Technique, radiation safety and image quality for chest X-ray imaging through glass and in mobile settings during the COVID-19 pandemic

Zoe Brady^{1,2} · Heather Scoullar¹ · Ben Grinsted¹ · Kyle Ewert¹ · Helen Kavnoudias^{1,2,3} · Alexander Jarema¹ · James Crocker¹ · Rob Wills¹ · Gillian Houston¹ · Meng Law^{1,2,4} · Dinesh Varma^{1,3}

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Abstract

The COVID-19 pandemic in 2020 has led to preparations within our hospital for an expected surge of patients. This included developing a technique to perform mobile chest X-ray imaging through glass, allowing the X-ray unit to remain outside of the patient's room, effectively reducing the cleaning time associated with disinfecting equipment. The technique also reduced the infection risk of radiographers. We assessed the attenuation of different types of glass in the hospital and the technique parameters required to account for the glass filtration and additional source to image distance (SID). Radiation measurements were undertaken in a simulated set-up to determine the appropriate position for staff inside and outside the room to ensure occupational doses were kept as low as reasonably achievable. Image quality was scored and technical parameter information collated. The alternative to imaging through glass is the standard portable chest X-ray within the room. The radiation safety requirements for this standard technique were also assessed. Image quality was found to be acceptable or borderline in 90% of the images taken through glass and the average patient dose was 0.02 millisieverts (mSv) per image. The majority (67%) of images were acquired at 110 kV, with an average 5.5 mAs and with SID ranging from 180 to 300 cm. With staff positioned at greater than 1 m from the patient and at more than 1 m laterally from the tube head outside the room to minimise scatter exposure, air kerma values did not exceed 0.5 microgray (μGy) per image. This method has been implemented successfully.

Keywords Chest imaging · X-ray · Pandemic · Radiation safety · Portable · COVID-19

Introduction

The World Health Organisation (WHO) classified the spread of the SARS-CoV-2 (COVID-19) virus as a pandemic on 11 March 2020 [1]. In Australia (population over 25 million), there are approximately 7500 cases of COVID-19 and 100 related deaths [2]. As of June 2020, Australia has been relatively spared from uncontrolled spread of the disease compared with international infection rates and only 10%

of cases acquired within Australia are from unknown transmission of the virus [2]. The isolation and social distancing measures implemented by federal and state governments have so far managed to “flatten the curve” and there has not yet been a surge of patients on healthcare networks as was predicted based on overseas experience.

Despite low numbers of COVID-19 cases, public healthcare networks have considerably expanded capacity in order to cater for potential increased demand in both Emergency Departments (ED) and Intensive Care Units (ICU). As part of this expansion within our network, options were assessed for mobile chest X-ray imaging, which is the widely accepted initial radiographic assessment of COVID-19 confirmed or suspected cases with respiratory symptoms admitted to hospital. Computed Tomography (CT) scans are reserved for further assessment of indeterminate findings on initial chest X-ray and to assess for pulmonary complications in deteriorating patients with widespread pulmonary involvement (e.g. pneumothorax (barotrauma), superimposed bacterial

✉ Zoe Brady
z.brady@alfred.org.au

¹ Radiology Department, Alfred Health, Melbourne, VIC, Australia

² Department of Neuroscience, Monash University, Melbourne, VIC, Australia

³ Department of Surgery, Monash University, Melbourne, VIC, Australia

⁴ Department of Electrical and Computer Systems Engineering, Monash University, Melbourne, VIC, Australia

pneumonia, abscess, pulmonary embolism), although they are not commonly required.

We became aware of the technique to perform mobile chest X-rays through glass based on a post on Twitter [3] and others have publicised similar techniques in recent weeks [4–6]. We developed a method within our institution, which requires a radiographer and a nurse wearing personal protective equipment (PPE) to position a double bagged digital detector and the bed inside the patient cubicle and a second radiographer to operate the X-ray unit outside the cubicle (Fig. 1). This technique is only used for clinically deteriorating suspected/confirmed COVID-19 patients who are able to be sat erect, necessitating nurse assistance in the room. The radiographer outside of the room positions the X-ray unit with the X-ray tube head close to the glass and collimates the X-ray beam appropriately, ensuring the X-ray beam is fully intercepted by the detector. The X-ray beam passes through the glass door/window and exposes the digital detector. This technique is not used through lead glass, which would attenuate the X-ray beam to a level that is no longer diagnostically useful.

The *through glass* technique is now performed when deemed appropriate for patients in ICU and ED. In this study, we assess the technical parameters required for this technique, determine radiation safety requirements through a simulated set-up and assess image quality. The standard technique of mobile chest imaging is also being required more widely in ED so that suspected COVID-19 patients are not transported to the fixed X-ray rooms, limiting risks to staff and reducing disinfection cleans. In addition to the *through glass* technique, we reassessed the radiation safety requirements for standard mobile chest imaging with the

aim of allowing it to be more readily performed in the ED context during the pandemic.

Methods

Institutional ethical board approval was obtained for this study, as well as informed patient consent for medical images used in this publication. This study reviewed patient images and technique factors using the *through glass* technique performed in the Alfred ED and ICU departments and the Sandringham Hospital ED. Both hospitals are part of the Alfred Health network in Melbourne, Australia. The Alfred, with over 600 ward beds (capacity 450 during reallocation of areas during the COVID pandemic) and 56 ICU beds, is a Level 1 Trauma Centre and provides 14 state-wide services and has one of the busiest EDs in the country. The Alfred usually has five mobile X-ray units and this has been increased to nine during the pandemic, in addition to the usual fixed room X-ray units. Sandringham Hospital is about 15 km from the Alfred and is a community-based hospital of 36 beds (excluding maternity) and is serviced by two mobile X-ray units, as well as fixed room units.

The *through glass* technique was implemented at the end of March 2020 at both hospitals. This study assesses the following features of the technique:

1. Characterising the attenuation characteristics of different types of glass;
2. Determining appropriate technical parameters for X-ray imaging through glass, collating the parameters clinically used and determining patient radiation dose;

Fig. 1 The radiographer inside the cubicle positions the bed close to the glass door and places the digital detector behind the patient for an erect anterior–posterior chest X-ray before stepping away from the patient during the exposure (**a**), while the radiographer outside the

cubicle positions the X-ray tube head close to the glass door and steps laterally away to initiate the X-ray while maintaining visual contact of the patient (**b**). Note, subject in the figure is not a patient but an author in this publication

3. Measuring scatter radiation in a simulated set-up to ascertain safe staff positioning for both the *through glass* technique and standard mobile X-ray imaging, as well as personal monitoring in the clinical setting; and
4. Assessing image quality for chest X-ray imaging performed through glass.

A mobile Carestream DRX Revolution X-ray unit (Carestream Health, US) was used for all simulated experiments. Clinical images were obtained on a range of mobile X-ray units including a GE AMX4 (GE Healthcare, US) with a Carestream DRX digital detector retrofit, a Carestream DRX Revolution, a DRX Revolution Nano (Carestream Health, US) and a Shimadzu DaRt Evolution MX8 (Shimadzu Corporation, Japan). All radiation measurements were taken with a RaySafe X2 radiation meter (Unfors RaySafe AB, Sweden) connected to either a stacked diode X2 R/F sensor for measurements in the primary X-ray beam or an energy compensated silicon diode array X2 survey probe for measurements of scattered radiation. Both probes were calibrated within the previous 12 months to a voltage standard calibrated by the SP Technical Research Institute of Sweden and/or to an air kerma standard traceable to the National Institute of Standards and Technology (NIST). Personal monitoring radiation measurements were made in the clinical environment with direct ion storage Instadose dosimeters (Mirion Technologies, US).

Glass attenuation

One of the major differences between a standard mobile chest X-ray and the *through glass* technique is that the X-ray beam passes through a sheet of glass before being incident on the patient. The glass attenuates or filters some X-ray photons in the beam. To characterise the effects of different types of glass on the X-ray beam, we assessed six types of glass found in different hospital areas. These included ICU cubicle glass, ICU “magic” frosted glass (having an adjustable opacity with electric switching), a patient bay window, a fire door glass panel, a double layer of glass on a reception window and a standard glass window in a tea room door. It is not expected that chest X-ray imaging will be performed in all of these locations. The air kerma of the primary X-ray beam was measured before and after transmission through a glass pane in an ICU cubicle at 10 kilovoltage (kV) increments from 90 to 120 kV inclusive. For each other type of glass the half-value layer (HVL) was measured after transmission through the glass. This was to allow comparison of the attenuation characteristics for each type of glass.

Technical parameters and patient dose

Typical parameters at our institution for a mobile chest X-ray using the standard technique (not through glass) are 85 kV, 1 mAs (tube current time product) for a small sized patient and 90 kV, 1.4 mAs for a medium sized patient, both without a grid and using a source to image distance (SID) of 180 cm. For large patients a grid is used with parameters of 95 kV and 6 mAs. Based on the HVL measurements of the X-ray beam after transmission through different types of glass and the additional distance between the source and digital detector, appropriate technical parameters were determined for the new *through glass* technique. These were implemented and the image quality assessed (see later section).

The technical and distance parameters (kV, mAs, SID) used for a sample of patients were collected to determine the most common values used. The kV and mAs were retrieved from the Digital Imaging and Communications in Medicine (DICOM) header, while the SID was estimated by the radiographer performing the imaging at the time of the exposure. The exposure index (EI) was also retrieved from the DICOM header to compare with standard mobile imaging that is not performed through glass. Where available in the DICOM header, the kerma area product (KAP) was also retrieved. From these parameters (kV, mAs, SID) the patient radiation dose range was determined using a dose calculator called PCXMC Dose Calculations [7]. PCXMC is a PC-based program, which runs a Monte Carlo simulation based on an X-ray beam projection and other user specified examination conditions, including the X-ray spectrum (kV and filtration), to calculate organ and tissue absorbed doses and effective dose according to the ICRP103 definition [8]. The added filtration of the glass could not be directly simulated in PCXMC which only allows for two single-element filters. The spectrum was first produced using the UK Institute of Physics and Engineering in Medicine (IPEM) Spectrum Processor [9] accompanying IPEM Report 78 [10] by matching the HVL values at different X-ray beam energies and determining an equivalent thickness of aluminium for the glass.

Scatter radiation measurements

A Computerised Imaging Reference Systems (CIRS) anthropomorphic phantom of an adult male (Model 701-D, CIRS Inc., US) was used to experimentally simulate the clinical set-up. The phantom is made from epoxy resins with photon attenuation values equivalent to human bone and tissue within the diagnostic X-ray energy range (Fig. 2). The phantom was placed on a bed in an ICU cubicle that was lowered to perform an anterior–posterior (AP) erect chest X-ray with a SID of 205 cm (Fig. 3). Scatter measurements were made with the X2 survey probe at 30 cm from the glass door outside the cubicle to measure the backscatter coming

Fig. 2 Anterior–posterior (a) and lateral (b) chest X-ray views of the CIRS anthropomorphic phantom which is tissue equivalent within the diagnostic X-ray energy range

Fig. 3 a The anthropomorphic phantom positioned for an erect AP chest X-ray with the X-ray unit positioned on the other side of the glass door to the cubicle (not shown); the light beam can be seen illuminated on the phantom. b The X2 survey meter positioned at 30 cm from the glass door to measure backscatter. c The position of the inside radiographer at 2 m from the centre of the patient's chest towards the back of the room with the X2 survey meter positioned in front of her. d 20 cm PMMA blocks to simulate a patient's chest

directly back off the glass. Measurements were also taken at 1 m lateral to the X-ray tube head, as this is the recommended position for the outside radiographer to stand to

reduce backscatter exposure. Measurements of air kerma in microgray (μGy) were made for 90–120 kV in 10 kV increments and at a setting of 10 mAs, then normalised to mAs (by dividing by 10 mAs to give $\mu\text{Gy}/\text{mAs}$).

Measurements were taken inside the cubicle with the X2 survey meter at 1 and 2 m diagonally distant from the centre of the phantom's chest (to measure patient scatter). The inside radiographer and nurse are recommended to step back in this direction during X-ray acquisition. Scatter measurements were repeated with different blocks of polymethyl methacrylate (PMMA) to simulate different sized patients. Thicknesses included 10, 15 and 20 cm of PMMA. These measurements were also undertaken for 90–120 kV in 10 kV increments and at 10 mAs, then normalised to mAs (by dividing by 10 mAs to give $\mu\text{Gy}/\text{mAs}$).

Further scatter measurements were undertaken with the X2 survey meter and anthropomorphic phantom for the standard portable (mobile) X-ray technique in the room (i.e. not through glass). There was increased demand to assess different room types in ED and ICU for suitability for performing mobile chest X-ray imaging rather than moving patients to the fixed X-ray rooms. Instead of needing to assess every room each time a new room was proposed, scattered radiation levels were determined so that an exclusion zone around the part of the patient's anatomy being imaged (most likely the chest) could be stipulated. Scattered measurements were made in the forward, side and backscatter directions as well as at a 45-degree angle behind the patient. These were undertaken for both AP erect (SID 180 cm) and supine (SID 125 cm) chest X-ray views (Fig. 4). These measurements were undertaken at only 120 kV (maximum kV) and at 20 mAs and then normalised to mAs (by dividing by 20 mAs to give $\mu\text{Gy}/\text{mAs}$).

Occupational exposure was assessed while the *through glass* technique was being used clinically. Three Instadose dosimeters were provided with a mobile X-ray unit in ED and one in ICU. One dosimeter was taped to the tube vertical arm, one was allocated to the inside radiographer and one to the outside radiographer (i.e. rotated between radiographers depending on who was performing the role).

Image quality assessment

A sample of consecutive patient chest X-ray images performed with the *through glass* technique were reviewed on the Picture Archiving and Communication System (PACS) by a senior Emergency and Trauma Radiologist and a senior Radiology Registrar with 25 and 5 years' experience, respectively. These were assessed using clinical criteria recommended by the AAPM Task Group 18 (TG18) [11] for assessing the TG18 anatomical images and adapted to our purpose. Additional criteria for the overall sharpness

Fig. 4 **a** The anthropomorphic phantom positioned for an erect AP chest X-ray with the X-ray unit positioned in the room. **b** The anthropomorphic phantom positioned for a supine chest X-ray with the X-ray unit positioned in the room

Table 1 Radiologist criteria for image quality assessment of chest X-ray images [11]

Criteria	Response
1. Overall contrast	Acceptable/Borderline/Not acceptable
2. Overall sharpness	Acceptable/Borderline/Not acceptable
3. Symmetrical reproduction of the thorax, as shown by the central position of a spinous process between the medial ends of the clavicles	Yes/No
4. Medial borders of the scapulae	Yes/No
5. Reproduction of the whole rib cage above the diaphragm	Yes/No
6. Visually sharp reproduction of the vascular pattern of the lungs, particularly the peripheral vessels	Yes/No
7. Sharp reproduction of the trachea and proximal bronchi	Yes/No
8. Sharp reproduction of the borders of the heart and the aorta	Yes/No
9. Sharp reproduction of the diaphragm	Yes/No
10. Visibility of the retrocardiac lung and the mediastinum	Yes/No
11. Visibility of subdiaphragmatic features	Yes/No
12. Visibility of the spine through the heart shadow	Yes/No
13. Visibility of small details in the whole lung, including the retrocardiac areas	Yes/No
14. Visibility of linear and reticular details out to the lung periphery	Yes/No

and contrast with ratings of acceptable, borderline and not acceptable were included. The list of criteria is provided in Table 1.

The same sample of patient chest X-ray images performed with the *through glass* technique was also reviewed by two senior radiographers with 22 and 13 years' experience. Criteria relating to the acquisition and quality of technique were used to assess the images. These criteria were based on McQuillen Martensen [12] and local experience and are provided in Table 2.

Inter-reader correlation was first assessed within each professional group. A Cohen's kappa score (κ) was calculated between the two radiologists and separately between the two radiographers, according to:

$$\kappa = \frac{Pr(\alpha) - Pr(e)}{1 - Pr(e)} \quad (1)$$

where $Pr(\alpha)$ represents the actual observed agreement (e.g. both observers agree yes or both observers agree no), and $Pr(e)$ represents chance agreement. Inter-reader agreement was considered slight for a kappa value of ≤ 0.20 ; fair for 0.21–0.40; moderate for 0.41–0.60; substantial for 0.61–0.80; and almost perfect for 0.81–1.00 [13].

An Image Quality Coefficient (IQC) was calculated separately for the radiologist and radiographer assessments of the patient images to compare the image quality judgement between the two professional groups. This was defined as:

$$IQC = \frac{1}{2} \times \left[\frac{\sum \text{Positive responses by both readers}}{N} + \frac{N - \sum \text{Negative responses by both readers}}{N} \right] \quad (2)$$

Table 2 Radiographer criteria for image quality assessment of chest X-ray images (based on [12] and local experience)

Criteria	Response
Anatomy	
1. Both lungs, from apices to costophrenic angles, are included within the exposure field	Yes/No
2. At least nine posterior ribs are visualised above the diaphragm	Yes/No
3. The image receptor was positioned crosswise or lengthwise correctly to accommodate the required anatomy	Yes/No
Collimation	
4. Collimation is demonstrable and sufficient	Yes/ No (over collimated)/ No (under collimated)
Positioning	
5. The image is demonstrated towards the centre of the image receptor to facilitate required anatomy	Yes/No
6. Seventh thoracic vertebra is at the centre of the exposure field	Yes/No
7. Distances from vertebral column to sternoclavicular ends are equal	Yes/No
8. Lengths of the left and right corresponding posterior ribs are equal	Yes/No
9. Posterior ribs demonstrate a gently superiorly bowed contour	Yes/ No (horizontal)/ No (vertical)
10. Manubrium is approximately at the level of the fourth thoracic vertebra with around 2.5 cm of apical lung field visible above the clavicles	Yes/No
11. Mandible is not in the exposure field	Yes/No
Motion	
12. The lung markings, diaphragm, heart borders, hilum, great vessels and bony cortical outlines are sharply defined	Yes/No
Exposure	
13. The Exposure Index number obtained at the ideal level or within the acceptable parameters for the digital system	Yes/Under/Over
14. The projection demonstrates quantum noise over the region of interest	Minimal/Some/Excessive
15. The projection demonstrates saturation	Yes/No
16. Thoracic vertebrae, posterior ribs and lines/tubes are faintly seen through the heart and mediastinal structures	Yes/No
17. Vascular lung markings are visible throughout the lung fields, including through the heart shadow and below the diaphragm	Yes/No
Artifacts	
18. Anatomical or external artifacts are removed where possible	Yes/No

where N is the total number of criteria answered by both readers for the image being considered. Positive response from both readers was weighted more highly than a single positive response. The IQC ranged from 0 to 1, where 1 represented complete agreement and all criteria scored positively.

Results

A sample of 30 consecutive clinical chest X-ray images for 23 patients was obtained from the three locations (ED, ICU at the Alfred and ED at Sandringham Hospital) where the *through glass* technique was used during the first month of implementation of the technique. The majority of images ($n=20$) were from Alfred ICU and acquired with a Carestream DRX Revolution, followed by Alfred ED ($n=8$) performed using a GE AMX4 with a Carestream DRX digital

detector retrofit and Sandringham ED ($n=2$) acquired with a Shimadzu DaRt Evolution MX8.

Glass attenuation

Measurements from the experimental set-up demonstrated that as the kV of the X-ray beam increased the tube output increased, as expected, and are shown in Table 3. The transmission of the primary X-ray beam through a glass door in an ICU cubicle ranged from 41 to 49% over a kV range from 90 to 120 kV. At higher beam energies (e.g. 120 kV) there was greater transmission of the X-ray beam through glass as the beam quality and effective beam energy increased; the X-ray beam was more penetrating. As the transmission of the X-ray beam through glass was approximately 50% at the higher beam energies (about 6% less when taking into account an inverse square law correction), it can be

Table 3 Normalised air kerma and transmission measurements of the primary X-ray beam before and after transmission through an ICU cubicle glass door

Kilovoltage (kV)	Air Kerma (uGy/mAs)		Percentage transmission (%)
	Before glass	After glass	
90	193	80	41
100	251	111	44
110	302	140	46
120	358	175	49

No inverse square law correction applied

considered that this type and thickness of glass is roughly equivalent to a single HVL.

The HVL measurements for X-ray beam after transmission through the six types of glass tested are shown in Fig. 5. At 110 kV, the HVL of the primary X-ray beam (sample 0) was 4.2 mm of aluminium (mm Al). Most types of glass tested resulted in an X-ray beam HVL of 5.7–5.9 mm Al for a 110 kV X-ray beam after transmission through one layer of glass. X-ray beam transmission through a double layer of glass was tested (sample 6) and the HVL was 6.9 mm Al at 110 kV. The “magic” glass in ICU (sample 5) resulted in a post-transmission HVL of 6.4 mm Al at 110 kV and therefore had a greater hardening effect on the X-ray beam than other types of glass tested, but had attenuation properties less than a double pane of ordinary glass.

Technical parameters and patient dose

Based on the initial work performed assessing the HVL of the X-ray beam after transmission through glass, the advice

Fig. 5 Half-value layer (HVL) measurements in terms of millimetres of aluminium (mm Al) at different kilovoltages (kV) for the primary X-ray beam and after transmission through six types of glass. 0: no glass; 1: ICU cubicle glass; 2: tea room glass window in door; 3: fire door glass window; 4: Radiology patient bay glass window; 5: ICU “magic” frost/unfrosted glass; 6: double layer of glass on reception window

given to radiographers for performing the *through glass* technique was to use 110–120 kV and an mAs value based on the patient’s size and scaled for the additional distance to the digital detector. Generally, for a SID of approximately 2 m, four times the equivalent standard AP erect chest X-ray mAs was used and this increased to five times for a SID approaching 3 m.

The majority of chest-X-ray images in the sample were acquired with 110 kV (20 out of 30, 67%) followed by 105 kV (5 out of 30, 17%) with a range between 90 and 120 kV, inclusive. Figure 6 shows the kV and mAs values used for variable SID distances for 29 of the 30 images sampled. One image did not have an estimated SID available. The mAs ranged from 1.4 to 12.5 mAs, with an average of 5.5 mAs. The most frequent combination was 105–110 kV and 4.5–5.0 mAs. The EI values were compared for the Alfired images only (28 out of 30) as these all use the same definition of EI (Carestream). The recommended EI range for chest imaging at our site on Carestream X-ray units is 1000–1200. The EI values for the chest X-ray images acquired using the *through glass* technique were within the range of the EI values acquired with the standard portable technique in ICU during the same four week period (Fig. 7). The EI values for the images acquired in ED with the *through glass* technique were within the top 25th percentile of EI values using the standard technique (Fig. 7). Overall the *through glass* technique gave an EI range from 966 to 1645, with an average value of 1335.

The X-ray spectrum for the Carestream DRX Revolution mobile X-ray unit was simulated using the IPEM Spectrum Processor [9]. Two filters were used to simulate the spectrum. The first was an aluminium equivalent thickness for a total tube filtration (inherent plus additional) of 2.7 mm (based on the labels on the X-ray unit) and the second filter was glass, processed over the kV range used (90–120 kV).

Fig. 6 Technical parameters (source to image distance (SID), mAs and kV) for a sample of clinical chest X-ray images using the through glass technique

Fig. 7 Box and whisker plots of the range of EI values (minimum, 25th, 50th, 75th percentiles and maximum shown) for both routine portable chest X-ray images and those acquired using the *through glass* technique performed on the same mobile X-ray units in ICU and ED, respectively, at the Alfred

By testing different thicknesses of glass in 1 mm increments, it was determined that 5 mm thickness of glass most closely matched the HVL measurements made earlier. There was a maximum 3% deviation between the measured HVL values and those calculated using the Spectrum Processor. It was then calculated that a single filter of 5.4 mm of aluminium was equivalent to two filters comprising 2.7 mm aluminium and 5 mm glass. There was less than 0.1% difference in HVL values between the one-filter and two-filter spectrums processed in the kV range used.

The effective dose was calculated using PCXMC [7] for each exposure in the sample of images. The spectrum was defined by the kV used for the clinical image, the total filtration of the relevant X-ray tube used and 2.7 mm Al filtration to simulate the 5 mm of glass. In the sampled images there were three mobile X-ray units used: Carestream DRX Revolution, GE AMX 4 and Shimadzu DaRt Evolution MX8 with total tube filtration of 2.7 mm Al, 4.0 mm Al and 3.0 mm Al, respectively. The actual patient exposure was simulated for each SID and assuming a patient to detector gap of only 1 cm (i.e. the patient was leaning back on the digital detector in an erect position). The image size was assumed to be landscape 35 cm × 43 cm at the digital detector, which is fairly standard for chest imaging. The average effective dose for chest X-ray images using the *through glass* technique was 0.02 millisieverts (mSv) with a range of 0.002–0.07 mSv (Fig. 8).

KAP values were only available for the images in the sample that were performed in ICU on the Carestream DRX Revolution (20 out of 30 images). The KAP values ranged from 0.04 to 0.30 Gy·cm² with an average value of 0.12 Gy·cm². The mean value for all portable chest X-rays

Fig. 8 Histogram of calculated effective dose values for patients included in the sample of images acquired using the *through glass* technique (average and median effective dose was 0.02 mSv). One image did not have an estimated source to image distance (SID) available and therefore, an effective dose was not estimated for this patient

in the same time period where a KAP value was recorded ($n > 1500$) was 0.10 Gy·cm².

Scatter radiation measurements

The measured scatter air kerma at the position of the radiographer operating the X-ray unit outside the room and standing at least 1 m from the tube position was up to 0.06 µGy/mAs depending on the kV used (Table 4). A typical exposure of 110 kV and 5 mAs resulted in a backscattered radiation dose from the glass of 0.3 µGy. For the position of the radiographer (and nurse) inside the room with the patient, the measured scatter air kerma from an anthropomorphic phantom was up to 0.08 µGy/mAs at 1 m depending on the kV used and this reduced to 0.02 µGy/mAs at 2 m (Table 4). For a typical clinical exposure of 110 kV and 5 mAs the scattered radiation dose will be 0.4 µGy at 1 m and 0.1 µGy at 2 m.

Table 4 Normalised scatter air kerma measurements for the *through glass* technique at the position of the radiographer outside the room (initiating the X-ray) and the position of the radiographer inside the room (positioning the patient and detector)

Kilovoltage (kV)	Scatter air kerma (µGy/mAs)			
	Radiographer outside room		Radiographer inside room	
	30 cm from glass	1 m from glass	1 m from phantom	2 m from phantom
90	0.29	0.03	0.04	0.01
100	0.37	0.04	0.05	0.01
110	0.46	0.05	0.07	0.02
120	0.55	0.06	0.08	0.02

The air kerma measurements were repeated for different thicknesses of Perspex to simulate different patient thicknesses. The scatter air kerma increased with kV and was similar between the different Perspex thicknesses (Fig. 9). The anthropomorphic phantom produced more scatter than the Perspex at 1 m (approximately 10%) and slightly less at 2 m (Fig. 9) where scatter measurements were very low.

The scatter air kerma was also measured for the standard technique (not through glass) for erect and supine chest views of the anthropomorphic phantom. Measured scatter air kerma using a maximum 120 kV was highest at 1 m from the phantom in the forward scatter direction (towards the feet) and lowest in the back scatter direction at the head of the patient for the erect view (Table 5). The air kerma dropped to 0.04 $\mu\text{Gy}/\text{mAs}$ at 2 m for an erect view when considering a typical location for the staff member(s). For the supine view the scattered air kerma was highest at a 45° angle from the patient and decreased to 0.08 $\mu\text{Gy}/\text{mAs}$ at 2 m for a typical location of the staff member(s). A typical clinical exposure for a mobile erect chest X-ray on an average sized patient is 90 kV and 1.4 mAs. Using the measurements at 120 kV, which will overestimate the dose at 90 kV, the scattered radiation dose will be 0.2 μGy at 1 m and less than 0.1 μGy at 2 m (not considering the forward scatter direction where a staff member would not stand). A typical

clinical exposure for a supine chest X-ray is 85 kV and 0.8 mAs. Using the measurements at 120 kV, which will overestimate the dose at 85 kV, the scattered radiation dose will be 0.3 μGy at 1 m and less than 0.1 μGy at 2 m.

Instadose dosimeters were used to measure clinical exposures for staff. In ICU, three Instadose dosimeters were used for a period of eight days and 22 chest X-rays using the *through glass* technique were performed. Similarly in ED, three Instadose dosimeters were used for a period of 20 days, but only nine chest X-rays using the *through glass* technique were performed during this time. Five of the six dosimeters recorded readings at or below the minimum detectable limit of the dosimeter (0.03 mSv). One dosimeter worn by the ED in-room radiographer recorded 0.04 mSv.

Image quality assessment

In the image quality assessment, the radiologists gave an overall critique of contrast and sharpness. The more experienced radiologist assessed 70% (21 out of 30) of images as acceptable for both contrast and sharpness, while the junior radiologist assessed 90% (27 out of 30) as acceptable for both criteria. Of the remaining images, the more experienced radiologist assessed 17% (5 out of 30) and 13% (4 out of 30) as borderline and not acceptable,

Fig. 9 Normalised scatter air kerma measurements as a function of kilovoltage for the *through glass* technique for different thicknesses of scattering object at 1 m and 2 m

Table 5 Normalised scatter air kerma measurements at different distances from an anthropomorphic phantom for the standard technique for an erect and supine chest X-ray using a maximum 120 kV

Measurement direction	Scatter air kerma ($\mu\text{Gy}/\text{mAs}$)					
	Erect			Supine		
	1 m	2 m	3 m	1 m	2 m	3 m
Side scatter	0.16	0.03	0.02	0.23	0.07	0.03
45 degrees	0.14	0.04	0.02	0.31	0.08	0.03
Back scatter	0.06	0.03	NA	0.27	0.06	NA
Forward scatter	0.25	0.06	NA	0.27	0.07	0.03

Due to the room set-up measurements in some directions could not be made at 3 m

respectively, allocating both contrast and sharpness the same judgements for each image (either both borderline or both not acceptable). The junior radiologist assessed only one image as having borderline contrast and a different image as having borderline sharpness. Furthermore, the junior radiologist assessed one additional image as having unacceptable contrast and borderline sharpness. The kappa score for the radiologists across all criteria was 0.5, representing moderate agreement.

The kappa score for the radiographers across all criteria was 0.6, also representing moderate agreement. The IQC values for the different categories of radiographer assessment (anatomy, collimation, positioning, motion, exposure, artifacts) are shown in Fig. 10. The IQC was highest (0.88) when assessing motion. A comparison of the IQC values between the radiologists and radiographers is shown in Fig. 11.

Fig. 10 Image Quality Coefficient values for radiographer image quality assessment categories (see Table 2)

Fig. 11 Comparison of the Image Quality Coefficient values for radiologist and radiographer image quality assessment for each of the 30 patient images assessed. The radiologists and radiographers used different criteria to assess the images (see Table 1 and Table 2, respectively)

Discussion

The International Commission on Radiological Protection (ICRP) recommends dose limits for occupational exposure and advocates optimising exposures so that they are kept as low as reasonably achievable (ALARA), taking into account economic and societal factors [8]. The normal operating procedure within our health network is for mobile X-ray imaging to be undertaken in the wards, ED, ICU and theatre recovery rooms if it is not possible to transfer the patient to a fixed X-ray room where the image quality is better and radiation safety more easily controlled. When undertaking mobile X-ray work, radiographers are required to ensure that no person other than the patient is within 2 m of the anatomy being imaged, or they otherwise must wear a lead apron and thyroid collar. The radiographer initiating the X-ray has responsibility for radiation safety and verbally advises “X-ray” when exposure is imminent.

Australia began to expect and plan for a surge of COVID-19 patients on healthcare institutions from early March 2020 based on international experience. In response, we anticipated a large number of chest X-ray images to be performed on suspected COVID-19 cases in the ED environment and confirmed positive patients in the ICU. When we became aware of a potential method of acquiring X-ray images through the glass door or window from outside a patient’s room, we decided to investigate the technique to protect radiographers from infection risk and also to reduce the time required for disinfection of the entire mobile X-ray unit.

We were satisfied with initial image quality using a higher kV and higher mAs technique through glass compared with the standard protocol. We then assessed the radiation safety requirements for the staff who remained in the room and the radiographer initiating the X-ray from outside of the room to determine if lead aprons or a mobile lead shield were required. For a high kV technique and typical exposure of 5 mAs, the dose to staff at 1 m from the patient or 1 m outside

the room from the glass was less than 0.5 μSv (effective dose will be less than the measured air kerma values). Each exposure situation will be different and the scattered dose will be higher for a larger patient and higher parameters. However, there will also be smaller patients where the dose is lower. Furthermore, radiographers are trained and understand that they must maximise distance to the radiation source in order to reduce exposure. In the clinical setting they are much more likely to achieve a greater distance than 1 m from the radiation source and therefore the exposure levels will be lower.

We provided information to radiographers on the possible exposure at a minimum distance of 1 m, so that if a situation arose where the least risk to the patient and best clinical outcome resulted in needing to stand at only 1 m from the source, then radiographers could confidently do so. Furthermore, staff experienced with the use of radiation (radiographers) were always responsible for radiation safety, either in the room or outside of it. If a nurse was remaining in the room, the radiographer advised on the optimal place to stand. Radiographers can explain that exposure at 1 m is equivalent to approximately three hours of natural background radiation (based on approximately 1.5 mSv in Australia annually) and that further away is even lower. Anecdotally, nursing staff, particularly in ICU reported that they felt relieved that we had researched the *through glass* technique and had considered all aspects of radiation safety.

In Australia, the occupational dose limit is 20 mSv per year averaged over five years, however, for the purpose of this scenario we used 1 mSv as a dose constraint. To determine the minimum distance that a staff member could stand from the radiation source without any further lead protection (apron or mobile shield) we predicted that for occupational exposure of approximately 0.5 μSv at 1 m from the radiation source, it would require 2000 chest X-rays per year to reach 1 mSv. Radiographer staffing rotating through our ICU and ED consists of approximately 60 radiographers at the Alfred (including split teams during the pandemic) with a total staff profile of 110 radiographers. The usage of the *through glass* technique to date demonstrates that it occurs far less frequently and based on this our radiographers might receive up to 0.1 mSv from this workload. Even allowing for their roster to include fluoroscopy or interventional angiography or cardiology this would still be expected to be 0.2 mSv or lower annually.

It should be emphasised that this technique is currently approved only for use during the COVID-19 pandemic. In ED, the technique must be specifically requested by an emergency consultant (or the senior registrar overnight) and the patient must be clinically deteriorating. The *through glass* technique is not intended to become common practice. At the end of this pandemic we may assess if there is a role for the technique for patients in isolation rooms in the future. At

this time we have justified the use of the *through glass* technique due to its benefits and we have carefully considered optimising doses for both the patient and staff.

Our experience justifies having two radiographers to clearly convey instructions as both verbal and non-verbal communication are necessary due to the thickness of glass to ensure appropriate positioning, bed height, collimation and SID. Discussion on achievable positioning first occurs before the radiographer enters the room. The patient bed is moved as close as possible to the glass door and lowered to achieve appropriate tube angulation. When all staff in the room are in a safe position, the inside radiographer gives a “thumbs up” or similar signal to say that the area is safe and ready to initiate an X-ray exposure. The inside radiographer ensures that all staff in the room are aware that the exposure is imminent. The outside radiographer signals with a “thumbs up” that they have received the signal and are ready to initiate the exposure. The radiographers must maintain visual contact during the X-ray exposure so that the inside radiographer can wave if something changes and it is no longer safe to expose. Improving visual contact may require the movement of curtains, equipment, or for the radiographers to move to ensure both a safe position and eye contact are maintained. After ensuring the external area is safe, the outside radiographer uses the standard verbal warning indicating the bed number and “X-ray” immediately prior to exposure. The outside radiographer determines the adequacy of the image and indicates this to the inside radiographer.

Rooms in the Alfred ED are smaller than in ICU and staff were given the option to vacate the room if possible during the X-ray exposure. However, this does require staff to doff their PPE, which has been shown to be frequently the point at which healthcare workers contaminate their skin or clothing with pathogens [14]. Reducing instances of doffing reduces healthcare worker infection risk. If the technique is used with staff staying in the room, then only those staff in the room require a surgical mask, protective eyewear, gown and gloves. This reduces the usage of PPE, which at times has been in short supply. Anecdotally, radiographers have reported that allowing one radiographer to stay outside of the room in a lower level of PPE and reducing infection risk has been helpful mentally. Furthermore, avoiding disinfection of the entire X-ray unit while wearing the required PPE has been gratefully accepted as reducing workload. In our technique, the digital detector is double bagged and after imaging, the outer bag is removed by the inside radiographer without touching the inner bag and then passed to the outside radiographer who is wearing gloves. Cleaning procedures for the detector and X-ray unit are followed based on the local department infection control guidelines.

This technique is not novel at The Alfred as a similar technique has been used by some of our radiographers for taking X-rays through a hyperbaric chamber window at a

very large distance (approximately 4 m). In reviewing the technique factors used in the images sampled for this study, there did not appear to be a strong correlation between mAs or kV selected by the radiographers and the SID. It was evident that radiographers preferred using 110 kV, which may be associated with radiographers attempting to adjust for an increase in SID solely by changing the mAs using the inverse square law. The mAs values may be better correlated with patient size, although this was not one of the parameters collected in this study. There was one low kV used (90 kV with 1.4 mAs at 280 cm SID), however on investigation it was found that the radiographers repeated the first exposure because of anatomy cut-off (Fig. 12a). After repositioning the detector they repeated the exposure, but the machine reverted back to standard factors and they did not readjust these for the *through glass* technique (Fig. 12b). Both images were kept and reported by a radiologist as together they answered the clinical question and no further imaging was required. There was one higher kV exposure in the sample (120 kV, 12.5 mAs at 250 cm SID). This was for a very large patient. To assist the radiographers with parameter selection, we had intended to assess any unknown types of glass by measuring the HVL of the X-ray beam after transmission through the glass. However, this has not been necessary as the types of glass have been fairly consistent.

Radiographers were able to rely on their knowledge of EI values and the expected range to help inform their choice of parameters. They are instructed that EI values are a guide only and they must also review image quality when deciding if an acquisition is optimal. Acquisitions are not repeated automatically outside of the recommended range, although values below these ranges are assessed for noise and mottle and repeated only if inadequate. Our department conducts a monthly quality assurance activity

to review EI values as well as rejected images for both percentage of rejects and the reason for a rejection. The EI values for the *through glass* technique were found to be higher than the recommended range at our site. However, it should be noted that our standard technique also results in a range higher than the target range (Fig. 7). The EI value is useful to compare between the two techniques as it is a comparison of the radiation reaching the detector. We were expecting EI values to be similar regardless of the method of acquisition. One area for optimisation may be to reduce the exposures for the *through glass* technique in ED. These tended to be at shorter SIDs than in ICU and potentially could reduce the kV and/or mAs. Furthermore, they were performed more infrequently in this area and less experience with the technique may have led to slightly higher EI values.

An initial review of the reject rate for mobile chest X-rays performed with the *through glass* technique demonstrated that more images were repeated than when using the standard technique. The *through glass* technique is technically challenging and although we expected the repeat rate might be lower than the traditional technique given the pressure not to repeat and the relatively high threshold for acceptability of poor quality images, the opposite occurred. The reject rate for the standard mobile chest X-ray technique is typically 6–7% (approximately 18,000 performed annually). The reject rate for the *through glass* technique in the first month of implementation was 13%. Interestingly this improved and dropped to 8% in the second month, possibly as radiographers became more competent with the technique and there was potentially less pressure and fatigue in the second month with fewer COVID-positive patients. Figure 12 shows an image that was repeated because of anatomy cut-off with the second image demonstrating an exposure error. However, the

Fig. 12 An example of a repeated chest X-ray using the *through glass* technique for both images for a COVID-positive patient. **a** The first image was a positioning error with missing anatomy (110 kV, 5 mAs, 2.8 m SID). Radiologist IQC of 0.64 and radiographer IQC of 0.45. **b**

The second image is an exposure error as the X-ray unit defaulted to the standard technique values and the radiographer did not manually change them (90 kV, 1.4 mAs, 2.8 m SID). Radiologist IQC of 0.42 and radiographer IQC of 0.50

two images reported together were considered diagnostic and not repeated further.

Image quality was assessed by both radiologists and radiographers for this study. Each professional group has quite different objectives in their review of the image. Radiologists are determining whether the quality is adequate to make a diagnosis and answer the clinical questions, whereas radiographers are critically assessing the technique and assuring the quality of the image. Both radiographers found under-collimation to be the most problematic issue (overall IQC of 0.18) for the *through glass* technique. At an excessively long SID, the resultant collimation is extremely sensitive to minor adjustment. The light field may have also been more difficult to see given the bright ambient ICU lighting combined with the long distance between the patient and the radiographer performing collimation. The agreement between the light field and X-ray field will also be an important factor. The greatest positioning challenge associated with this technique was achieving adequate tube height and angulation with the long SID. In particular, this was noted for patients who had equipment limiting how much the bed could be lowered or for those unable to be sat fully upright. This contributed to both anatomy and positioning issues, with clipping of the lung apices a common finding, shown in Fig. 13 on an otherwise good quality radiograph.

One or both radiographers found approximately 10% of the images (4 out of 30) to have excessive noise. Some of these may have led to repeated images. Overall the radiologists considered the images more acceptable than the

radiographers. The radiologists' assessment resulted in 16 images (53%) with an IQC of 0.8 or higher, whereas the radiographers only had one image (Fig. 11). The highest rated image (radiologist IQC of 0.97 and radiographer IQC of 0.89) is shown in Fig. 14 as an example of a good quality image.

The effective dose to the patient from a single chest exposure using the *through glass* technique was on average 0.02 mSv, which is standard for a chest X-ray (Fig. 8). The incorrectly set low exposure parameters (90 kV, 1.4 mAs) resulted in an effective dose of 0.002 mSv. Excluding this from the assessment gave a dose range 0.01 to 0.07 mSv, with the average still 0.02 mSv. The KAP value is usually an indicator of the patient dose, however, this is not the case for the *through glass* technique as it does not include the glass attenuation of the beam. The KAP values for the sampled images using the *through glass* technique were typically double those for a standard technique, as expected. Published values for chest X-ray diagnostic reference levels are 0.15 Gy·cm² for an AP view (UK) [15] and 0.12 to 1 Gy·cm² for a posterior-anterior (PA) view (European Union countries) [16]. Our median mobile chest X-ray values are typically much lower than this and the median KAP value for the *through glass* technique is in fact comparable (0.10 Gy·cm²) even though it does not represent the dose to the patient (i.e. after the X-ray beam has passed through the glass).

The radiation safety assessment was based on an X-ray beam collimated to the digital detector. The radiographers are advised on the importance of ensuring that the X-ray beam is not beyond the edges of the detector as it only results in unnecessary radiation exposure to both the patient and staff. We advise that the best option is to get it right the first time and that a non-diagnostic exposure is a wasted

Fig. 13 An example of the difficulty and potential inability at times to position the X-ray tube high enough to acquire the full chest using the *through glass* technique (110 kV, 5.6 mAs, 3 m SID). In this case the top of the apices were cut-off. Radiologist IQC of 0.86 and radiographer IQC of 0.58

Fig. 14 An example of good *through glass* technique and image quality (110 kV, 5 mAs). Radiologist IQC of 0.97 and radiographer IQC of 0.89

exposure. They must consider whether an X-ray through glass is appropriate for each specific patient. Reasons for reverting to the standard technique include patients requiring supine imaging, larger patients, queries on nasogastric tubes where the upper abdomen may be better imaged without increased part thickness or patient lordosis. Where it is not possible to get the bed close enough to the glass or low enough for sufficient tube angle, the technique reverted to a standard mobile erect or supine view with both radiographers and all equipment in the room.

The scatter radiation dose to staff was assessed for both new and old techniques. During the pandemic we have advised that for mobile chest X-ray imaging, whether using the standard or *through glass* technique, radiographers must ensure all people other than the patient being imaged are at least 1 m away (from the scatter source which is the anatomy being imaged or the glass for staff outside the room for the *through glass* technique). Ideally, staff are further than 1 m and know that maximum distance is the preferred position to keep doses ALARA. The scattered radiation levels approximated the inverse square law (i.e. when distance was doubled the dose was approximately a quarter). For typical clinical exposures the scatter radiation dose will be less than 0.5 μGy for staff positioned at 1 m from the radiation source for either technique. There will be situations, particularly for larger patients, where this will be higher and radiographers must exercise professional judgement for maintaining radiation safety in these situations.

To verify the experimental scatter measurements undertaken, we used Instadose dosimeters to assess staff exposure in the clinical setting. These were in use for approximately one week in ICU and three weeks in ED. The Instadose dosimeter utilises direct ion storage in combination with a proprietary algorithm for radiation detection, and has a minimum reportable reading of 0.03 mSv. The dosimeters recorded negligible exposure and were used to confirm that the scatter radiation doses were not higher than expected. All radiographers wear optically stimulated luminescent (OSL) dosimeters and dose reports are reviewed by the Radiation Safety Officer on a 12-weekly basis. All reported doses are still very low for radiographers (< 0.1 mSv for the last quarter which includes the period in which this new technique was implemented).

There are several limitations with this study, some arising due to its implementation at a critical time during the pandemic when resources were stretched. The experimental measurements were made for only one type of mobile X-ray unit and could be repeated on some of the other X-ray units available to confirm results. Furthermore, it would be beneficial to better map the scatter radiation levels at different heights relative to the ground and more points in different directions from the scatter source. Only one type of glass was thoroughly assessed and further

quantification of the effect of glass could be undertaken. No information on patient size was collected or correlated with image quality and the parameter selection. More detailed quantitative assessment of the images, particularly to determine the noise variation with the higher X-ray beam quality, would be beneficial. We will aim to do more work in this area. Finally, different jurisdictions will have different radiation safety requirements and these should be checked before implementing the technique that we have described here.

Conclusion

We have implemented a new *through glass* technique for mobile chest X-ray imaging during the COVID-19 pandemic. It is not intended to use this technique in the long term, but rather to utilise it while significant efficiencies can be gained. In particular, the time to perform a chest X-ray for a confirmed/suspected COVID-19 patient is significantly reduced by avoiding a full disinfection of the X-ray unit, which will ensure that all patients receive timely imaging in the case of a surge of patients. More importantly, the risk to radiographers of infection is reduced. Instead of two staff being in the room with the infected patient, only one is required. This halves the number of times staff may be in direct contact with COVID-19 patients when the technique is used. Finally, this has been a multi-disciplinary effort by medical physicists, radiographers, radiologists and research staff. This collaborative effort underpins the strong team culture that already existed, but has been strengthened by the complex challenges arising during this pandemic.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Low risk ethics approval (project number 261/20) has been granted by the Alfred Health Human Research Ethics Committee.

Informed consent Informed consent was obtained from patients for medical images included in this publication.

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