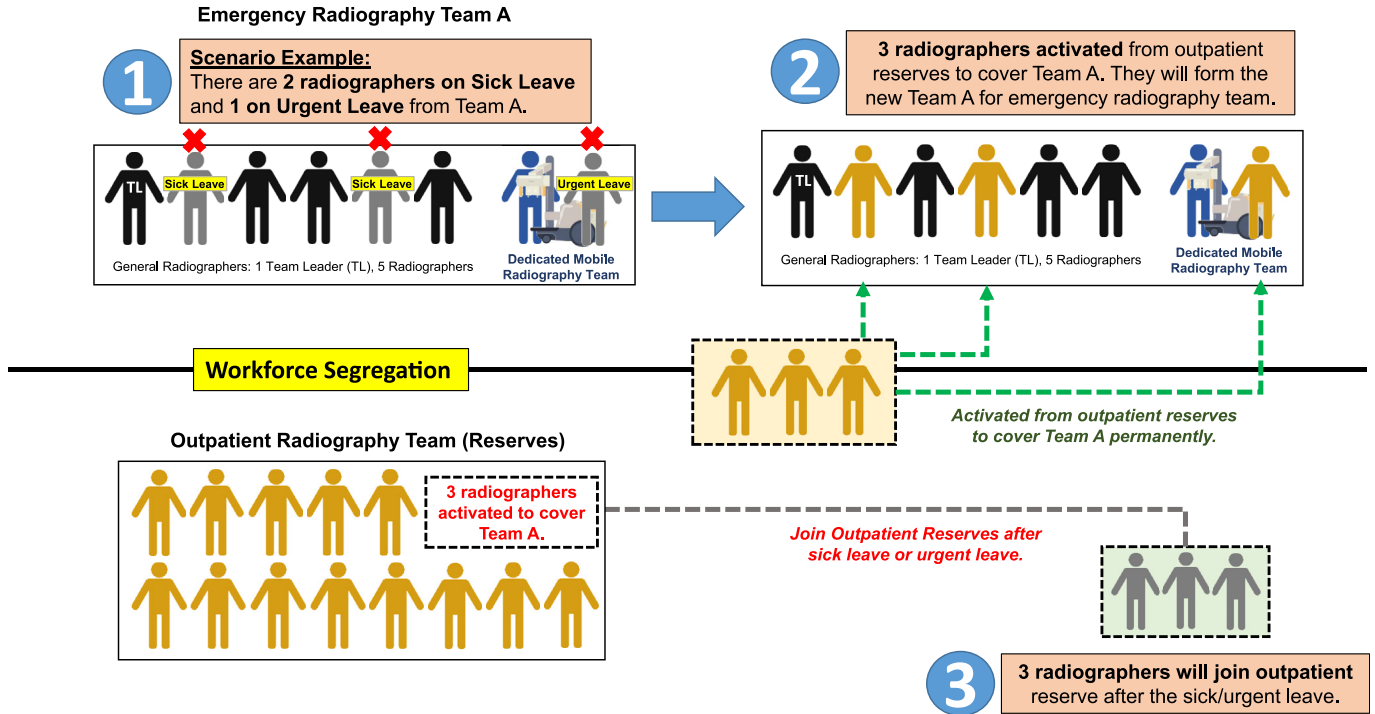


Figure 1. Exigency manpower allocation plan during unexpected staff absence (scenario depicting staff on sick/urgent leave or placed on quarantine, stay home notice or leave of absence).

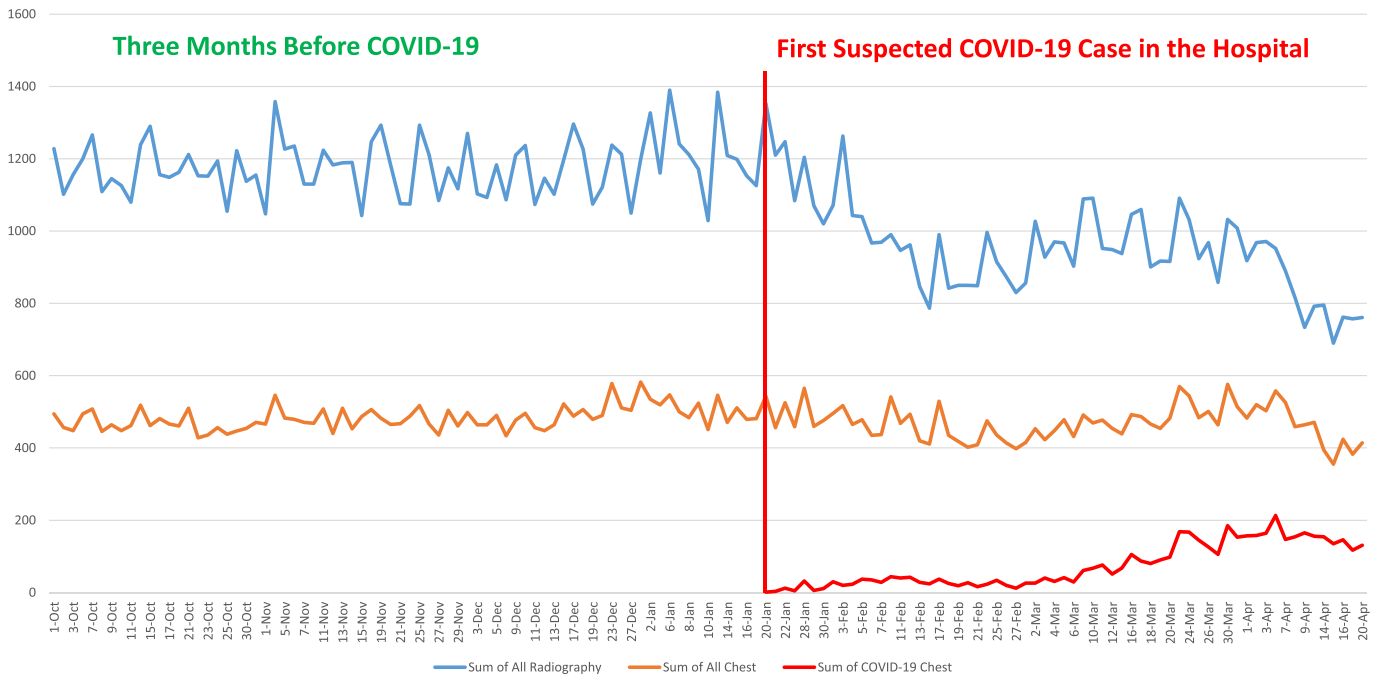


Figure 2. Graph showing the decrease in general radiography and chest radiography demands against the rising demand for COVID-19 related chest radiography.

By the end of March 2020, we observed an increase in the local community spread of COVID-19. The existing 38 beds in the fever isolation area were insufficient to meet the demands from the increased community outbreak. The Department of Emergency Medicine converted a nearby multi-storey car park into a temporary fever isolation area with a bed capacity of 64. Additionally, we equipped the multi-storey car park with a lead-lined room which served as the isolation chest radiography room. We observed an

increased patient throughput of 50% by setting up a stationary radiography area as compared to pushing a mobile unit to each patient’s cubicle for chest radiography.

Inpatient Imaging Centre

Our inpatient wards have been reorganised into three different risk levels that are segregated from one another: high-risk areas for

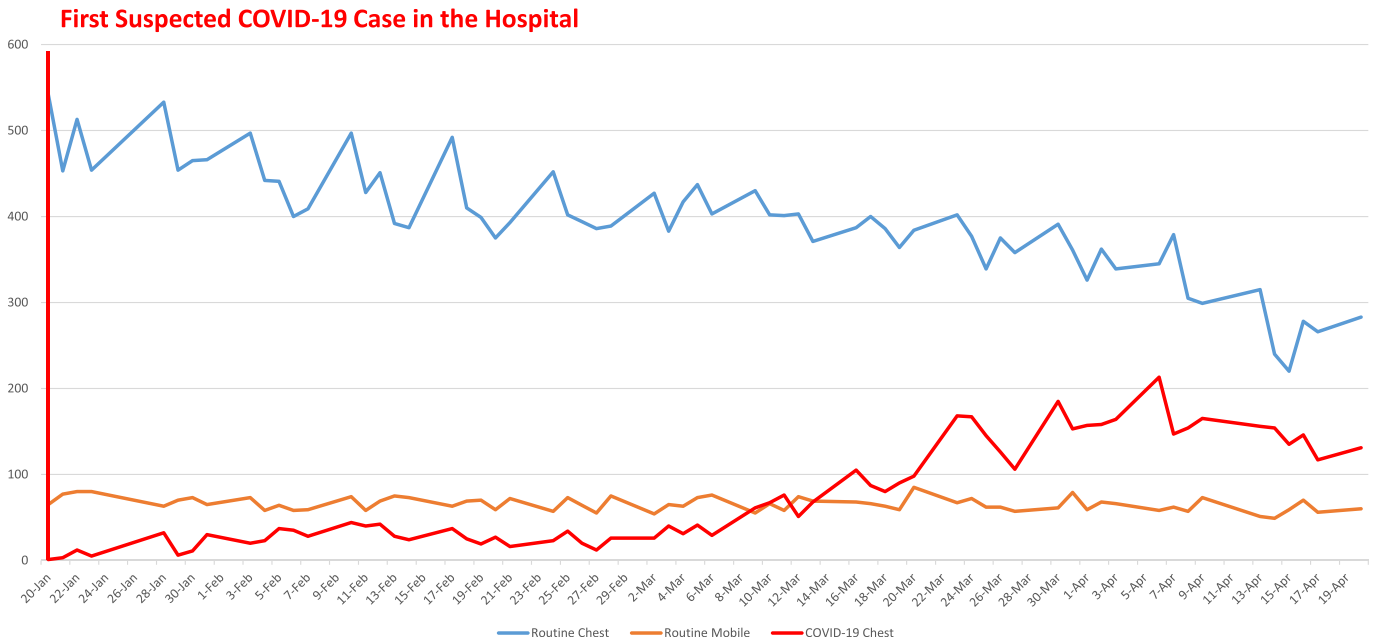


Figure 3. Graph showing a decrease in overall volume of routine chest requests and inpatient mobile chest requests against the rising demand for COVID-19 related requests.

Table 2
Manpower status board denoting daily manpower data.

Domain	Staff Strength	Manpower Status			Leave / Off Days			
		Green	Amber	Red	Non-recallable		Recallable	
					SL / HL / LOA / ML	AL (Overseas) / TL / NPL	Day Off	AL(Local) / FCL / CCL
CT	18 / 40	≥ 18	12 -17	<12	3	1	18	0
MRI	16 / 36	≥ 17	11 -16	<11	4	0	16	0
General Radiography	75 / 118	≥ 65	55-64	<55	9	1	33	0
Breast Imaging	14 / 14	≥ 10	9	<9	0	0	0	0
Ultrasound	28 / 31	≥ 25	18-24	<18	2	1	0	0
Vascular and Interventional Radiology	18 / 21	≥ 18	14 - 17	<14	2	1	0	0
Admin	6/7	≥ 5	4	<4	1	0	0	0
Imaging Informatics	5/5	4	3	2	0	0	0	0
Total	247 / 272							
Status	Definition			Action				
Green	Operates with room norm with/without an excess of manpower			NIL				
Amber	Operate room with bare minimum manpower. May incur overrun of sessions and backlog of cases.			May require: 1) Staff to work extended hours 2) Reduction in workload 3) Activation of deployable off days' personnel				
Red	Manpower is unable to support normal operations, resulting in the closure of rooms			Need to: 1) Close selected rooms 2) Activate deployable off days' personnel				

SL: Sick Leave; HL: Hospitalization Leave; LOA: Leave of Absence; ML: Maternity Leave; AL: Annual Leave; TL: Training Leave; NPL: Non-paid Leave; FCL: Family Care Leave; CCL: Child Care Leave

suspected and confirmed COVID-19 patients, intermediate-risk areas for patients with acute respiratory symptoms but with less epidemiological risk factors, and low-risk areas (general wards) for those

with no suspicious symptoms. There is one designated mobile unit stationed in the high-risk isolation wards to provide dedicated mobile imaging services for COVID-19 cases (Fig. 5). At the time of

Department of Emergency Medicine Fever Isolation Area (Converted from a day surgery recovery ward)

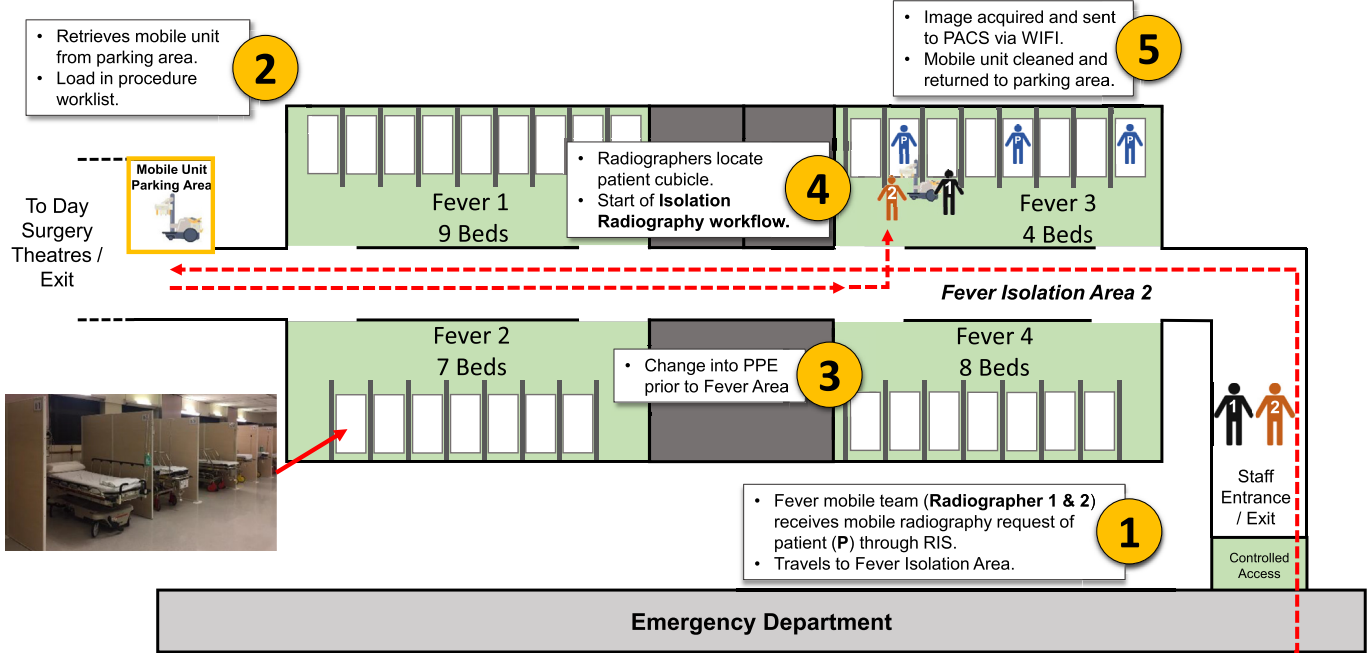


Figure 4. The layout of the additional fever isolation area at Emergency Imaging Centre (EIC). The numbers 1–5 illustrate the steps taken by a radiographer to perform a mobile chest radiograph in the fever isolation area.

Inpatient Isolation Ward

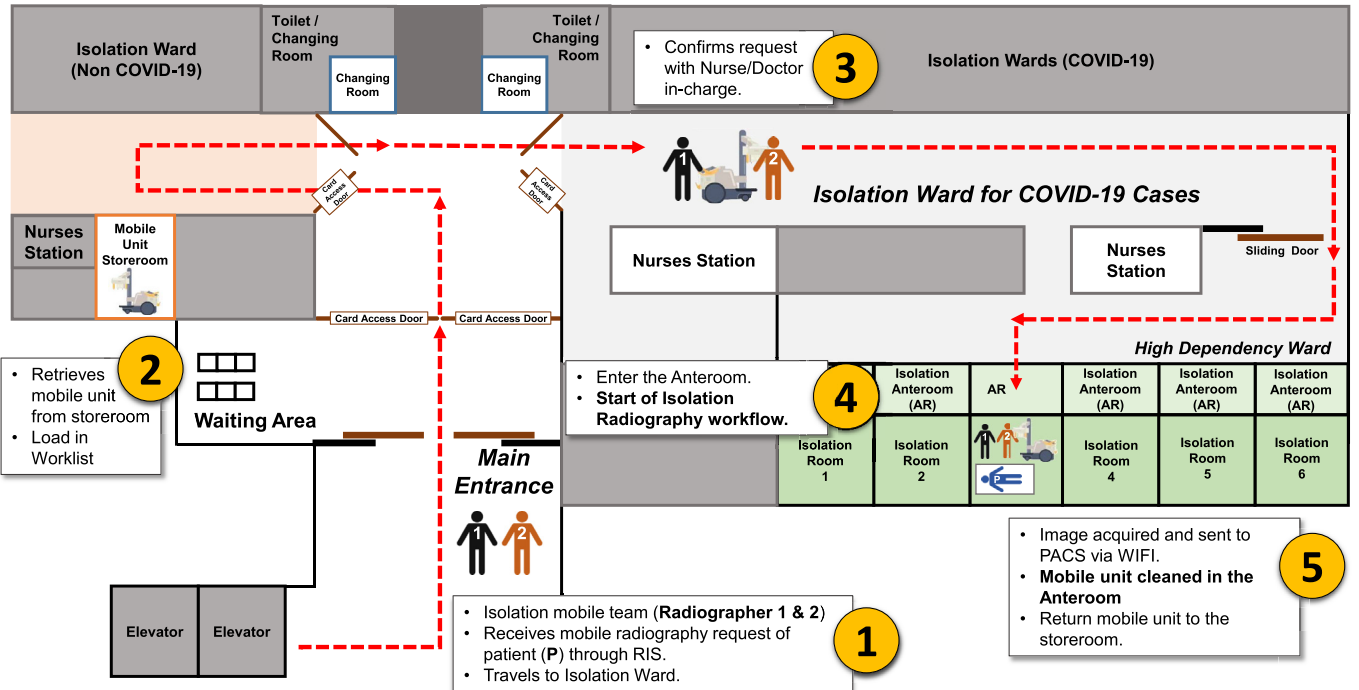


Figure 5. The layout of an isolation ward at the inpatient setting. The numbers 1–5 illustrate the steps taken by a radiographer to perform a mobile chest radiograph in a negative pressure isolation room that is equipped with an anteroom.

writing, the hospital is planning for expanding our existing COVID-19 isolation wards and intensive care unit (ICU) capability as the

demand for these facilities increases. This would be achieved by decanting existing wards and converting them into ICUs.

Outpatient Imaging Centre

In response to the SARS outbreak in 2003, a negative pressure isolation room was set up in our outpatient radiography area. This has proven beneficial during the current outbreak to temporarily isolate and screen suspected patients immediately after they enter the department premises. Patients who present to the outpatient setting with a positive travel history or relevant symptoms suspicious for COVID-19 are promptly isolated into our negative pressure isolation room (Fig. 6). The patient is escorted to the isolation room by a radiographer gowned in full PPE. The radiologist on duty will be informed to screen the patient in the isolation room.⁹ If necessary, the radiologist will consult the Infectious Disease (ID) physician. A chest radiograph can be requested on-site and performed immediately in the adjacent radiography room (Fig. 6) and sent for urgent reporting. If there is a need for further investigation, arrangements will be made for urgent admission, and the patient will be escorted by security to the assigned isolation ward.

Modification of routine radiographic practice

Mobile radiography services

Pre-COVID-19, mobile radiography was only performed in the ward for non-ambulatory patients who were clinically unfit to be transported down to the radiology department. To reduce patient transfer and to decrease the risk of cross-infection to staff and other patients, we have converted all COVID-19 related radiography examinations to portable exams.¹² COVID-19 patients are only imaged within their isolated area. We segregated our existing mobile machines into “clean” and “dirty” units based on their respective clinical locations. These segregated units cannot be used

interchangeably. The designated “dirty” mobile units are stationed at high-risk areas such as EIC and IIC isolation areas.

At the onset of the outbreak, we were short of DR mobile units to meet the increasing clinical demands. We therefore acquired four more mobile units to cover COVID-19 screening areas. To mitigate the shortage of equipment, we engaged existing vendors for loan of additional mobile radiography units. We created four additional mobile radiography teams designated for COVID-19 screening within the hospital. Apart from providing mobile imaging for COVID-19 patients, the existing mobile radiography units also continue to cater to the routine non-COVID-19 patients to ensure smooth provision of clinical services (Table 3). In addition, we deployed all DR mobile units for COVID-19 purposes and kept the remaining computed radiography mobile units as reserves. The classic radiographic appearance of COVID-19 pneumonia demonstrates ground glass opacities, typically at the periphery of the lower lobes.^{13–16} As these radiographic findings may be subtle, it is crucial for chest radiographs to be imaged with the highest possible image quality. By using mobile DR units, there are fewer errors due to inadequate exposures as the DR detector has a higher dynamic range, and the image can be reprocessed if there are slight under or overexposure errors. Utilizing DR is also quicker and decreases the potential for staff exposure to COVID-19. All our DR mobile units are equipped with wireless capabilities to facilitate quick image upload for early reporting and access by radiologists and clinicians.

Two person isolation mobile radiography workflow

It is essential for staff to adhere to strict infection control guidelines while performing mobile radiography for suspected and confirmed COVID-19 cases in the isolation ward. The risk of contracting the virus is a real concern given the close contact with the

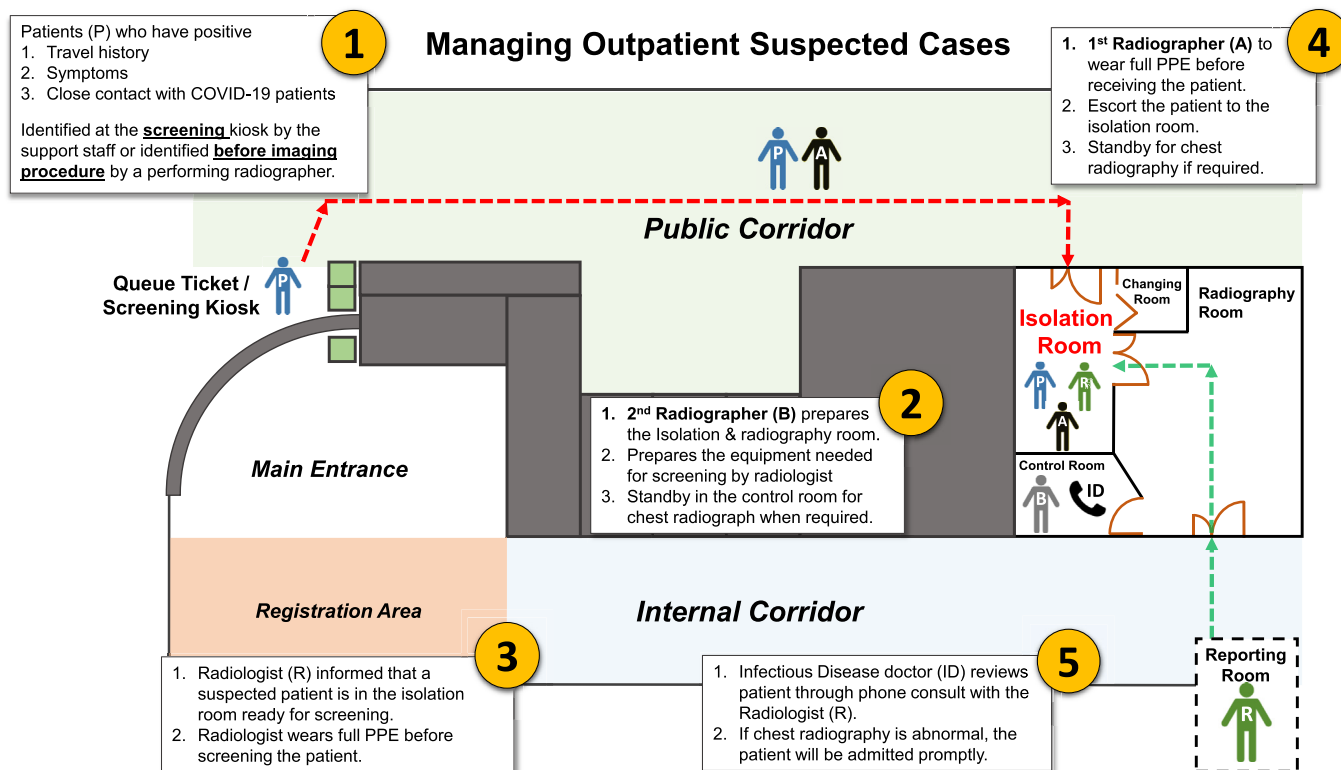


Figure 6. Management of patients who required isolation in the outpatient setting. The numbers 1–5 illustrate the steps taken by a radiographer to coordinate the screening of the suspect patient.

Table 3
Distribution of mobile radiography resources.

	Location	Mobile Unit (In-service)	Mobile Unit (Reserve)
1.	Outpatient Imaging Centre	1	1
2.	Inpatient Imaging Centre	4	1
3.	Emergency Imaging Centre	2	2

patient during the procedure. Therefore, we developed a two-radiographer team during mobile radiography to minimise the risk of cross-contamination between patient, staff, and equipment. One radiographer is designated the 'contact' radiographer, who is designated to perform patient positioning while the other 'non-contact' radiographer operates the mobile unit without patient contact (Table 3). We have found our two person team greatly reduces patient contact time which is one of the main risks of contamination for bedside imaging of contagious patients.

The mobile radiography team works together in a pre-planned workflow (Table 4) created in conjunction with the radiographers and the infection control department. As a preventive measure to ensure full compliance, an infection control nurse is tasked to evaluate the radiographer's PPE attire before entry into the isolation area. After image acquisition, both radiographers remove their PPE and perform a thorough cleaning of the mobile unit in the anteroom (Table 5).

Effects upon radiologist workflow

All COVID-19 related radiographs are categorised for immediate radiologist reporting, requiring a self-imposed turnaround time of one hour or less. For suspected or confirmed COVID-19 radiographs, the radiographer manually marks each case with a special flag on our Radiology Information System (RIS) system. The visual marker allows the radiologist to see a conglomerated filtered COVID-19 worklist to facilitate a quicker reporting turnaround time for such cases. There is an assigned consultant radiologist to report all COVID-19 cases around the clock. Because of teleradiology, radiologists are able to report from various locations from within or even outside of the main hospital campus. Globally, home teleradiology is being used by multiple institutions to promote safe distancing.^{17,18} However, in our institution, we have been unable to do this on a large scale due to the infrastructure and internet security limitations.^{10,19}

Radiographers are encouraged to be familiar with the radiographic appearances of COVID-19 and screen all chest radiographs for any evidence of pneumonic changes during post-processing. If

there is an abnormality, our radiographers contact the radiologist for immediate reporting.

Equipment and surface cleaning protocols

A recent study reported widespread deposition of SARS-CoV-2 in a confirmed patient's isolation room.²⁰ Fortunately, the virus can be eliminated by cleaning with a disinfectant such as sodium dichloroisocyanurate.²⁰ Therefore, medical imaging equipment and accessories such as mobile radiography units, digital radiography (DR) detectors or positioning aids should be thoroughly cleaned after every case to avoid the possibility of fomite-mediated transmission. For the mobile unit, DR detectors and lead apron, we use WIP'Anios Excel disinfectant wipes. It is non-alcohol based, and it does not degrade the surface coating of the imaging equipment.

We implement additional cleaning protocols for radiography room surfaces twice a day: once before the start of the shift and the second after meal breaks. The surface cleaning is performed using Medipal® Disinfectant Wipes. Apart from the routine cleaning regime, the hospital's environmental services perform terminal cleaning for all radiography rooms twice a day using Sodium hypochlorite 1000 ppm.

Central command and changes in communication pathway during COVID-19

At the onset of the pandemic, the previous radiology management organization was too large and bulky to respond effectively to the rapid changes. A smaller radiology task force was immediately created, consisting of leaders from various sections of the division who had prior experience in managing large scale operations. The task force formally sits down together on alternate weekdays and also conducts short daily 'huddle' sessions in the morning to discuss on key updates or events that happened the day before.¹⁷

At an even higher level, the hospital-level central command outbreak task force created and routinely updates a consolidated routine instruction (RI) which is disseminated to the entire hospital staff daily. This RI ensures staff receive the latest updates and

Table 4

Detailed workflow describing the task of a two-man team in the ward performing mobile chest radiography. Anteroom workflow is only applicable to the isolation wards.

Non-Contact Radiographer (RG1)	Contact Radiographer (RG2)
1 Wear Full PPE.	1 Wear Full PPE.
2 Wait in the anteroom with the mobile unit and DR detector wrapped in plastic.	2 Proceed to the isolation room.
3 Perform read back on patient information. Push mobile unit into the isolation room.	3 Perform identifier check with the patient.
4 Hand Over wrapped detector to RG2.	4 Receive wrapped detector from RG1
5 If necessary, assist RG2 in the positioning of the patient. After that, remove the gloves, alcohol hand rub and wear a new pair of gloves.	5 Position patient.
6 Centring of the X-ray Tube, collimation, exposure activation and image review.	6 Stand behind RG1 for radiation protection.
7 Return tube to the parking position.	7 Remove wrapped detector from the patient.
8 Exit the Isolation room into the anteroom with the mobile unit.	8 Exit the Isolation room into the anteroom with the wrapped detector.
9 Remove PPE accordingly. Change to a new pair of gloves and clean the detector slot of the mobile unit.	9 Unwrap the plastic cover of the detector.
10 Receive the detector from RG2 .	10 Hand over detector to RG1 . Remove PPE accordingly. Change a new pair of gloves.
11 Perform a total cleaning of the mobile unit with antimicrobial wipes.	
12 Exit the isolation room and discard the N95 mask.	

Table 5
Steps on cleaning the mobile radiography unit after isolation cases.

Non-Contact Radiographer (RG1)		Contact Radiographer (RG2)	
Both RG1 and RG2 will clean the mobile unit together. Use 1 new disinfectant wipe for each cleaning step. Discard gloves and perform hand hygiene after cleaning regime.			
Step 1	Remove PPE and <i>don a new pair of gloves</i> .	Step 1	Unwrap the plastic-covered detector and hand over to RG1 .
Step 2	Clean the detector slot.	Step 2	Remove PPE and <i>don a new pair of gloves</i> .
Step 3	Receive detector from RG2 and clean thoroughly. Place the detector into the slot.	Step 3	Clean the X-ray tube head.
Step 4	Clean the body of the (handle, touch screen, exposure switch, slots & casing).	Step 4	Clean the extendable arm.
Step 5	Clean the base of the unit (wheels, casing).	Step 5	Clean the retractable column and cables.
Step 6	End of RG1 cleaning regime. Proceed to image post processing.	Step 6	Clean the lead rubber apron.

contains information such as infection control and PPE guidelines, suspect case definition, patient management and administrative instructions. The RI serves as an official guideline to harmonise different practices across departments. Further, senior management sends out daily emails emphasizing key changes to workflow, updates on the number of cases in the hospital, and general words of encouragement to boost morale.¹⁰ Within the radiography teams, during daily roll call before the start of each shift, we review the hospital level RI to ensure communication of key updates.

To promote safe distancing, many non-essential events have been cancelled or postponed, and large group meetings have been scaled down as part of heightened infection control measures. We have leveraged on technologies with the use of various web conferencing platforms such as Zoom and WebEx to host teleconference meetings in place of the large group meetings. The department leverages on secure messaging applications such as TigerText messaging for dissemination of workplace information.¹⁰

PPE: requirements and supply management

The hospital follows the Personal Protective Equipment (PPE) requirement recommendations by the WHO.²¹ Even prior to the COVID-19 pandemic, all staff are required to undergo online hand hygiene and infection control courses to re-educate and train on the proper use of PPE. The hospital continues to conduct additional N95 mask and powered air-purifying respirator fitting sessions to ensure staff are fitted with the correct protective equipment.

Currently, there are no shortages in PPE supply in the hospital. The hospital draws PPE stock from the national stockpile. In view of the rising demand for PPE, the logistics section of the radiology department has created a monitoring chart for all PPE supplies. The stocks are actively monitored on a daily basis. The radiology department maintains a baseline of 10 days' worth of PPE supplies in house to ensure there are sufficient PPE stocks in the event of a large case surge.

Contact tracing

Contact tracing for COVID-19 cases is predominately overseen by the Ministry of Health. The operation involves the hospital's infectious disease department, police force, volunteers and other government agencies. On a larger context, contact tracing is done by phone call interviews to trace previous contacts and locations, reviewing CCTV footage and tracking mobile phone GPS. Contact tracing for hospital staff is done differently from the national protocol. Our infectious disease department will inform radiology regarding any patient of unknown COVID-19 status that eventually tested positive for COVID-19. The administrative team in charge will then perform activity mapping of the patient through

reviewing the audit trail records from the Radiology Informatics Systems. Staff with known COVID-19 exposure will then be interviewed via phone regarding the details of the PPE worn during the case and details of other staff members he/she had close contact with within a certain time period. Peripheral staff at risk for COVID-19 infection will also be contacted by the Infectious Disease department to monitor their body temperature twice daily and to seek urgent medical intervention if relevant symptoms develop. Depending on the risk level, some staff are required to quarantine for 14 days at home.

Conclusion

To safely and sustainably manage a large general radiography service during the era of COVID-19, teams need to consider how to re-organize their workforce structure, adhere to patient segregation measures, and modify their current radiographic workflows and infection control protocols to protect radiographers and patients from risk of cross-infection. Clear and open communication channels from a central command task force allow unfiltered instructions and words of encouragement to be directly disseminated to staff. During the last three months, we have treated approximately 150 COVID-19 patients, and we have zero incidences of healthcare worker infections (as of 27th April 2020). Feedback from radiographers suggests the newly implemented 12 h shift pattern is sustainable and maintains a constant work–rest cycle. We believe our experience may lend support to the radiology community currently facing the pandemic and serve as a blueprint for future infectious disease outbreak contingency plans.

Conflict of interest statement

The authors declare that there are no potential conflict of interest.

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