





## ORIGINAL ARTICLE

# COVID-19 pandemic and the effect of increased utilisation of mobile X-ray examinations on radiation dose to radiographers

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## Keywords

Clinical site, general, general radiography, medical imaging, radiation effects, respiratory

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## Abstract

**Introduction:** The use of ionising radiation results in occupational exposure to medical imaging professionals, requiring routine monitoring. This study aims to assess the effect of increased utilisation of mobile X-ray units, mobile imaging of non-routine body regions and radiographer work practice changes for impact on staff radiation dose during the early stages of the COVID-19 pandemic. **Methods:** A retrospective analysis of general radiology departments across two metropolitan hospitals was performed. Personal radiation monitor exposure reports between January 2019 and December 2020 were analysed. Statistical analysis was conducted using a Mann–Whitney *U* test when comparing each quarter, from 2019 to 2020. Categorical data were compared using a Chi-squared test. **Results:** Mobile X-ray use during the pandemic increased approximately 1.7-fold, with the peak usage observed in September 2020. The mobile imaging rate per month of non-routine body regions increased from approximately 6.0–7.8%. Reported doses marginally increased during Q2, Q3 and Q4 of 2020 (in comparison to 2019 data), though was not statistically significant (Q2:  $P = 0.13$ ; Q3:  $P = 0.31$  and Q4  $P = 0.32$ ). In Q1, doses marginally decreased and were not statistically significant ( $P = 0.22$ ). **Conclusion:** Increased utilisation and work practice changes had no significant effect on reported staff radiation dose. The average reported dose remained significantly lower than the occupational dose limits for radiation workers of 20 mSv.

## Introduction

The World Health Organization classified the Sars-Cov-2 virus (COVID-19) as the world's first-ever coronavirus pandemic in March 2020.<sup>1</sup> By November 2021, Australia (population exceeding 25 million) recorded over 204,000 cases with approximately 1900 deaths.<sup>2</sup> Though the relative caseload has been low in Australia compared to

the rest of the world,<sup>3</sup> Victoria has been the pandemic's epicentre, representing approximately 118,000 of the nation's cases, as of November 2021 (Fig. 1).<sup>2</sup> The first known Australian case presented to a Victorian hospital in late January 2020, signalling the first wave's commencement.<sup>4</sup> In response to this, governments and health services worked quickly to build capacity for the foreshadowed increased demand to treat patients

suspected of having COVID-19.<sup>5</sup> By early May 2020, case numbers had plateaued, as shown in Figure 1. However, in July, case numbers increased again in what is known as the 'second wave'.

Like other coronaviruses, COVID-19 targets the respiratory system, with fever, cough, chest tightness and dyspnoea the most common symptoms.<sup>7</sup> COVID-19 is readily transmittable via infected respiratory secretions.<sup>7,8</sup> As a result, the Victorian Department of Health's guidelines recommended that many patients presenting to hospitals with these symptoms be classified as suspected COVID (sCOVID), as they sought to understand the viral characteristics and potential impact.<sup>9</sup> These patients required extra precautions as an early-stage infection is often asymptomatic.<sup>10</sup> Staff adhered to both contact and airborne precautions when working with COVID-positive and high-risk sCOVID patients per local protocol. Tier 3 personal protective equipment (PPE), including a plastic full-length long-sleeve gown, gloves, eye protection/face shield and N95 mask, were used, following the Victorian Department of Health and Human Services' guide to the conventional use of PPE.<sup>11</sup>

Due to the high transmission risk, departments such as radiology swiftly imposed a change in workflow. For example, radiographers perceived an increased demand for imaging at the patient's bedside, using mobile X-ray units.<sup>8,12,13</sup> This is possible as mobile X-ray units are widely available, time-efficient and can be effectively cleaned between patients while producing high-quality

radiographs.<sup>12-16</sup> Typically, mobile imaging is conducted when patient health and safety may be compromised using a fixed system.

Chest X-rays are recognised as a frontline imaging tool for patients with respiratory symptoms and are commonly included in the initial assessment of patients presenting with COVID symptoms.<sup>8,10,17,18</sup> Though recent literature has found radiographic characteristics observed in COVID-19 patients, such as multifocal peripheral lung changes of ground-glass opacities and bilateral consolidation, initial chest X-rays can have a normal radiographic appearance for patients infected with COVID-19.<sup>18,19</sup> A respiratory polymerase chain reaction test is considered the gold standard for the formal diagnosis of COVID-19.<sup>20</sup> Despite this, chest X-rays have also found a place in diagnosis, utilised in conjunction with clinical judgement.<sup>18</sup> The Cochrane review into thoracic imaging for the diagnosis of COVID-19 suggests that chest X-rays are moderately sensitive and moderately specific in the diagnosis of COVID-19.<sup>21</sup> This is supported by Brady et al. and Jacobi et al.<sup>8,12</sup>

Since COVID-19, mobile X-ray imaging has been used for both the chest and other regions at an increased rate, improving efficiency and patient management. A recent Australian radiographer survey reported increased pressure upon mobile, general radiography and computed tomography (CT) services due to increased service demand.<sup>22</sup> As a result, radiographers anticipated an increase in their reported radiation dose.<sup>22</sup>

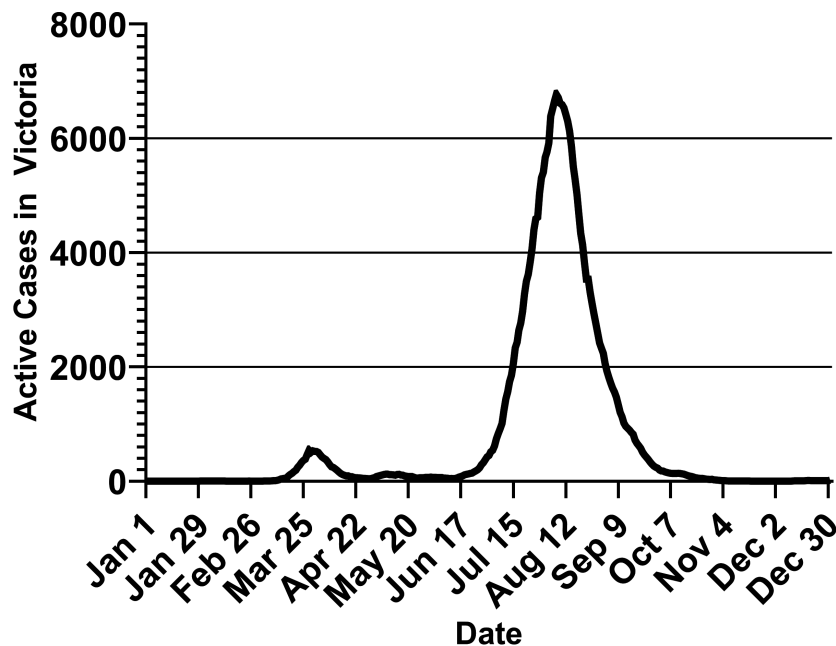


Figure 1. Daily active COVID-19 cases in Victoria in 2020 reproduced using freely accessible, open-access data via a GitHub repository.<sup>6</sup>

Radiation safety in medical imaging is paramount for all staff and patients. Thus, the radiation dose should be limited to as low as reasonably achievable.<sup>23</sup> Standard protective measures employed in general X-ray rooms, such as lead-lined walls, are not always available in areas outside the radiology department. Ionising radiation generated from mobile X-ray units can lead to unwanted radiation exposure if mishandled.<sup>24</sup> Radiation can cause adverse biological effects, including cancerous changes or cell death, dependent upon the magnitude of radiation exposure and the organ's radiosensitivity.<sup>11</sup> To minimise the risk of radiation-induced biological effects, radiographers must adhere to the three principles of radiation safety: shielding, time and distance.<sup>25</sup> The International Commission on Radiological Protection (ICRP) recommends a whole-body dose limit of 20 mSv per year, averaged over 5 years, for occupationally exposed staff.<sup>26</sup>

Many hospitals increased their patient capacity during the pandemic, adapting clinical, non-clinical or administrative spaces to meet the expected demands. For example, intensive care unit (ICU) capacity increased by converting single to shared rooms or introducing ad hoc measures such as additional equipment to non-utilised areas, further limiting space.<sup>27</sup> Due to the aforementioned airborne precautions surrounding COVID-19, patients were often allocated to isolation rooms with limited space. Furthermore, radiographers were encouraged to enter and exit via anterooms, rather than via main doors. Where no anteroom was present, radiographers were encouraged to remain in the room to decrease exposure risk to other staff during the examination.

Consequently, radiographers had difficulty establishing an adequate distance between them, the radiation source, and the resultant scattered radiation at all times. While the International Society of Radiographers and Radiologic Technologists recommends a distance of 2 m between the patient and radiographer, studies have shown that yearly maximum permissible doses are not exceeded for mobile X-ray imaging at distances of 1 m.<sup>8,28</sup> Since COVID-19, stricter infection control measures have recommended limiting the use of additional equipment such as restraints or lead equivalent protection.<sup>29</sup> This provided further challenges to mitigate the radiographers' radiation risks. This study aims to assess the effects of work practice changes on radiographer radiation dose with mobile X-ray use during the initial phase of the pandemic.

## Methods

### Ethical considerations

Ethics approval for this study has been provided by the Monash Health research office, our local Human

Research Ethics Committee (HREC reference number: QA/70407/MonH-2020-239841(v1)).

### Study setting

The study was conducted across a large Victorian Health network in multiple metropolitan Melbourne radiology sites. The network specialises in emergency care, paediatrics, neurosurgery, orthopaedics, oncology, urology, mental health, general medical, rehabilitation, maternity, cardiology, gynaecology, plastics, thoracic surgery, maxillofacial surgery, infectious diseases, respiratory, vascular, special care and neonatal nurseries.

The network primarily consists of five hospital sites, including three hospitals with emergency departments, one independent oncology hospital and one paediatric-dedicated hospital. In preparation for the anticipated health crisis, all sites purchased additional mobile X-ray units to ensure medical imaging could meet clinical demand.

### Inclusion/Exclusion criteria

Participants were included in the study if they were rostered to the general X-ray department for more than 50% of their monthly roster and performed more than the quarterly average number of mobile X-ray examinations at their respective site (site 1  $\geq$  4.7–65.1; site 2  $\geq$  35.9–72.5; full data available in Table 1). The averages are represented under each site due to workload differences due to differing subspeciality or site size.

Data were described in quartiles, consistent with dose reading reporting.

Staff on extended or maternity leave were excluded. Staff with less than the minimum reportable dose limit of 0.01 mSv were excluded from the median dose analyses. However, they were included when comparing the number of staff exceeding the minimum reportable threshold between quarters.

**Table 1.** Quarterly average of mobile X-ray examinations for 2019 and 2020.

	Site 1		Site 2	
	2019	2020	2019	2020
Q1	4.7	6.1	32.7	35.9
Q2	3.6	23.7	37.1	48.8
Q3	5.5	65.1	36.1	72.5
Q4	3.5	23.6	36.8	32.8

Q1 (January 1st to March 31st), Q2 (April 1st to June 30th), Q3 (July 1st to September 30th) and Q4 (October 1st to December 31st).

Of the five sites eligible for this study, only two sites were included. Two sites did not treat sCOVID or COVID-19 positive patients (clean sites), while the third site was excluded due to variability in staff rostering across multiple modalities during the study period.

### Site specifications

Across both sites, there were 11 mobile X-ray units used. There were seven Shimadzu DaRt Evolution MX8s (Shimadzu Corporation Japan), which serviced the ICU, emergency department and general wards, one GE AMX-4 (GE Healthcare, US) with a Carestream DRX digital detector retrofit (Carestream, US) servicing the emergency department, two Carestream DRX Revolution Plus (Carestream, US) units that service the emergency department and the neonatal ICU, and one Carestream DRX Revolution (Carestream, US) that serviced the paediatric ICU and the COVID ICU.

Local radiation safety requirements state that radioprotective PPE is not required when radiographers are >2 m from the patient when using mobile X-ray units. Staff members at both sites used Landauer Luxel+™ optically stimulated luminescence personal radiation monitors.

### Data collection

Between January 2019 and December 2020, personal dose data were extracted from the radiation dose reports recorded on the Landauer Web Client Portal. The deep-dose equivalent (DDE), measured in mSv, was analysed. The DDE was selected for statistical analysis as it is recognised as representative of approximate whole-body radiation dose.<sup>30</sup> The years were divided into quarters to reflect the period where Landauer collected and analysed radiation monitors. Mobile radiography numbers were extracted from the RIS.

### Statistical analysis

A Mann–Whitney *U* test was used to analyse workplace changes on radiographer radiation exposure in each quarter from 2019 to 2020. All categorical data were compared using a Chi-squared test. The significance threshold was set at 0.05. Statistical analysis was performed on GraphPad Prism version 9.1.0 for Mac (GraphPad Software, San Diego, California USA).

### Results

In this study, 81 radiographers ( $n = 152$  dose records) in 2019 and 83 radiographers ( $n = 166$  dose records) in

2020 were included. Ninety-eight dose records were excluded as they did not meet the inclusion criteria. A total of 318 records were used for the analysis.

As shown in Figure 2, an increase of 1.7-fold in mobile X-ray examinations was observed between 2019 and 2020. Most notably, the peak variance of mobile X-rays was 228% between September 2019 and September 2020. The increase in mobile X-ray examinations can be correlated to the number of COVID-19 cases in Victoria, as shown in Figure 1, with the first case presenting in late January 2020.

Figure 3 demonstrates the percentage of mobile X-rays performed, pre- and post-COVID, for the chest and non-routine regions, such as abdominal, musculoskeletal and neurological. Before COVID-19 (January 2019–December 2019), approximately 94% of mobile radiographs were of the chest. This decreased to approximately 92% post-COVID as mobile X-rays for other regions increased (Fig. 3).

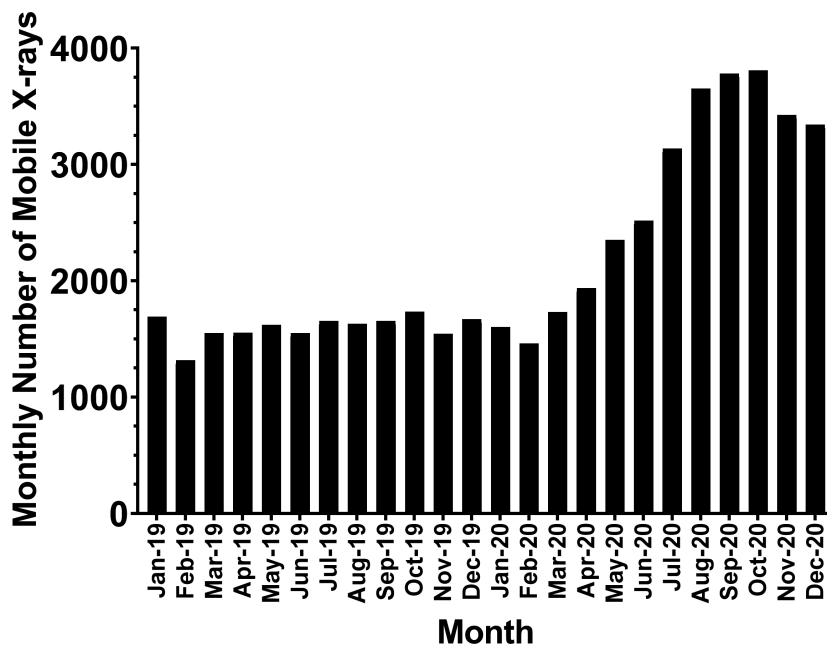
Table 2 presents the summary statistics for the 318 dose records included in this study. The number of dose records with a DDE below 0.01 mSv was analysed. In Q2 of 2019, 42% of dose records ( $n = 15$ ) did not measure a radiation dose exceeding the reportable limit compared to only 21% ( $n = 9$ ) in Q2 of 2020. This quarter exhibited the greatest difference in the reported DDE. However, a Chi-squared test indicated that each quarter's results between 2019 and 2020 did not reach statistical significance ( $P > 0.05$ ; Q1  $P = 0.29$ , Q2  $P = 0.05$ , Q3  $P = 0.42$  and Q4  $P = 0.13$ ).

Median DDE to radiographers was lower in Q1 2020 when compared to Q1 2019 (0.02 vs. 0.03 mSv). The median DDE was greater in Q2 (0.05 vs. 0.04 mSv), Q3 (0.04 vs. 0.03 mSv) and Q4 (0.05 vs. 0.03 mSv). The Mann–Whitney *U* test indicated that none reached statistical significance ( $P > 0.05$ ; Q1  $P = 0.22$ , Q2  $P = 0.13$ , Q3  $P = 0.31$  and Q4  $P = 0.32$ ). Figure 4 shows the median DDE between 2019 and 2020 in the different quarters.

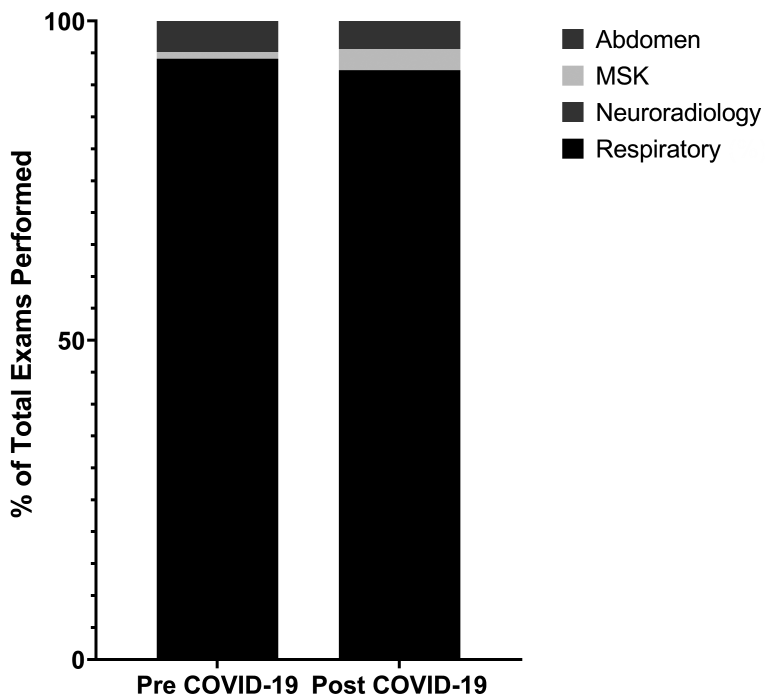
### Discussion

This study showed that mobile X-ray examinations increased following the first reported Australian case of COVID-19. Other studies have reported a significant decrease in imaging utilisation across radiology services worldwide.<sup>31–34</sup> While early data (January to March 2020) in Australia has demonstrated a minimal change in the rate of chest X-rays performed,<sup>35</sup> mobile chest X-ray use increased at the two study sites from April 2020 onwards.

Shanahan *et al.* found that diagnostic radiographers perceived an increase in demand for mobile radiography, consistent with our sites' experiences.<sup>22</sup> Significant



**Figure 2.** Monthly number of total completed mobile X-ray examinations across sites (data extracted from the radiology information system (RIS)).



**Figure 3.** Mobile examinations by specialty pre- and post-COVID-19. Numbers are the percentage of each region versus the total number of mobile X-rays.

**Table 2.** Summary statistics for radiographer dose record data for 2019 and 2020.

	Q1			Q2			Q3			Q4		
	2019	2020	P	2019	2020	P	2019	2020	P	2019	2020	P
n	41	42		36	42		39	40		36	42	
DDE, median (IQR) (mSv)	0.03 (0.02– 0.04)	0.02 (0.01– 0.03)	0.22	0.04 (0.03– 0.05)	0.05 (0.03– 0.06)	0.13	0.03 (0.02– 0.05)	0.04 (0.03– 0.07)	0.31	0.03 (0.02– 0.05)	0.05 (0.01– 0.06)	0.32
<Minimum reportable limit, no./total (%)*	6/41 (15)	10/42 (24)	0.29	15/36 (42)	9/42 (21)	0.05	11/39 (28)	13/40 (33)	0.42	19/36 (53)	15/42 (36)	0.13

DDE (Deep Dose Equivalent, mSv); IQR (Interquartile range, Q3 - Q1); Q1 (January 1st to March 31st), Q2 (April 1st to June 30th), Q3 (July 1st to September 30th) and Q4 (October 1st to December 31st).

\*The minimum reporting limit for the personal radiation monitoring service used at this site is 0.01 mSv.

changes in mobile X-ray demand can be attributed to the pandemic's first and second waves in Victoria, Australia. We observed an annual increased demand of approximately 70% for mobile X-ray examinations, at our health service. This is not in line with the findings of O'Brien and Clements, who found a 0.16% increase in chest X-ray imaging and 6.0% in CT chest imaging.<sup>35</sup> Australian chest X-ray and CT chest Medicare data studies may have diluted the impact of Victorian chest imaging utilisation during the pandemic's first and second waves as Victoria contributed the majority of Australian COVID-19 cases in 2020.<sup>36</sup> The chest X-ray provided a practical workup for triaging patients. This assisted in screening suspected-COVID-19 patients using the recommended criteria.<sup>9</sup>

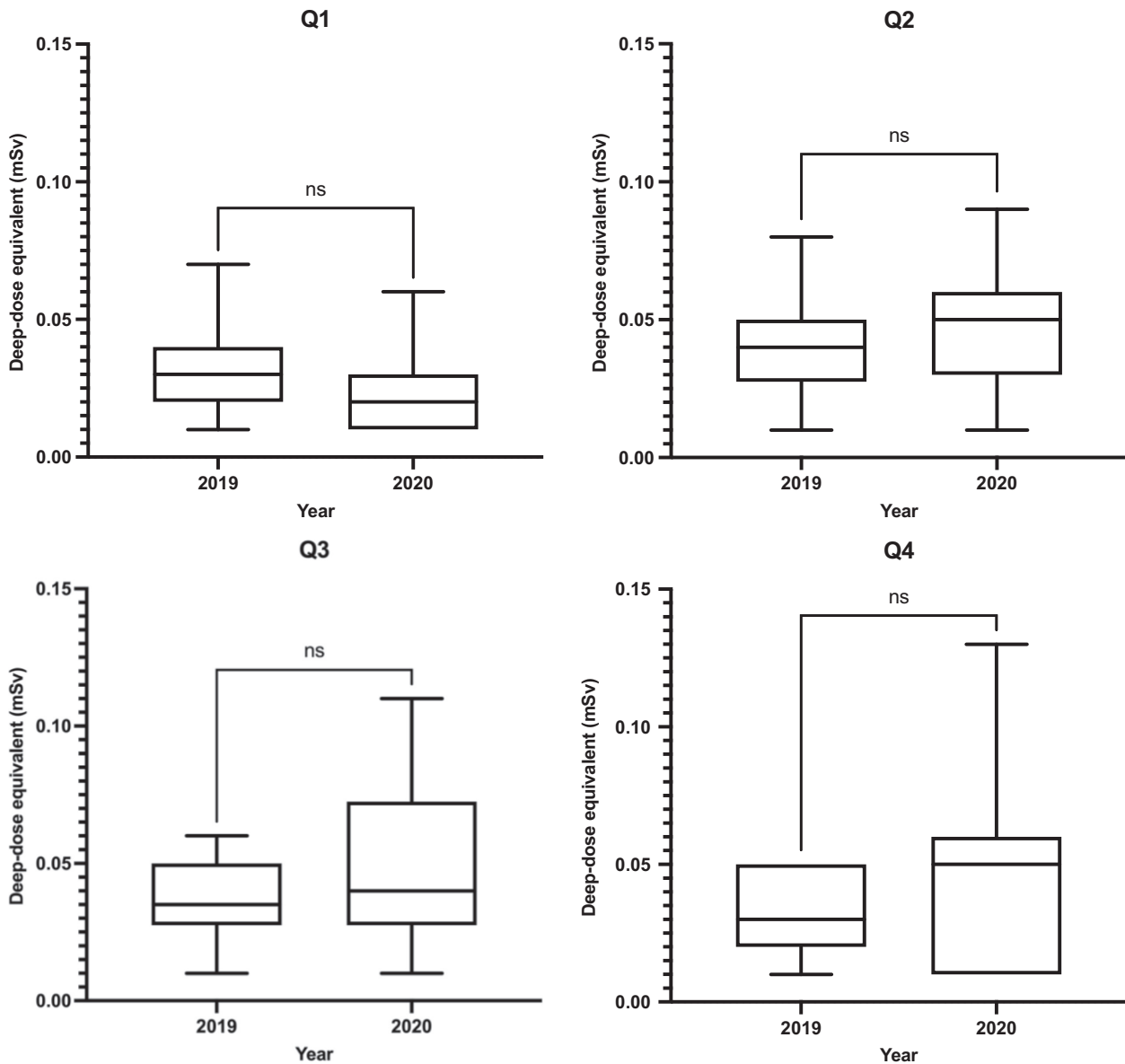
The sites included in this study employed two additional staff for the mobile X-ray team, one staff member for the general X-ray team, and one for afternoon and evening shifts. This was to help manage increases in patient presentations during viral surges and manage workflow. This staffing adjustment is supported by Koehler et al., who investigated the demand for chest imaging during the pandemic's first wave.<sup>37</sup> The greatest demand for chest imaging was between 2 and 10 pm for emergency patients and 6 am to 2 pm for inpatient requests.<sup>37</sup> The radiographers rostered to mobiles did not separate into teams without crossover; however, others considered this work practice.<sup>5</sup> While additional staff may improve workflow during the peak period, health services are well placed to manage any changes in demand.<sup>35</sup>

This work also identified that an increasing number of regions other than the chest were imaged using mobile radiography. Due to patient presentation diversity, timely diagnosis of patients' clinical questions often required imaging to be performed at the patient's bedside. The use of mobile radiography helps minimise staff exposure, patient transfers and possible contamination.<sup>10,15</sup> These were considered case-by-case based on clinical need or

delayed to confirm a negative swab result. Before the COVID-19 pandemic, mobile imaging of regions other than the chest was relatively rare at the study sites (<6%). Other institutions have reported higher rates of up to 25%.<sup>38,39</sup>

Although there were changes to work practices, locally, these changes did not result in a statistically significant increase in radiographer radiation exposure. While there was no statistically significant difference between the median DDE, the interquartile range shows that the range of doses increased during the COVID periods. However, due to the limitations of this study, we cannot attribute this increase due to mobile radiography use. Additionally, there was no statistically significant increase in the number of staff receiving doses greater than the minimal reportable limit of 0.01 mSv per quarter. Thus, it can be assumed that there is no significant increased radiation risk to radiographers. These findings are consistent with others who reported doses of  $\leq 0.03$ – $0.04$  mSv over 1 month.<sup>8</sup> Gange et al. found a dose of 16  $\mu$ Gy per chest X-ray at six feet with the radiographer positioned behind the mobile unit, compared with the standard reading of 1  $\mu$ Gy.<sup>9</sup> These fall well below the recommended yearly dose of 20 mSv for radiation workers.

Usually, local hospital regulations require the radiographer to wear radioprotective PPE within a 2-m radius of the patient. In some rare instances, due to infection control measures, isolation room size and time constraints of the examination, this was not possible, and the radiographer may have been unshielded while close to the patient. Scattered air KERMA measurements from mobile chest X-rays published by Brady et al. infer that unshielded personnel who are consistently positioned 1 m from the patient are unlikely to exceed the occupational dose limits.<sup>8</sup> Even assuming a maximum air KERMA to DDE conversion,<sup>40</sup> the number of examinations required to exceed the occupational dose limit surpasses the examinations that could be realistically performed in a



**Figure 4.** Comparison of deep-dose equivalent (mSv) to radiographers in Q1 (Jan-Mar), Q2 (Apr-Jun), Q3 (Jul-Sep), and Q4 (Oct-Dec) between 2019 and 2020 (ns denotes 'no statistically significant difference between the means').

year. Despite the changes following the COVID-19 pandemic, it is still unlikely that a radiographer would stand within 1 m of the patient. Regardless of the low radiation exposure to the radiographer, radiographers should wear radioprotective PPE where possible. This ensures a conservative approach to radiation protection in an environment where radiographers may be exposed to other radiation sources.

A large number of radiographers were excluded from this study due to roster variability. While a minimum number of mobile X-rays performed by radiographers were required for study inclusion, each radiographer's

completion rate varied. A repeat study to prospectively monitor a larger radiographer cohort, specifically rostered to mobile units over a designated time frame, could further clarify the dose attributed to the changes in mobile X-ray use. These findings are the experience of one Victorian health service and may not be generalisable to other health services. Given the ongoing nature of the COVID-19 pandemic, it would be valuable to also prospectively monitor a radiographer cohort across multiple health services to improve study quality. Using a cohort of radiographers employed only to perform fixed general radiography within the department as control

versus radiographers using mobiles. However, factors such as the number of X-rays performed and the consistency of radioprotection measures (example.g., shielding versus no shielding and distance) would need to be considered. Comparison of COVID-19 and non-COVID-19 sites using mobile imaging may also help identify significant changes in radiation doses between cohorts. Finally, real-time personal dosimeters during mobile imaging would be beneficial to better demonstrate the expected dose from using mobile radiography. However, the low sensitivity of electronic personal dosimeters mixed with the low dose expected when mobile imaging, would be challenging. It may require a large number of exposures to get measurements with sufficient reproducibility.

While the relative number of Australian COVID-19 cases compared to other nations is low, we have shown that the radiation dose received by radiographers performing mobile X-rays during a pandemic is well within the safe limits for radiation workers. In our study, the reported DDE did not change significantly during the pandemic, even though the workload for mobile X-rays increased by 1.7-fold between 2019 and 2020.

## Conclusion

There was a substantial increase in the utilisation of mobile X-rays following the COVID-19 pandemic. Additionally, mobile X-ray work practices evolved to reduce infection transmission risk, such as imaging patients in isolation rooms. Despite the increase in the utilisation of mobile radiography, there was no statistically significant increase in radiation exposure to radiographers during the COVID-19 pandemic.

## Conflict of interest

The authors have no conflicts to declare.

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