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Retrospective Study

Imaging volumes during COVID-19: A Victorian health service experience

Imaging volumes during COVID-19

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Abstract

BACKGROUND

The World Health Organisation declared the coronavirus disease 2019 (COVID-19) a pandemic on 11th March 2020. While globally, the relative caseload has been high, Australia's has been relatively low. During the pandemic, radiology services have seen significant changes in workflow across modalities and reduction in imaging volumes.

AIM

This study investigates differences in modality imaging volumes during the COVID-19 pandemic across a large Victorian public health network.

METHODS

Retrospective analysis from January 2019 to December 2020 compared imaging volumes across two time periods corresponding to the pandemic's first and second waves. Weekly volumes across patient class, modality and mobile imaging were summed for time periods: wave 1 (weeks 11 to 16 for 2019; weeks 63 to 68 for 2020) and wave 2 (weeks 28 to 43 for 2019; weeks 80 to 95 for 2020). Microsoft Power BI linked to the radiology information system was used to mine all completed examinations.

RESULTS

Summed weekly data during the pandemic's first wave showed the greatest decrease of 29.8% in adult outpatient imaging volumes and greatest decrease of 46.3% paediatric emergency department imaging volumes. For the same period, adult nuclear medicine demonstrated the greatest decrease of 37.1%. Paediatric nuclear medicine showed the greatest decrease of 47.8%, with angiography increasing by 50%.

The pandemic's second wave demonstrated the greatest decrease of 23.5% in adult outpatient imaging volumes, with an increase of 18.2% in inpatient imaging volumes. The greatest decrease was 28.5% in paediatric emergency department imaging volumes.

For the same period, nuclear medicine showed the greatest decrease of 37.1%. Paediatric nuclear medicine showed the greatest decrease of 36.7%.

Mobile imaging utilisation increased by between 57.8% and 135.1% during the first and second waves. A strong correlation was observed between mobile and non-mobile imaging in the emergency setting (Spearman's correlation coefficient = -0.743, $p=0.000$). No correlation was observed in the inpatient setting (Spearman's correlation coefficient = -0.059, $p= 0.554$).

CONCLUSION

Nuclear medicine was most impacted, while computed tomography and angiography were least affected by the pandemic. Impact was less during the pandemic's second wave. Mobile imaging shows continuous growth during both waves.

Key Words: COVID-19; Pandemic; Radiology; Imaging volume; Modality; Mobile imaging

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Core Tip: Analysis of weekly imaging modality volumes provides an overview of changes in service demand over time. We describe the observed changes in imaging modality and mobile imaging volumes during Victoria's first and second waves of the COVID-19 pandemic.

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INTRODUCTION

The World Health Organisation declared the coronavirus disease 2019 (COVID-19) a pandemic on 11th March 2020^[1]. Healthcare facilities implemented strict infection control, social distancing protocols, and other measures in the interest of public health

and safety^[2]. In preparation for the surge in hospitalisations across the globe, overall elective surgical services decreased by approximately 72%^[3]. In comparison in Australia this fell by about 69%. Others utilised computational modelling to help predict the health services saturation point for ICU beds and ventilators^[4]. While globally, the relative caseload has been high, Australia's has been relatively low. In this context, during 2020, Victoria has experienced most of Australia's cases, with the new daily caseloads shown in Figure 1.

Due to the overwhelming prevalence of COVID-19 in various countries, for example, Italy, some radiology departments were dedicated to imaging COVID-19 patients only^[5]. Radiology services have also seen significant changes in workflow across modalities and a reduction in imaging volumes^[6,7,8]. For example, departments were re-configured to separate COVID-19 patients from non-infected patients, segregation of staff to reduce infection transmission, increased demand for PPE, radiologists reporting from home, and expansion of video conferencing use^[5,9]. For patients presenting to the emergency department, general radiography was primarily used due to its accessibility, availability and low radiation levels. For patients with typical symptoms of COVID-19 such as shortness of breath on exertion (SOBOE), persistent cough and chest pain, the chest X-ray was an ideal first choice^[8]. To minimise the transmission risk of suspected COVID-19 (sCOVID) patients while in hospital, the use of mobile imaging became particularly important to manage workflow^[10,11]. Imaging in the ward wearing PPE could reduce staff exposure, with effective cleaning of mobile units possible between imaging patients, without compromising patient care.

While it has been reported there was a decrease in patients presenting with stroke to our institution during the pandemic^[7]. To our knowledge, little is known about the severity of impact on radiology volumes in Australia. While overall Australian imaging volumes were analysed through Medicare, no institutional experience has been presented^[12].

Objectives

This study investigates the imaging volume changes during the pandemic across the network at a large Victorian public health service provider. A secondary aim was to study changes in mobile imaging utilisation, and whether that impacted the use of fixed (non-mobile) X-ray imaging systems. This data will help inform radiology practices for service adaptation with subsequent pandemic phases or other “once in a lifetime” events.

MATERIALS AND METHODS

This health network has 98 imaging systems across eight imaging modalities analysed according to Table 1.

Study setting

Our network provided over three million episodes of care in 2019 to 2020. Three of our five hospitals provide accident and emergency services, one is a geriatric centre and the other an oncology centre that did not service COVID-19 positive patients (‘clean site’). Data from the geriatric and oncology centre were excluded due to heterogeneity in these sites. Significant federal, state and local health policy and guideline changes were implemented and updated during the pandemic that impact the imaging pathway include: patients with typical respiratory symptoms (fever, chest tightness, dyspnoea, cough) were classified as sCOVID-19 (suspected COVID-19); recommendation for all eligible sCOVID-19 patients to have CTPA instead of V/Q scans^[13]; rescheduling of non-urgent cases as discussed with referring clinicians; use of mobile X-ray to reduce infection transmission; social distancing guidelines restricting patient waiting room numbers and minimum area of 4 m² per person in shared areas.

Data collection

Microsoft Power Business Intelligence (BI) linked to the radiology information system was used to mine all completed examinations between 1st January 2019 and 31st December 2020 across three sites. Imaging modality was defined as the device or technology used in medical imaging (general X-ray, mammography, nuclear medicine, CT, MRI, fluoroscopy, angiography, ultrasound, with mobile X-ray being a subset of X-

ray). Fixed or non-mobile imaging was defined as an X-ray system permanently secured in an X-ray room. Mobile imaging was defined as use of a portable X-ray imaging system capable of moving to different locations. Patient classes were defined by location (inpatient (IP), outpatient (OP) or emergency department (ED)). Adult patients were ≥ 16 years, while paediatric patients were aged < 16 years. Examinations were filtered by modality and patient class. March 2020 and April 2020 (week 63 (March 11th to March 17th) to week 68 (April 15th to April 21st)) corresponded to Victoria's first wave of the pandemic; July 2020 to October 2020 (week 80 (July 9th to July 14th) to week 95 (October 21st to October 26th)) corresponded to the second wave of the pandemic. Figure 2 provides the timeline of the first and second waves for considering impact to departmental caseloads. Outcome measure was total weekly completed imaging case numbers from Wednesday to Tuesday commencing Wednesday 2nd January to Tuesday 8th January 2019 (week 1) for direct day matched weekly comparisons between 2019 and 2020, allowing for any periodic variability observed. Weekly modality data was summed to reflect the first and second waves of the pandemic.

Statistical analysis

Weekly volumes across patient class, modality and mobile imaging were summed for defined time periods: wave 1 (weeks 11 to 16 for 2019; weeks 63 to 68 for 2020) and wave 2 (weeks 28 to 43 for 2019; weeks 80 to 95 for 2020). This was to evaluate the impact of COVID-19 on patient class, modality and mobile imaging case volumes during each COVID-19 wave. For analysis of mean weekly case numbers, pre COVID data were defined as the mean of weeks 1 to 60 (i.e. 2nd January 2019 to 29th February 2020), while COVID-19 data were defined as the mean of weeks 61 to 104 (i.e. 1st March 2020 to 31st December 2020). Independent sample t-tests were performed comparing the mean weekly imaging case volumes in years 2020 and 2019 for each imaging modality type stratified by patient service locations for the pre-COVID-19 and post-COVID-19 periods with results presented as means and 95% confidence intervals (95%CI). The relationship between mobile and non-mobile imaging volumes was assessed using Spearman rank correlation. Statistical significance was considered for p values < 0.05 .

All analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC, USA). The statistical methods of this study were reviewed by Dr Eldho Paul from Monash University.

This study was approved by the Monash Health Human Research Ethics Committee.

RESULTS

Adults

Total Volume (all modalities)

During the pandemic's first wave in Victoria, total adult imaging volume across all modalities declined by 20.7% between 11th March and 21th April 2020 (weeks 63 to 68) when compared to the same time in 2019 (13th March and 23th April 2019, weeks 11 to 16). During the pandemic's second wave, adult imaging volume across all modalities declined by 6.6% between 8th July and 27th October 2020 (weeks 80 to 95) when compared to the same time in 2019 (10th July and 29th October 2019, weeks 28 to 43).

Volume by Patient Class

Table 2 shows the summed weekly imaging volumes for the defined time periods and the percentage of adult image volume change across all included modalities by patient class for weeks 11 to 16 (13th March and 23th April) and 28 to 43 (10th July and 29th October) in 2019 and weeks 63 to 68 (11th March and 21th April) and 80 to 95 (8th July and 27th October) in 2020.

Volume by Modality

During the pandemic's first wave between 11th March and 21th April 2020 (weeks 63 to 68), adult angiography, bone mineral densitometry, computed tomography, fluoroscopy, general radiography, magnetic resonance imaging, mammography, nuclear medicine and ultrasound imaging volumes declined between 10.3% and 37.1% when compared to the same time in 2019 (13th March and 23th April 2019, weeks 11 to 16) shown in Table 3.

During the pandemic's second wave between 8th July and 27th October 2020 (weeks 80 to 95), adult angiography, bone mineral densitometry, fluoroscopy, general

radiography, magnetic resonance imaging, mammography, nuclear medicine and ultrasound services declined between 1.6% and 31.6%, while computed tomography increased by 1.7% when compared to the same time in 2019 (10th July and 29th October 2019, weeks 28 to 43) shown in Table 4.

Figure 3 highlights the weekly adult modality imaging volumes.

Comparison of the adult mean weekly 2019 (pre-COVID-19, Jan 1st 2019 to 29th Feb 2020, weeks 1 to 61) with 2020 (March 1st to Dec 31st 2020 wk 61 to 104) imaging volumes by modality, categorised by inpatient, outpatient and emergency services (Table 5) shows statistically significant declines in six imaging modalities ($p=0.042$ to $p<0.0001$). There were statistically significant declines in one inpatient imaging modality ($p=0.002$), and nine outpatient imaging modalities ($p=0.027$ to $p<0.0001$). Statistically significant increases were observed in five inpatient modalities ($p=0.0003$ to $p<0.0001$). Overall declines across all patient classes were observed across seven imaging modalities ($p=0.027$ to $p<0.0001$).

Mobile and non-mobile X-ray imaging

During the pandemic's first wave in Victoria, total adult mobile imaging volume increased by 57.8% between 11th March and 21th April 2020 (weeks 63 to 68) when compared to the same time in 2019 (13th March and 23th April 2019, weeks 11 to 16). During the pandemic's second wave, adult mobile imaging volume increased by 135.1% between 8th July and 27th October 2020 (weeks 80 to 95) when compared to the same time in 2019 (10th July and 29th October 2019, weeks 28 to 43). Table 6 highlights the mobile imaging changes across inpatient and emergency patient classes during the first and second waves.

Comparison of the adult mean weekly 2019 (pre-COVID-19, Jan 2nd 2019 to 29th Feb 2020, weeks 1 to 61) with 2020 (March 1st to Dec 31st 2020 wk 61 to 104) mobile and non-mobile X-ray imaging volumes, categorised by inpatient and emergency services (Table 7) shows statistically significant changes across all mobile and non-mobile imaging ($p=0.001$ to <0.0001). A strong correlation was observed between mobile and non-mobile imaging in the emergency setting (Spearman's correlation coefficient = -0.743, $p=0.000$).

No correlation was observed in the inpatient setting (Spearman's correlation coefficient = -0.059, $p= 0.554$). Figure 4 shows the weekly adult X-ray mobile and non-mobile imaging volumes.

Paediatrics

Total Volume (All modalities)

Total paediatric imaging volume across all modalities declined by 28.6% between 11th March and 21th April 2020 (weeks 63 to 68) when compared to the same time in 2019 (13th March and 23th April 2019, weeks 11 to 16). During the pandemic's second wave, paediatric imaging volume across all modalities declined by 6.6% between 8th July and 27th October 2020 (weeks 80 to 95) when compared to the same time in 2019 (10th July and 29th October 2019, weeks 28 to 43).

Volume by Patient Class

Table 8 shows the percentage paediatric image volume change across all included modalities by patient class for weeks 11 to 16 and 28 to 43 in 2019 and weeks 63 to 68 and 80 to 95 in 2020.

During the pandemic's first wave between 11th March and 21th April 2020 (weeks 63 - 68), paediatric IP, OP and ED services declined by between 3.7% and 46.3%, when compared to the same time in 2019 (13th March and 23th April 2019, weeks 11 to 16).

During the pandemic's second wave between 8th July and 27th October 2020 (weeks 80 to 95), paediatric IP, OP and ED services declined by between 16.1% and 28.5% when compared to the same time in 2019 (10th July and 29th October 2019, weeks 28 to 43).

Volume by Modality

During the pandemic's first wave between 11th March and 21th April 2020 (weeks 63 to 68), paediatric imaging modality services declined by between 18.6% and 47.8% and 18.6%, while angiography increased by 50% when compared to the same time in 2019 (13th March and 23th April 2019, weeks 11 to 16 shown in Table 9).

During the pandemic's second wave between 8th July and 27th October 2020 (weeks 80 to 95), paediatric imaging modality services declined by between 5.2% and 36.7% when compared to the same time in 2019 (10th July and 29th October 2019, weeks 28 to 43),

shown in Table 10. Figure 5 highlights the weekly paediatric modality imaging volumes.

Comparison of the paediatric mean weekly 2019 (pre-COVID-19, Jan 2nd 2019 to 29th Feb 2020, weeks 1 to 61) with 2020 (March 1st to Dec 31st 2020 wk 61 to 104) imaging volumes by modality, categorised by inpatient, outpatient and emergency services (Table 11) shows statistically significant changes in two emergency imaging modalities ($p=0.0001$ to $p<0.0001$), two inpatient imaging modalities ($p=0.0003$ to $p<0.0001$), and four outpatient imaging modalities ($p=0.019$ to $p<0.0001$). Overall changes across all patient classes were observed in five imaging modalities ($p=0.037$ to $p<0.0001$).

Mobile and non-mobile X-ray imaging

During the pandemic's first wave in Victoria, total paediatric mobile imaging volume decreased by 0.7% between 11th March and 21th April 2020 (weeks 63 to 68) when compared to the same time in 2019 (13th March and 23th April 2019, weeks 11 to 16). During the pandemic's second wave, paediatric mobile imaging volume decreased by 6.7% between 8th July and 27th October 2020 (weeks 80 to 95) when compared to the same time in 2019 (10th July and 29th October 2019, weeks 28 to 43). Table 12 highlights the mobile imaging changes across inpatient and emergency patient classes during the first and second waves.

Comparison of the paediatric mean weekly 2019 (pre-COVID-19, Jan 2nd 2019 to 29th Feb 2020, weeks 1 to 61) with 2020 (March 1st to Dec 31st 2020 wk 61 to 104) mobile and non-mobile X-ray imaging volumes, categorised by inpatient and emergency services (Table 13) shows statistically significant changes across all mobile and non-mobile imaging ($p=0.025$ to <0.0001). The correlation between mobile and non-mobile imaging was -0.29 ($p=0.003$) in the emergency setting, while no correlation was observed in the inpatient setting (Spearman correlation coefficient 0.044, $p=0.656$). Figure 6 highlights the weekly paediatric X-ray mobile and non-mobile imaging volumes.

DISCUSSION

We found a reduction in imaging volume of between 2% and 30% across all adult patient classes, and 10% and 37% in adult imaging volumes by modality during the first wave of the pandemic. Nuclear Medicine was the modality most impacted, and angiography the least impacted. While time periods analysed may differ slightly, the findings for adult imaging volumes were less than those reported in Germany of (41%, all modalities)^[14], New York (14% to 53%)^[15], California, Florida, Michigan, Massachusetts and New York (40% to 70%)^[16], and Ohio (53%)^[17]. During the second wave of the pandemic, all adult radiology modalities reported a reduction of between 2% and 32% in imaging volumes, and a reduction of between 9% and 24% in imaging volumes across all patient classes. Adult computed tomography imaging volumes experienced a 2% increase. Nuclear medicine was the modality most impacted. This is less than the data obtained from Medicare reported by Sreedharan *et al*^[12] who found that general radiography and ultrasound were most impacted, while computed tomography and nuclear medicine services were less affected. It was unclear whether paediatric data was included in their analysis^[12].

Similarly, during the first wave of the pandemic, there was a reduction in paediatric imaging volumes of between 19% and 48% across all modalities except for angiography reporting a 50% increase in imaging volume. There was a reduction of between 4% and 46% across all paediatric patient classes. Nuclear Medicine was the modality most impacted, with ultrasound was least impacted. While paediatric emergency patient presentations decreased by 25% in one Sydney health service, we observed a larger decrease in paediatric imaging service utilisation, both in the emergency department and inpatient settings^[18].

During the second wave of the pandemic, there was a reduction of between 5% and 37% in paediatric modality cases, and a reduction of between 16% and 28% across paediatric patient classes. Nuclear Medicine was most impacted, while magnetic resonance imaging was least affected.

Decline in adult services (2% IP, 30% OP, 26% ED) were generally less to those reported by Naidich *et al* (ED (27%), OP (57%), IP (14%))^[15,19]. Furthermore, outpatient services

reported in South Africa (40% over six months)^[5]. outpatient imaging (58%, 72%)^[14,17], inpatient imaging (41%, 43%)^[14, 17], and emergency department imaging (39%, 49%)^[14, 17] in Ohio and Berlin highlighted greater declines in demands than we observed. Australia utilised the experience of other nations in preparation for COVID-19. For example, Australia reduced elective medical procedures in line with other countries, implemented PPE measures, social distancing, and stay at home measures for non-essential workers^[5]. We found most of our outpatient imaging services were severely impacted (19 – 50% loss in imaging volume) by new social distancing and appropriate cleaning measures. Inpatient services were also affected by the decline in elective surgeries while emergency patient volume reduced due to more people isolating at home.

From July to September 2020, Australia experienced the pandemic's second wave. This was most prevalent in Victoria. The government implemented border closures, curfews, limiting movement to a five kilometre radius, working from home for non-essential workers, business and education closures, wearing masks indoors and outdoors, and physical distancing measures to reduce COVID-19 cases^[5]. During this phase of the pandemic, we observed a minor reduction in patient volume across all modalities at our institution compared to the first wave's impact. This could be due to health services becoming better equipped, informed and organised to manage pandemic outbreaks^[5]; earlier diagnosis of COVID-19 *via* more rigorous PCR testing^[5,20]; patients were better informed about the risks of contracting COVID-19, thus more likely to seek medical care. Earlier in the pandemic, it had been reported patients were afraid to come to the hospital, potentially compromising their health^[21,22].

Angiography

Our angiography statistics represented interventional radiology procedures performed in the angiography suite primarily guided by fluoroscopy or ultrasound. Like other modalities, the angiography suite was substantially impacted in outpatient volume when the Department of Health and Human Services ruled that only Category 1 patients could attend. In April and August 2020, there was a decrease in inpatient

studies. However, recovery in this patient class was swift, with patient volume surpassing pre-COVID attendances. Patients delayed procedures during the first wave of COVID-19 for fear of contracting the virus while in hospital.^[7] This led to an increase in unplanned hospital admissions with patients requiring procedures, leading to increased service demand. Some patients may have also been scheduled to relieve burgeoning waitlist times.

BMD

UK BMD wait lists increased during the pandemic, resulting in treatment delays for osteoporosis^[23]. We observed the same relative reduction in imaging volumes during the first and second waves of the pandemic, likely determined by clinic closures^[24], use of telehealth to minimise hospital visits^[5], staff redeployment^[25], or delaying medical treatment^[26].

CT

CT was one of the modalities least impacted by new policies and guidelines implemented during the pandemic. This is not surprising given the importance of CTPA for early contribution to patient diagnosis^[5]. While early in the pandemic, CT was the modality of choice for assisting in COVID-19 diagnosis^[5], this changed due to the high radiation doses and availability of PCR testing^[5]. While there was a reduction in CT demand during the peak waves of the pandemic, we observed an increase in CT utilisation during the second wave of the pandemic, consistent with other reports^[27]. During the pandemic, outpatient CT studies for malignancy staging were delayed based on criteria set by senior management due to the risk of cross-contamination between inpatients and outpatients. Access to an independent CT scanner within the hospital at an onsite research facility improved workflow for this patient cohort. During the pandemic, elderly Victorians in aged care were dying from the virus as transmission rates among staff members in certain aged care facilities increased. The government intervened by placing aged care residents into Victorian hospitals as a safety measure for our most vulnerable. The increase in inpatient CT scans during this period can likely be attributed to this mandate.

Fluoroscopy

Many non-clinically urgent fluoroscopy studies, such as barium swallows for outpatient studies, were placed on hold or rescheduled during the pandemic. Following Victoria's second wave, there was a resurgence of patient bookings from October 2020. The end of September 2020 marked the easing of stage 4 restrictions, with COVID-19 infections decreasing significantly. Thus outpatient and inpatient bookings were rescheduled over the coming months to cope with demand. A significant change in imaging volume was observed between June and July, with a below-average patient number in July (Figure S2). This can be likely attributed to the similar timing of outbreaks in COVID-19 at aged care centres, prompting a move by the Victorian government to move aged care residents to hospitals to prevent further COVID-19 related deaths.

General Radiography

While adult general X-ray was particularly impacted during the pandemic's first wave, likely due to the cancellation of elective surgery and outpatient clinics, less impact was observed during the second wave. Conversely, paediatric general X-ray imaging volumes were significantly reduced throughout both pandemic waves. During 2020, the utilisation of mobile imaging saw significant growth. This can be attributed to workflow changes such as infection control measures to reduce patient movement^[28]. Senior management purchased extra mobile imaging systems to manage the increased demand, which also contributed to the changes observed. Other imaging protocol modifications to reduce risk of contracting COVID-19, such as imaging through glass were performed, however not used routinely at our institution^[8]. Utilisation of mobile imaging more than doubled during the peak of the pandemic at our institution, particularly in the emergency setting. This is comparable with the findings of others. Surveyed Western Australian medical imaging professionals perceived an increase in mobile chest imaging, particularly in the public hospital setting^[29], while in Singapore there was a three-fold increase in emergency department mobile imaging usage^[30]. Although mobile imaging utilisation increased, there was little change in radiographer reported doses^[31]. There was a small shift in imaging regions other than the chest (data

not shown)^[31]. We also observed, that when adult mobile imaging increased in the emergency setting, fixed X-ray imaging decreased. This was likely to reduce transmission risk^[32], and manage potential increased demand^[8]. The greatest impact on adult mobile imaging usage was observed during the pandemic's second wave when risk of cold and influenza is heightened (July - September 2020)^[33].

MRI

We observed appreciable declines due to work practice changes implemented in adult and paediatric MRI services (Figure S2 and S4) during the pandemic contributed to long waiting lists across our network. Elective general anaesthetic cases were placed "on hold" as per Victorian Government recommendations, and aerosol-generating procedure (AGP) policies to allow room resting and cleaning that extended the total examination time particularly impacted paediatric services^[3,34,35].

Mammography

As with other imaging modalities, our mammography service also experienced a reduction in imaging volumes during the first and second waves of the pandemic. This is consistent with other findings, though to a lesser extent in our health service^[15,36,37]. In Australia, breast screening services were temporarily suspended, with services reopening based upon government recommendations. Similarly, changes in workflow required stricter patient management protocols, and cleaning protocols to minimise transmission risk^[28,37,38].

Nuclear medicine

We found nuclear medicine, then mammography were the modalities most impacted by the pandemic and consistent with the findings of others^[15,16,36,37]. This could, in part be due to logistical changes to isotope supply. During March to July, and October to November 2020, there were significant issues with isotope transportation locally and overseas, particularly during the first wave of the pandemic. Due to unforeseen mechanical problems at the Australian Nuclear Science and Technology Organisation (ANSTO) manufacturing site, there were also supply interruptions. These included a broken conveyer belt, storm causing electrical faults, production failure, isotope

refinement and contamination issues. Other challenges included scheduled reactor shutdown, with difficulty in alternate isotope sourcing to meet demand. These interruptions could have contributed to the significant changes observed.

Ultrasound

At our institution, ultrasound was less impacted than other modalities, which is consistent with other experiences^[16,19]. However, data reported from Germany found ultrasound was the most significantly affected imaging modality, though not all modalities were included in their analysis^[14]. Ultrasound services were significantly transformed in the early weeks of the outbreak, with expansion of ambulatory centres to provide 'clean' sites. In the main hospital centres, there was a substantive need for mobile ultrasound examination both in ED and in the wards. In the lead up to the pandemic, we observed a decrease in ED patients. ED patient imaging volume stabilised during the pandemic, with some growth observed. The reason for this surge was thought to be multi-factorial. There seemed to be a tendency for patients to attend an ED rather than their local GP. It was also thought that patients' examinations were initially delayed, and the surge compensated for this. There was no obvious change in the referral patterns for the types of examinations requested. Anecdotally, point of care ultrasound (PoCUS) examinations decreased across this period. This seemed to be related to clinicians minimising patient contact, and a decision to suspend PoCUS training.

Inpatient services overall increased but there were small reductions in patient volumes during the first and second waves. While other services reported some value for use of lung ultrasound^[10], this was not used in evaluating COVID-19 positive patients at our institution. Consistent with the other modalities, we did see a decrease in outpatient attendances, which returned relatively quickly. This is likely due to outpatient clinic closures, halting of non-essential ultrasound intervention, and patients choosing to delay their scan. As with other modalities, ultrasound was less impacted during the second wave. Obstetric cases throughout this period were deemed an essential service and did not change. Sonographers were activated to perform blood pressures as part of

a third trimester pathway as many women were seen *via* telehealth. The Early Pregnancy Bleeding pathway and clinic were also relocated to ultrasound. Small changes were made to scan protocols. Targeted scans were introduced for high risk patients. Timing of paediatric hip screening was adjusted to minimise the risk of repeat examinations.

Paediatrics

Overall, there was a decrease of approximately 55% from April to October 2020 compared to 2019. Recovery of paediatric imaging, particularly after the second wave (September to December 2020) was more rapid, coinciding with the gradual reduction in Melbourne's COVID-19 case numbers and the subsequent easing of restrictions. Many patients and families deferred non-urgent imaging during the lockdown. Moreover, lockdown, home-schooling and suspension of group sports, further reduced paediatric cases from sporting injuries^[39]. We did observe a slight increase in some services such as MRI during 2020 despite COVID-19 disruption, as services returned to pre-COVID-19 demand (Figures S3 and S4). This was due to the new software and hardware upgrade in February 2020, reducing the total scan time, potentially increasing patient throughput while providing additional time for cleaning. As observed with adult modality data, following lockdowns in April and July-September 2020 and elective surgery deferral, there was a dramatic decrease in paediatric imaging across all modalities, except for angiography (very small imaging volume). Recovery was observed between the first and second waves, however, it did not reach the pre-COVID-19 Levels. We also observed an increase in mobile usage in emergency to help reduce the transmission risk.

Study Limitations

While our health service cared for the first Australian COVID-19 patient, other health services across Melbourne, particularly in the north and west, experienced higher caseloads. Consequently, these health services may have experienced greater declines in radiology services than we observed across our health service. Our institution purchased additional mobile X-ray units in preparation for the pandemic, contributing

to the significantly increased use. Of note, the MRI software and hardware upgrades did not significantly increase the imaging volume, however, they did provide additional time for practise changes such as improved infection control measures. Nuclear medicine experienced even greater challenges during the pandemic, due to unforeseen interruptions to isotope supplies as a confounding variable. This required additional patient rescheduling, often at short notice. Given data was analysed between 2019 and 2020, there may be some underlying baseline year to year variability contributing to the findings. Timeframes defining COVID-19 may vary worldwide making data comparison somewhat difficult.

This work represents of one large Victorian health service, however it may not be generalisable to other health services.

Lessons learned:

1. Once in a lifetime events such as a global pandemic can have a significant impact upon workflow across imaging modalities, with the need to implement new processes.
2. Our experience during the pandemic was not the same as those experiences described by other nations due to the variation in severity.
3. Modalities across our health network were impacted differently due to changes in service demands, closures of outpatient clinics, and rescheduling of elective surgeries.

CONCLUSION

Collected data provides an evidence-based insight into changing imaging volume related to COVID-19. This information will allow the network to predict the dynamic demands in imaging more accurately and promptly adapt its policies. We found adult CT, angiography and ultrasound recovery following the first and second waves of the pandemic recovered faster than nuclear medicine, BMD and MRI. Paediatric MRI and ultrasound recovered faster than nuclear medicine and general radiography following the first and second waves of the pandemic. Modalities were less impacted during the second wave (July - September 2020), than during the first wave (April 2020), except angiography outpatients. At our health network, nuclear medicine was the imaging

modality most impacted by COVID-19 in both the adult and paediatric settings. There may have been other factors, however impacting these results. Adult CT imaging increased during the second wave, while paediatric ultrasound was the least affected. Radiology departments can minimise the impact of future COVID-19/public health outbreaks on imaging volumes by ensuring each modality is appropriately resourced to continue providing safe and patient-centred care.

ARTICLE HIGHLIGHTS

Research background

Medical imaging modalities worldwide were significantly impacted by the COVID-19 pandemic, however each countries' experience differed. This study provides an in-depth analysis of the impact to adult, paediatric, inpatient, outpatient, emergency and mobile services across both the first and second waves of the COVID-19 pandemic in a large public health network in Victoria, Australia.

Research motivation

This work provides evidence for managing and redeploying resources during "once in a lifetime" events such as a pandemic, and the duration of impact. Using this work modeling and forecasting of anticipated changes to imaging demand can be performed, allowing optimal utilisation of departmental staffing to manage workloads.

Research objectives

The objectives were to identify adult and paediatric imaging volume changes, including mobile imaging across a large Victorian public hospital network. We realised our objectives, and the findings highlighted significant differences across the modalities analysed. Future research could monitor the long term impacts of such events, such as staff burnout or opportunities for additional training to address deficiencies identified.

Research methods

Use of statistical methods in data analysis highlighted the modalities, patient classes and differences between adult and paediatric imaging. Particularly, methods to identify any correlation between mobile and non-mobile imaging volumes was novel.

Research results

We identified the greatest impact occurred in Nuclear Medicine during both the first and second waves, with all modalities less affected during the second wave, Other modalities such as CT were less impacted, requiring greater resources to manage service demand. We observed a shift in regions imaged using mobile imaging. It would be important to understand the impact of this in terms of image quality, workflow and patient radiation dose.

Research conclusions

Medical imaging modality services across a large Victorian public health network were significantly affected during the COVID-19 pandemic, however the impact to different modalities varied relative to studies performed in other countries. It is important to have a broad perspective of the impact to each imaging modality in both the adult and paediatric context to help better address the need for workflow changes. It is important to consider whether imaging services are inversely correlated, to also address optimal departmental resourcing.

Research perspectives

Future research could further investigate the long term impact of lockdowns and the pandemic on imaging modality volumes and their recovery. This can help inform future budgeting requirements, need for additional equipment and staffing to manage continuous workflow demands.

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