Radiology Resilience Now and Beyond

Report from the Canadian Radiology Resilience Taskforce

Canadian Association of Radiologists
L'Association canadienne des radiologistes

October 5, 2020

Executive Summary

The COVID-19 pandemic has profoundly affected patient access to the healthcare system in Canada. The impact of the pandemic raises questions about the resiliency and ability of the health system to continue "to protect, promote and restore the physical and mental well-being of residents of Canada and to facilitate reasonable access to health services" per the Canada Health Act.[1] *At the onset of the pandemic, many jurisdictions postponed non-urgent care due to concerns about the spread of COVID-19, surge capacity, and hospitals being overrun with SARS-CoV-2 cases. The disruption to health care services affected diagnostic imaging examinations, tests, and procedures. Though decisions about postponement and deferral of care were based on the best available evidence, we have experienced a steep rise in wait times and a large backlog of patient studies needing to be rescheduled.* **Obtaining a clear picture of the extent of the disruption and drop in imaging volumes is challenging, due to the variability of data collection and the lack of adherence and reference to standardized benchmarks for wait times across Canada.**

Building Resilience, Ensuring a More Sustainable Future

The radiology community in Canada responded to the disruption caused by COVID-19 with a strong, agile response as it endeavoured to adapt to volatile, uncertain, complex, and ambiguous circumstances, while ensuring the continuity of high-quality patient care to the greatest extent possible. Through this experience, ***the radiology community worked to build resilience and foster the ability to recover after a challenging or traumatic event and emerge stronger on the other side****. As the pandemic continues the radiology community has collectively accumulated many lessons learned in responding to the challenge while best serving patients. There are numerous stories of courage and leadership in uncertain times gathered through surveys by the Canadian Association of Radiologists as well as the Canadian Association of Medical Radiation Technologists. Patients have been affected by deferral of imaging studies and lengthening wait lists; solutions are needed to ensure a sustainable system so that Canadians can access quality, safe, appropriate care.*

The Radiology Resilience Report

This report, which is the culmination of research, surveys, and data analysis on the part of the Canadian Radiology Resilience Task Force, explores the ways that radiology has been affected by the circumstances created by COVID-19, while providing a perspective on how some of the adaptations necessitated by those circumstances can be harnessed and re-tooled to incite lasting, positive change to medical imaging care in Canada. It includes four sections:

1. Lessons Learned from COVID-19 and its Effect on Radiology Services in Canada
2. The Status of Radiology Services in Canada
3. Recovery, Improvement, Optimization
4. Re-Imagining Radiology for the Future

Examining a System Under Pressure

Much like the way radiologists analyze a patient's images, accounting for prior findings while working to identify abnormalities and areas of concern before making a diagnosis and recommendation for treatment or follow-up, this report examines a system under immense pressure, and makes recommendations for recovery, improvement, and renewal of that system. It takes a patient-oriented, industrial view of radiology. It examines the resources required to produce a diagnostic imaging report for a patient: human resources, capital equipment, information technology. The pressures on all resources were and remain severe. Burnout is an ongoing issue for radiologists and technologists. Aging equipment is being overtaxed, and technological platforms are being pushed to their limits.

Relative Volume Decrease in MRI and CT Volume due to COVID-19 Slowdown, Feb-Jun 2020

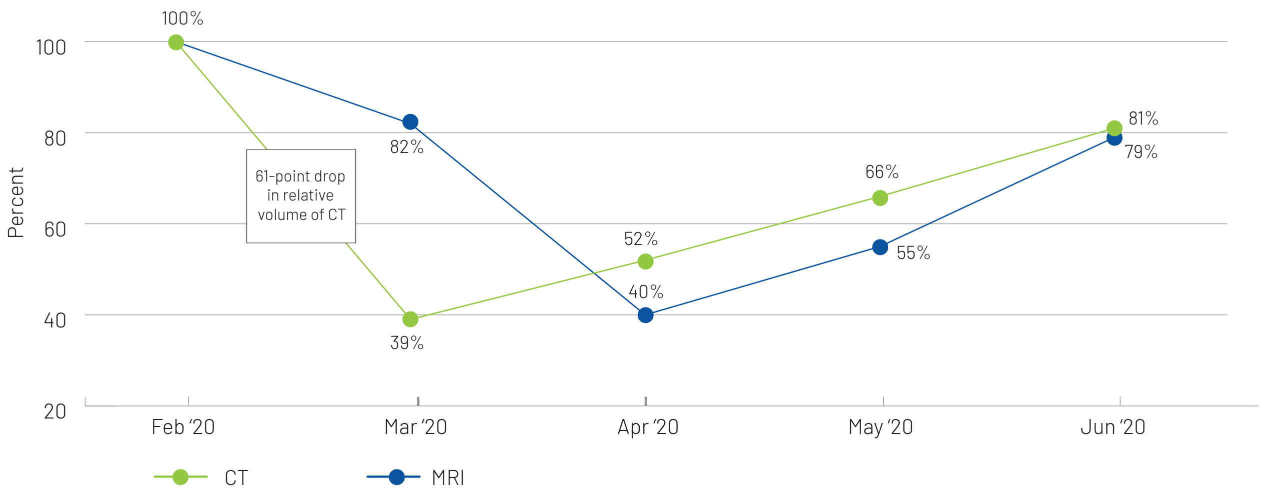


***Figure 1**: Percentage of CT and MRI volume as relative to February 2020 immediately prior to the COVID-19 induced slowdown.*

Source: CAR Wait Time Data Survey, June 2020-Aug 2020, [Appendix A – Data Sources]

Preparing for a New Normal

COVID-19 will prompt long-term, structural change to the delivery of radiology services in Canada. In order to support a more sustainable radiology community, build resilience, and improve patient care, we need a thorough assessment of how COVID-19 has affected capacity, where we are today, and where we might go in the future. While the system did work through the pandemic, it was less than ideal. In addition to the human and capital resources required to create a more sustainable system, there needs to be enhanced training and management to be better able to respond to a second wave, another pandemic or other stress on the system. This report takes stock of the adaptations made in departments, clinics, and hospitals across Canada, and makes strong recommendations about improvements to the delivery of radiology services to achieve balance between optimizing patient care, ensuring resilience, and supporting medical imaging team members. The COVID-19 pandemic has highlighted the strength of the radiology community, while identifying areas that require improvement and investment to prepare for the future.

Table of Contents

Canadian Radiology Resilience Task Force Membership

Heidi Schmidt, MD, FRCPC
Task Force Chair

Department Head Medical Imaging and Program Medical Director, Joint Department of Medical Imaging (JDMI)
University Health Network, Sinai Health, Women's College Hospital
Professor of Radiology, University of Toronto
Chief and Medical Imaging Program Medical Director, Health Sciences North, Sudbury ON
Radiology Quality Lead, High Risk Lung Cancer Screening | Cancer Care Ontario

Bill Anderson, BSc, MD, FRCPC, DABR
Provincial Medical Director Diagnostic Imaging for Alberta Health Services (AHS)

Thor Bjarnason, BEng, MASc, PhD, MCCPM
Chair, Imaging Committee, COMP

Gregory Butler, MD, FRCPC
Assistant Professor, Department of Diagnostic Radiology, Dalhousie University

Tara Chegwin
Manager, Professional Practice, Sonography Canada

Carole Dennie, MD, FRCPC
Head of Cardiac and Thoracic Imaging, Professor of Radiology, University of Ottawa,

Clinician Investigator, Ottawa Hospital Research Institute,

President, Canadian Society of Thoracic Radiology

Magalie Dubé, MD, ABR
President, Clinique Radiologie Gatineau and Clinique Radiologie Aylmer

Darren Ferguson, MD, FRCPC
Department of Diagnostic Imaging, Saint John Regional Hospital

Mark Given
Director, Professional Practice, CAMRT

Alison Harris, MD, FRCPC
Clinical Professor of Radiology, University of British Columbia

Division Head for Abdominal Imaging, Vancouver General Hospital

Past President, BC Radiological Society

Casey Hurrell, PhD
Manager of Research and Policy Development, Canadian Association of Radiologists

Ania Kielar, MD, FRCPC
Associate Professor, University of Toronto, Deputy Chief JDMI, Quality and Practice Improvement

Emil Lee, MD, FRCPC
Department of Radiology, Valley Medical Imaging, Langley, British Columbia, Canada;

Department of Medical Imaging, Fraser Health Authority

Andra Morrison, BSc ACLIP
Canadian Medical Imaging Inventory Lead, CADTH

Amol Mujoomdar, MD, FRCPC
Division Head for Interventional Radiology, LHSC/SJHC, Associate Professor Radiology and Oncology, Western University,

President, Canadian Association for Interventional Radiology

Nick Neuheimer, CAE, MSc
CEO, Canadian Association of Radiologists

Angela Pickles, MD, FRCPC
Clinical Assistant Professor of Radiology, Regional Clinical Chief, Diagnostic Imaging Program, Eastern Health

Lisa Pyke, MA, RTR, RTMR
Manager Implementation Support, Eastern Canada,

Knowledge Mobilization and Liaison Officer Program, CADTH

Jean Seely, MD, FRCPC
Head of Breast Imaging, Professor of Radiology, University of Ottawa, Clinician Investigator Ottawa Hospital Research Institute

Regional Breast Imaging Lead, Ontario Breast Screening Program,

President, Canadian Society of Breast Imaging

Gilles Soulez, MD, MSc, FRCPC, FSIR
Professor of Radiology, Université de Montréal

Director of the Laboratory of Clinical Imaging Processing, CHUM Research Center

An Tang, MD, MSc, FRCPC
Full Clinical Professor, Radiology Department, Université de Montréal

Micheline Turnau, MSc
Manager of Research and Affiliates, Canadian Association of Radiologists

Marc Venturi, MHA
Manager of Accreditation and Quality Improvement, Canadian Association of Radiologists

Sheldon Wiebe, MD, MSc, FRCPC
Department of Medical Imaging, University of Saskatchewan

Laura Zychla
Manager, Professional Practice, CAMRT

Health Canada participated in the capacity of a health system knowledge user. The Task Force also included international consultation and participation from the United Kingdom, Netherlands, and Germany.

Key Messages

1. ***Radiology is adaptable*** *in the face of adversity, due to the integrity of all staff and their ongoing commitment to patient care.*

2. *COVID-19 led to a* ***significant drop in imaging volumes from March to May 2020*** *for all modalities. A late resurgence of imaging throughput was observed in June, but overall throughput remains at a level of roughly 80% of baseline volume.*

3. ***More robust and timely data is needed****. The absence of a national database and standardized reporting of imaging wait times is a major barrier to evidence-based policy decisions regarding system investment. The data compiled for this report overrepresents the experience of large tertiary care centres due to reporting patterns, skews the overall picture.*

4. ***Additional patients will not receive care in an appropriate timeframe****. While progress is being made in addressing the backlog of patients not seen during the postponement of care during COVID-19, many patients waiting for non-critical imaging may not undergo imaging or procedures this year due to radiology capacity constraints.*

5. ***Equipment procurement and investment in infrastructure must be data-driven*** *and prioritized based on accurate metrics related to imaging volume and throughput. Investing in equipment in clinical settings outside the hospital is especially important to prepare for future outbreaks which may limit access to hospital-based imaging.*

6. ***More investment is needed for health human resources****. Additional technologists and support staff are needed to maintain the operational efficiency of radiology departments. Existing capital equipment could meet the urgent demand for imaging in many jurisdictions, but is dependent on adequate staffing.*

7. ***Strong communications are key*** *for optimal functioning of medical imaging care teams; strong multidisciplinary communications between radiologists, referring physicians, and other specialists enhance patient care and improve operational efficiency. Open lines of communication between radiology departments, hospital administration, and health authorities can also facilitate resilience in times of crisis and disruption.*

8. ***Eliminating redundancy in imaging orders and improving coordination*** *between hospitals and clinics would help to tackle existing imaging backlogs and lay the foundation for a more efficient system.*

9. ***Improvements to the patient experience are possible*** *if meaningful adjustments are made to our current referral and operational models.*

10. ***The future of radiology in Canada is optimistic****, particularly if we harness technology to streamline service delivery, improve workflows, and increase patient engagement in the continuum of care.*

Context and background

COVID-19 has caused disruptions to virtually every facet of our lives. Radiology practices and medical imaging departments across Canada are facing the challenge of resuming services under the "new normal" with little data or historical precedent. **The economic recovery is going to take an indeterminate amount of time**,[2] and it is unlikely that there will be new funding made available for healthcare beyond emergency measures. Other aspects of medicine are also vying for limited resources.[3] **Radiology services are often a central aspect of the patient journey**, and the existing backlog of imaging requisitions has been exacerbated in a multitude of ways by the pandemic. Radiology can again take a leadership role in the COVID-19 recovery by optimizing service delivery while focusing on the patient experience.

In response to the COVID-19 pandemic, the Canadian Association of Radiologists (CAR) established a Canadian Radiology Resilience Task Force. The Task Force examined wait time data for medical imaging and surveyed the current challenges facing radiology departments, with the intent to make recommendations about how to build resilience in the face of disruption. **For radiology, resilience means the ability to recover quickly from difficulties and disruptions** – COVID-19 for now, and from whatever may arise in the future [**Appendix A – Data Sources**]. Resilience also requires capacity and flexibility within the health system to adapt to shifting demands.

We cannot improve what we do not measure. There is a dearth of real data to understand and track imaging volume and demand in Canada, within and across jurisdictions. After the shuttering of the Wait Time Alliance, responsibility for collecting and tracking wait time data for priority procedures in Canada fell to CIHI. Unfortunately, CIHI does not have an established benchmark for medical imaging wait times, and data is not being collected for all provinces and territories.[4] The COVID-19 pandemic is a complex global public health crisis presenting clinical, organisational and system-wide challenges. The complexities of pandemic recovery make it even more essential to track and analyze data to inform system modelling and decision-making.[5]

The Task Force is building on the CAR's Radiology Resumption of Clinical Services report, which focused on providing guidance for radiology groups to safely resume medical imaging services in Canada.[6] By providing a national picture on the state of medical imaging along with a thorough review of best practices, we intend to examine whether our existing healthcare system, physical resources and human resources, can resolve the backlog in medical imaging , or whether additional resources are needed to meet patient need.

Abbreviations and Definitions

AI: *Artificial intelligence*

COVID-19: *Coronavirus Disease of 2019*

CADTH: *Canadian Agency for Drugs and Technology in Health*

CAIR: *Canadian Association of Interventional Radiologists*

CAMRT: *Canadian Association of Medical Radiation Technologists*

CANM: *Canadian Association of Nuclear Medicine*

CAR: *Canadian Association of Radiologists*

CIHI: *Canadian Institute for Health Information*

CMII: *Canadian Medical Imaging Inventory*

COMP: *Canadian Organization of Medical Physicists*

CT: *Computed tomography*

FIFO: *First-In-First-Out*

HCP: *Healthcare Professional*

IHF: *Independent Health Facility*

MRI: *Magnetic resonance imaging*

PET-CT: *positron emission tomography–computed tomography*

PM: *Preventative Maintenance*

PPE: *Personal Protective Equipment*

SARS-CoV-2: *Severe Acute Respiratory Syndrome Coronavirus 2*

US: *Ultrasound*

Technologists: *MRTs and Sonographers*

Section 1: The Lessons of the COVID-19 Pandemic and its Effect on Radiology Service Delivery Across Canada

Data Assumptions and Limitations

To better understand the impact of the pandemic on wait times, we surveyed Canadian radiology administrative directors in provinces having a centralized inventory of wait lists. For provinces without a centralized inventory the survey was addressed directly to administrative directors of imaging departments for a specific region or hospital. We collected data for the following modalities: CT, MRI, ultrasound (US), and mammography [**Appendix A – Data Sources**]. We opted to not include the mammography data as it seemed weighted toward high priority level patients and did not provide an accurate representation on the status of mammography in Canada.

An additional assumption is that the relative values which we apply to all of Canada may be weighted towards centres which provided data – likely larger tertiary care centres. Larger hospitals have higher volumes of critical (P1) and urgent (P2) studies while having lower levels of non-urgent (P3 and P4) studies. For MRI and CT, which are more likely to take place in tertiary care settings, the data we compiled gives an accurate representation of the Canadian radiology landscape. For ultrasound, however, the available data may not provide a completely accurate picture. Like mammography, most ultrasound studies conducted in Canada are done in smaller imaging centres and Independent health facilities (IHFs). Smaller centres and IHFs are less likely to report their volumes, and more likely to have experienced disproportionate decreases in volume of non-critical imaging during the slowdown. Moreover, smaller centres have fewer staff to enhance coverage during the ramping up of services.

CIHI reports annually on CT and MRI scan wait times but this does not include the priority classification system with priority definitions and does not include benchmark data.[4] Several provinces do report publicly on imaging wait times, but the data is not standardized to allow comparison in a national dashboard. Other provinces do not report imaging wait times publicly and the data can only be obtained by approaching each institution. This lack of data is a major hurdle to examining the true picture of this important issue for the health of the Canadians. Moreover, not all provinces are using the standardized medical imaging wait time benchmarks recommended by the CAR.[7] Pan-Canadian medical imaging wait time benchmarks are necessary to create a national dashboard and methodology which can be used to "support and promote equitable access to imaging based on medical need, regardless of geographic challenges."[7]

Impact of COVID-19 on the Wait Times for Radiology Services

During the COVID-19 crisis, according to surveys administered by the CAR and CAMRT (March 11-April 30), overall radiology service output dropped between 50-70% and mammography dropped by over 90%.[6] This service disruption worsened existing wait lists for imaging services, including cancer screening. Many radiology departments, in collaboration with referring physicians, have revisited their wait lists to re-prioritize imaging requisitions to ensure the most urgent requisitions namely Priority 1 (P1) (same day – maximum 24 hours) and P2 (maximum 7 calendar days) were processed within the acceptable benchmarks.[7] This reallocation had a significant impact on less-urgent imaging, namely P3 examinations (maximum 30 calendar days) and P4 examinations (maximum 60 calendar days). The prioritization levels and benchmarks P1-P4 are those recommended by the CAR and are not the same for every province.[7] These discrepancies are a serious issue and undermine our collective ability to make evidence-based recommendations for improvements to the healthcare system.

Radiology departments across Canada have reorganized their workflows to ramp up productivity by adapting bookings and extending operational hours, despite increased turnaround times due to disinfection and physical distancing protocols. Imaging requisitions for non-urgent examinations decreased during the pandemic, due to disruption of patient visits with primary care providers and other referring physicians. Radiology departments must now prepare for a return to the pre-pandemic volume of imaging requisitions while preserving patient and staff safety and need to catch up from significant delays accumulated during the outbreak until now.

Relative Imaging Volumes (March-June 2020)

We collected provincial data on the number of examinations from the following provinces (AB, SK, MB, ON, PEI) and regional data from QC. We then examined the relative imaging volumes of CT, MRI, and ultrasound (US) for February-June 2020 relative to February 2020, immediately prior to the COVID-19 induced slowdown [**Figure 2**]. We observed a significant drop in the relative volumes for all imaging modalities, which is in line with the published literature on the impact of COVID-19 on radiology in other nations.[8-10] The lower throughput was observed in March or April depending on the modality. The lowest throughput ranged between 39% for CT, 40% for MRI, and 62% for ultrasound. The steeper decline in CT volume is likely explained by virtue of CT being a higher throughput modality than either ultrasound or MRI. The additional protocols put in place to safely turn around CT suites would have a relatively disproportionate effect on patient throughput. In addition, CT suites have purposely been reserved for COVID-19 related patients.

Relative Volume Decrease in MRI, CT and Ultrasound Volume due to COVID-19 Slowdown, Feb–Jun 2020

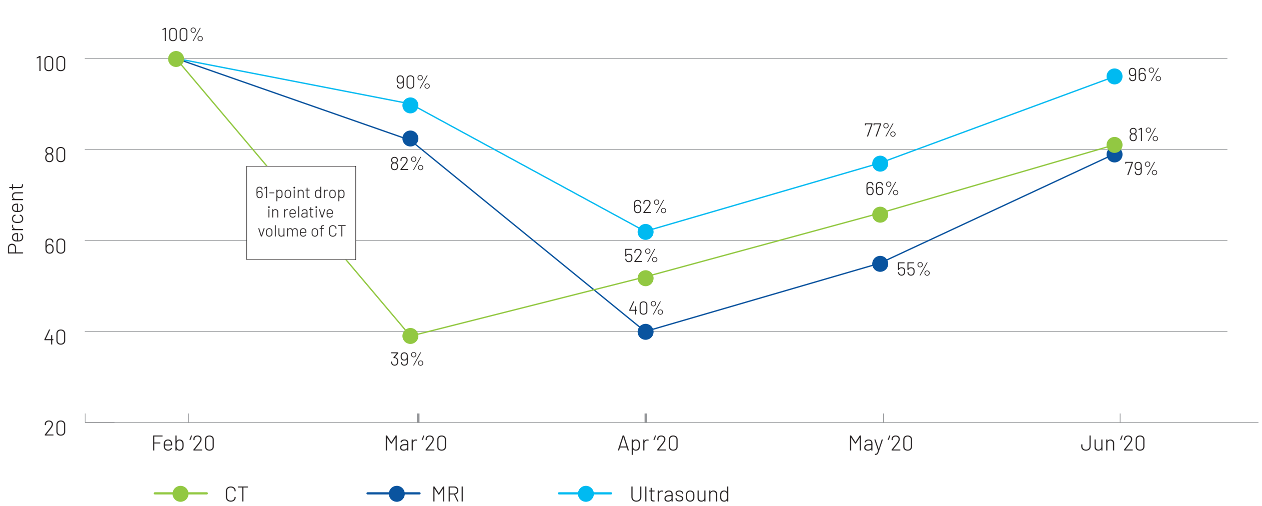


***Figure 2**: Percentage of CT (green), MRI (navy) and Ultrasound (blue) volume as relative to February 2020 immediately prior to the COVID-19 induced slowdown. For a complete explanation of the data and the limitations of what data was available for this analysis, see* Data Assumptions and Limitations *and* Relative Imaging Volumes *above.*

Source: CAR Wait Time Data Survey, June 2020-Aug 2020 [Appendix A – Data Sources]

Relative (to Feb) Referral Volumes for CT, MRI and Ultrasound (2020)

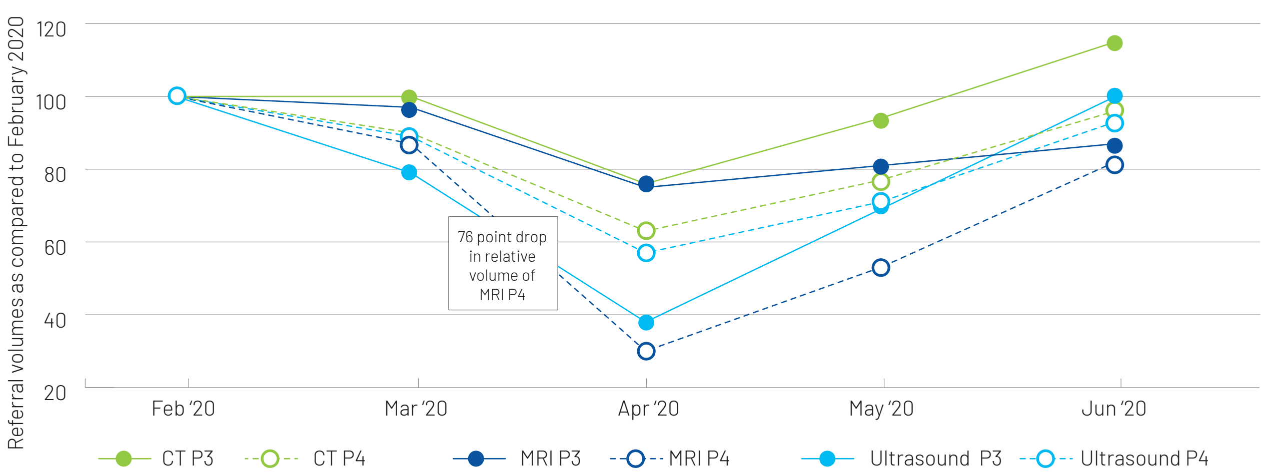


***Figure 3**: Percentage of referrals between February and June 2020 relative to January 2020 broken down by CT (green) P3 and P4 categories, MRI (navy) P3 and P4 categories and Ultrasound (blue) P3 and P4 categories.*

Source: CAR Wait Time Data Survey, June 2020-Aug 2020 [Appendix A – Data Sources]

We observed a significant increase of throughput for each modality in June when compared with the spring (March-May). The resumption of services to 81% of baseline activities for CT, 79% for MRI and 96% of US is a testament to the resilience of radiology services across the country. An August 2020 survey of radiologists indicated broad agreement with these data points, with over 50% of respondents reporting that their volumes had returned to 80-100% of pre-COVID levels.[11] Similarly, a CAMRT survey indicated that services are largely back to pre-COVID levels at the time of this writing.[12] Based on this data, we can assume that many centers are back to pre-COVID volumes. However, these volumes are being achieved by increasing utilization – extending hours, adding shifts, improving process – and may not be sustainable. Other facilities are operating at approximately 70-80% of pre-COVID capacity due to increased cleaning requirements and lack of ability to increase utilization.

Relative Referrals

The slowdown in healthcare affected all aspects of medicine including primary care. As the primary source of medical imaging referrals, we observed a decrease in referrals during March-May of 2020. **Figure 3** explores the decrease in referrals for CT, MRI and US. We can see a particularly dramatic decrease in US referrals, which can be partially explained as US being a high-contact modality under circumstances when strict physical distancing measures are necessary. The health of Canadians has likely not changed dramatically during these months; therefore, we would expect a demand for CT, MRI, and US to surpass January and February 2020 demand over the coming months (if not already). Already, CT referrals in June of 2020 are at 115% relative to February of 2020.

Returning to normal ?

We examined the number of patients scanned and the number of requisitions at a provincial and/or regional level for several provinces. By examining the number of patients being scanned relative to the number of requisitions per month, we can determine the percentage of demand being met. **Figure 4** shows the relative percentage of patients assigned to P3 and P4 categories being CT scanned. This plot demonstrates a serious issue. If the demand for CT scans was the same as the supply the result would be a flat line at 100%. Ultimately, P3 volumes are trending in a positive direction, while P4 requisitions are not being addressed within appropriate timeframes, if at all. What this means is that for every 100 requisitions that are submitted as P4, we have capacity for about 25 of them. In fact, there is zero (0) capacity for new P4 scans because of the waitlists that existed before COVID-19.

Patients being scanned – MRI

The same trend can be observed for MRI, though not to the same degree as CT [**Figure 5**]. This discrepancy may be explained by the fact that MRI has a lower throughput and is less affected by disinfection and distancing protocols than CT. In other words, slowing down already slow MRIs does not affect throughput much. Additionally, the disturbing trend for P4 MRI is that there is effectively no progress being made to meet demand and close the gap on imaging referrals vs. capacity.

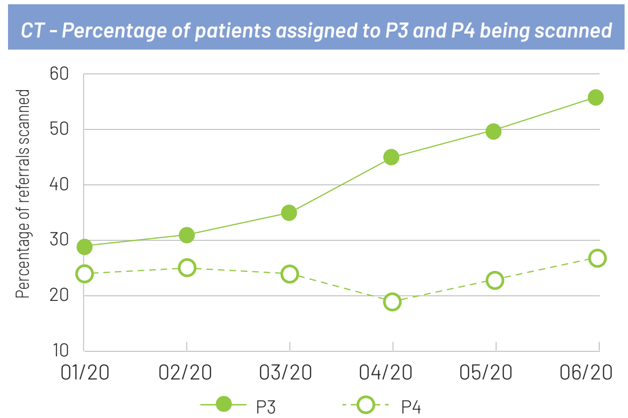


Figure 4: *CT scans as a percentage of referrals for P3 and P4s (dotted)*

Patients being scanned – Ultrasound

The trend with ultrasound is doubly concerning as there is no improvement for patients waiting for non-critical imaging studies (P3, P4). Further, the referral values we included are the actual reduced referrals [**Figure 6**]. If there is an increase in demand as we would expect, US services do not have the capacity to provide for patients needs. This figure can be partially explained because like CT, US is a high-throughput modality with a close contact between the staff and patients, and therefore more prone to decreases in throughput necessitated by disinfection and social distancing protocols.

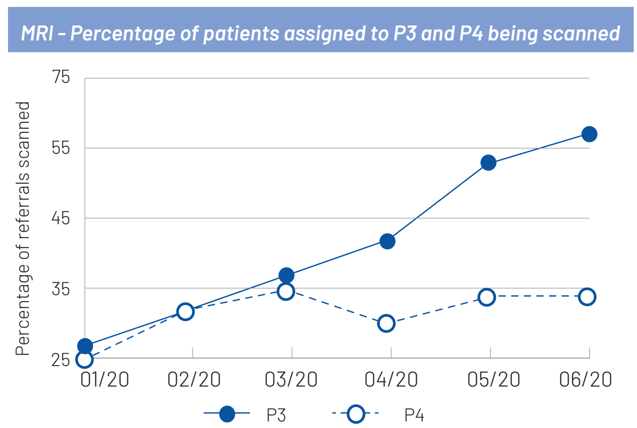


Figure 5: *MRI scans as a percentage of referrals for P3 and P4s (dotted)*

Patients being scanned – Mammography

We opted to not include mammography data as it overrepresented tertiary care facilities, which primarily perform diagnostic rather than screening mammography. Screening mammography was halted for a period of several months. We felt that the data would not sufficiently represent the true situation Canadians face. Mammography screening was suspended from March 2020 with gradual resumption beginning around June in most provinces.[13] A recent modelling study based out of the UK predicts over 3000 additional deaths due to delays in diagnosis in the UK. Correcting for the differences in population size between the UK and Canada we arrive at between 1856 to 2042 additional deaths due to delays in diagnosis in Canada. Specific to mammography between 9 and 9.6%, or almost 200, of those deaths will be due to breast cancer.[14,15]

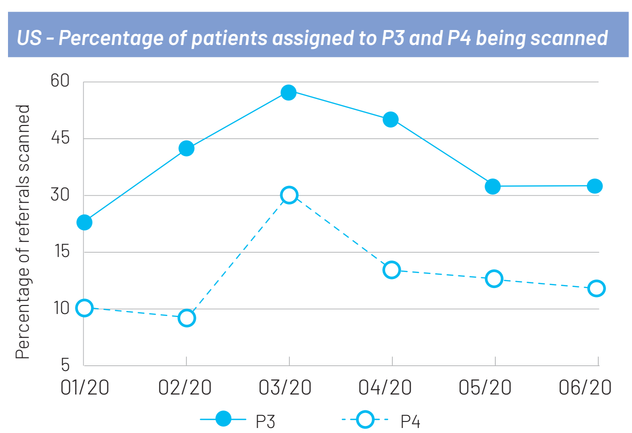


Figure 6: *CT scans as a percentage of referrals for P3 and P4s (dotted)*

Source: CAR Wait Time Data Survey, June 2020-Aug 2020
[Appendix A – Data Sources]

Patients Will Wait

We attempted to analyse wait time data; however, we could not do so in a generalised Canadian context for the following two reasons. One, wait time data is not available for every province or jurisdiction and two, the provinces that do have wait time data utilize different benchmarks. We know that benchmarks can drive behaviour; therefore, comparing wait times based on different benchmarks provides little value.

Examining CT and MRI volumes since 2007, we can see a steady increase in volume [**Figure 7**]. The only exception is the recent decrease in CT volume in 2019 which can be explained by the decommissioning of several end of life CT systems. Consistently, demand for imaging has outpaced supply even with demand being relatively predictable.

Prior to COVID-19, wait times for CT and MRI exceeded recognized standards in most provinces, particularly for patients assigned to priority levels P3 and P4. We know that patients assigned to P3 have a chance of getting a scan in the near term if we can increase utilization of the current capacity in the system. By September 2020, patients designated as P4 during and prior to the pandemic are effectively being ignored by the majority of CT and MRI centers. We asked ourselves why there is any throughput on P4s when there is still such a reduced capacity on P3s. The reason is that medical imaging is not evenly distributed across the country. Some radiology centres have been able to resume to effectively normal operations and perhaps beyond, while others struggle to meet demand. The decrease in non-urgent studies created availability for urgent imaging studies. In the early days of the pandemic, patients in need of critical or urgent imaging were seen without delay.

COVID-19 led to a significant drop in medical imaging examinations from March to June 2020. We observed a late resurgence of imaging throughput in June, but the overall level remained below 80% of pre-COVID activities. The important drop in requisitions during the same period helped to maintain the gap between requisitions and examinations performed at a similar level to before COVID-19. However, we can observe a widening of this gap and anticipate an increasingly difficult situation when general referral patterns resume to pre-pandemic levels. We have new volume data indicating growing wait lists for non-urgent patients (P3, P4) across modalities [**Figures 4-6**]. Modalities with high throughput (US and CT) are more problematic, as there is a greater gap to overcome.

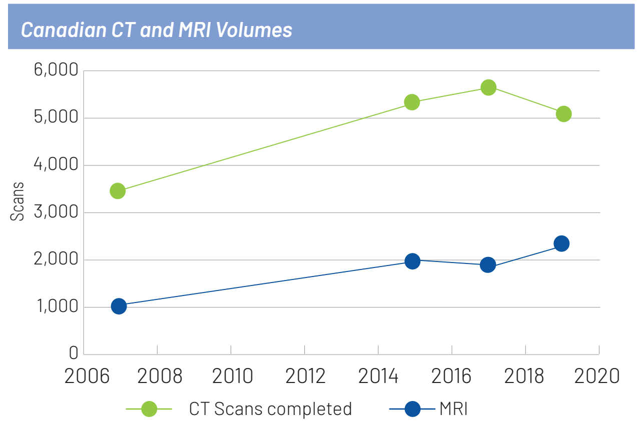


***Figure 7**: CT and MRI imaging volume from 2007, 2015, 2017 and 2019.*
Source: CMII 2020 [Appendix A – Data Sources]

When Will We Close the Gap?

Though demand for imaging decreased between March and June of 2020, the number of Canadians who have a health condition that necessitates getting a scan has not changed. This means demand will likely return to pre-COVID levels over time, and likely surpass pre-COVID demand to make up for the current decrease. Determining how far behind in imaging demand we are requires a few assumptions due to the lack of available data.

Using linear extrapolation, we can determine expected demand for CT and MRI into 2022, along with an assumed gradual return to pre-COVID utilization. In so doing, we can get an idea of the backlog created by the COVID-19 slowdown [**Figure 8**]. Between March and June, there were approximately 275,00 MRI and 615,000 CT exams missing. Putting our most optimistic assumption forward as to how quickly CT and MRI services can recover, the total difference between the expected provision of CT and MRI and what is missing accounts for 1,440,000 CT and 612,000 MRI scans between March 2020 and Dec 1, 2022.

Comments from the National and International Radiology Directors Survey

"It seems we may have scaled back non-essential exams too much, further increasing wait lists. Now that appropriate safety measures are in place, we do not anticipate future reductions unless required due to staff shortages."

"We had to significantly increase the time slots in order to successfully complete the same number of exams as during the pre-COVID period. The main issue remains the recruitment of staff (technologists and support staff) which remains a challenge, making it difficult to meet all needs and the extended working hours"

"Ultrasound wait lists are so enormous that they are not even manageable."

Expected and actual CT and MRI Volume

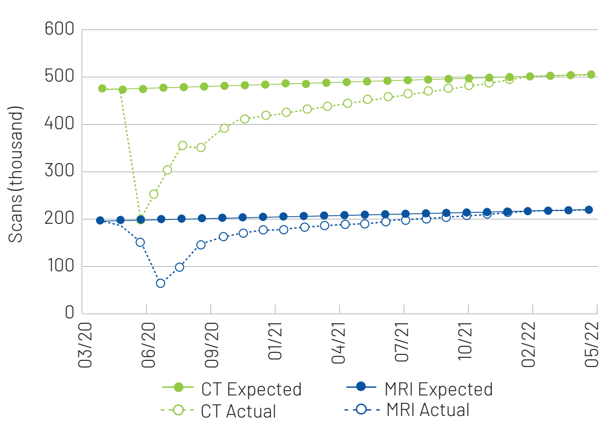


Figure 8*: Linear extrapolation of expected CT (blue) and MRI (green) volume month over month Canada wide. Estimated actual volumes of CT (dashed blue) and MRI (dashed green) between January 2020 and June 2020 along with assumed recovery profile ending in 2022.*

Source: Composite of CMII 2020, linear extrapolation, relative volume [Appendix A – Data Sources]

We can conclude that patients assigned to P1 and P2 prioritization levels are being seen in a timely manner. Patients in P3 and P4 are less fortunate (depending on where they live), and some have little hope of getting their scans done in a timely manner.

The average Canadian CT in 2017 performed 7,689 scans, but there is uneven distribution across Canada. Some provinces achieved utilization of 13,210 scans/CT while others were as low as 2000 scans/CT.[16] We do not have CT-specific volumes, leading to additional possible discrepancies in utilization. Flattening distribution across Canada is impossible: a CT in the Yukon will be used at a lower capacity than one in downtown Toronto. We know that a CT operating at maximum efficiency 24 hours a day will have a throughput of approximately 9000 scans/year. Averaging the total number of CT scans per year in Canada by the number of scanners yields approximately 5000 scans/year - highlighting that not all systems are operating to their maximum potential, though some are.

MRI is one of the slowest modalities to operate, and as a result is often operated 24hrs a day to attempt to meet demand. As such the most recent data provided by CADTH shows 6163 scans/MRI in Canada.[16] With the return to pre-pandemic levels of throughput for CT and MRI [**Figure 8**], every scanner in Canada will have to make up for approximately 2624 scans/CT and 1625 scans/MRI by 2022, based on the discrepancy between expected volume and recovery-level volume. CT and MRI volumes are not evenly distributed across the country, which means some areas will be able to recover more quickly than others.

We do not know the full extent of the backlog for ultrasound services. **Figure 6** provides the best reference point for the dire lack of ultrasound capacity. If operations continue status quo, we collectively could address the backlog of CT exams by increasing utilization. To provide necessary care to all MRI patients waiting, and who will be waiting, the only option is to increase capacity and utilization – more scanners and people to run them. Perhaps most concerningis facilities which are operating past 100% of pre-COVID levels. Without an increase in the number of technologists and equipment there is a real potential for staff burnout in radiology.

Impact of COVID-19 on Medical Imaging Equipment and Supplies

Adequate Supply of Personal Protective Equipment

Personal Protective Equipment (PPE) is vital for radiologists, radiographers, technologists, sonographers, and other frontline healthcare professionals, as they can help minimize the likelihood of infection. A shortage of PPE was reported globally at the beginning of the pandemic given the high demand.[17] In Canada, access to PPE was a concern in the early stages of COVID-19 and there were reports of supply limitations.[18,19] Additionally, there were frequent changes with PPE protocols, and conflicts between institutional protocols and public health guidance.

One study on Canadian Interventional Radiology Services found that most respondents had adequate access to PPE. However, for those in centers where there was a shortage of PPE, shortages were identified as an area in urgent need of solutions.[20] A survey of CAMRT members also found concern about the lack of PPE provided to technologist staff.[12] Although 64% of the staff reported they had adequate access to PPE, of those who felt they did not have adequate access, 61% felt they did not have the same access to PPE as other frontline healthcare workers within the facility or institution. The situation was particularly hazardous for technologists who are in direct contact with patients, and who cannot adhere to social distancing protocols by virtue of their job requirements. Moreover, some technologists may see up to 40 patients in a day and bring mobile services to several hospital areas within a single shift, thereby elevating their personal risk in the absence of adequate PPE.

Nuclear medicine experienced delays due to disruptions in the shipment of radioisotope supplies.[17] This was highlighted in the CAMRT survey that found that there were issues with the airlines delivering the supplies.[12] The radiology directors survey [**Appendix B**] also found that 48% experienced delays with nuclear medicine imaging (e.g. PET-CT Scans). The main issues identified included shipping and social distancing protocols.

Disruptions to Radiology Procedures

"Adjustment of regular flight schedules and overall reduction of flights locally led to multiple disruptions in our local generator availability. This, along with the challenges associated with social distancing impacted our MIBI studies due to the amount of radioactivity required and length of studies. Social distancing also impacted the daily volume of patients that we have been able to serve in PET-CT as well."

- *Respondent to CAR National and International Radiology Resilience Survey on COVID-19* ***[Appendix B – Aug 2020]***

Physical space and utilization modifications

As imaging requisitions increased with the lifting of COVID-19 restrictions, radiology departments modified their physical environments and found ways to increase capacity. Radiology departments also needed to re-organize their facilities and staff in order to enhance safety and minimize the risks of infection.[17] 83% of radiology directors said they made significant physical space or utilization modifications to their institutions due to COVID-19 [**Appendix B**]. The leading modifications included installing physical barriers, enhanced use of mobile X-ray systems, dividing areas to accommodate the different categories of patients via dedicated entrances, passages and waiting rooms. Other innovative modifications included creating a new booking template to provide more social distancing between appointments, setting up dedicated community access sites for COVID-19 imaging and implementation of readings outside of normal hours to better control traffic.

Modifications being taken to reduce COVID-19 risks

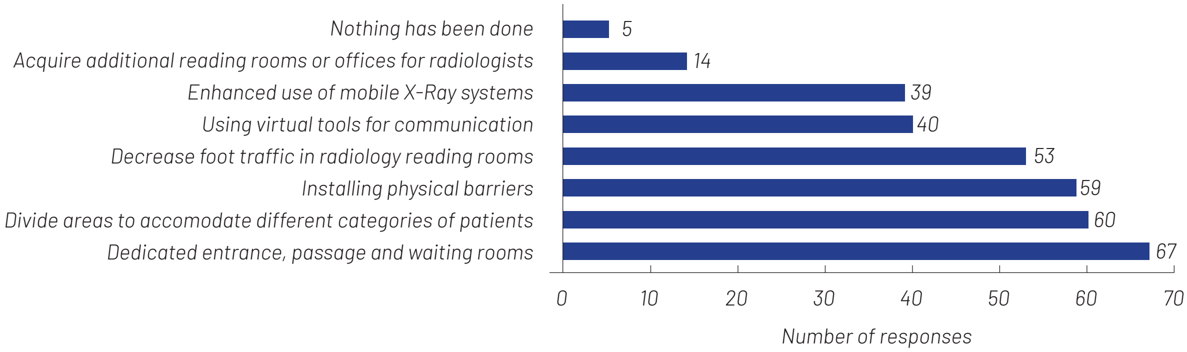


***Figure 9**: Leading schedule and/or workflow modifications to drive safe patient throughput.*

Source: CAR National and International Radiology Resilience Survey [Appendix C]

Responsiveness on Safety, Scheduling and Workflow

Radiology departments remained flexible and responsive when considering how to reorganize their scheduling and workflow due to COVID-19. New work processes and protocols most often included changing scheduling templates to allow more time per imaging exam, facilitating a greater number of exams, and extending the hours of staff and imaging equipment [**Figure 9**]. The triage, categorization, and segregation of patients of varying risks also continues to be an operational necessity.[21] Many imaging departments also received additional funds for specific COVID-19 related expenditures. The additional budgets were used mostly for personal protective equipment, imaging equipment, physical distancing measures and to support cleaning protocols.[11]

COVID-19 Guidelines

After the outbreak of the COVID-19 pandemic, many professional bodies and professional societies were responsive by issuing official guidelines on how medical imaging should optimally be performed for early diagnosis and related management of these patients, but also how staff should be protected from cross-infection.[17] The Canadian Association of Radiologists, Canadian Association of Interventional Radiologists, Canadian Society of Breast Imaging, and Canadian Society of Thoracic Radiology and Sonography Canada all published guidelines for performing procedures on patients with suspected or confirmed SARS-CoV-2.[22–24] These guidelines were created to safely care for SARS-CoV-2 patients while minimizing the risk to non-SARS-CoV-2 patients and healthcare professionals. These guidelines proved helpful to the directors and leadership of radiology departments and private clinics, but some contradictions between the documents led to confusion at times.

Section 2: Status of Radiology Services in Canada

The effect of the COVID-19 pandemic on radiology workplaces was immediate. The following section of this report provides an update on the status of radiology services in Canada, from the perspective of the radiologists, technologists, and staff that are involved in the day-to-day operations of those departments and clinics. Their perspectives add additional colour to the data points in the preceding section, providing a clearer picture of where radiology stands at this point in the COVID-19 experience, looking both backward and forward.

Radiology is Resilient

In response to the pandemic, new policies decreased foot traffic in reading rooms by encouraging remote interpretation from home or other sites. The literature shows that departments across North American enacted similar policies to improve capacity for remote interpretation while reducing the possibility for exposure.[25,26] Some sites instated protocols to allow for imaging through glass for SARS-CoV-2-positive patients, in the interest of protecting the health and safety of staff.[27] Medical imaging teams proved flexible and resourceful in their adaptation to new working conditions, or in the event that there were technological challenges (e.g. inadequate bandwidth or workstations to support remote reading of CT and MRI studies). Ultimately, 80% of health authorities facilitated remote work.[11] Radiologists can provide immense value from off-site locations if necessary and adapted quickly to new schedules and remote reporting. It was equally important that technologists and staff moved quickly to adjust workflows, manage bookings, and meet requirements for PPE, physical distancing, and additional equipment cleaning.

Status Update on Health Human Resources

During the first phase of the pandemic, 67% of radiology departments re-tasked or hired additional staff to adapt to the COVID-19 specific workflow requirements.[11] Technologists, administrative and infection control/cleaning staff were most acutely needed in the departments surveyed. Current capacity is constrained by the availability of highly skilled technologists to perform ultrasound, CT and MRI examinations, a reality which will be explored further in the next section of the report.

The COVID-19 pandemic has substantially impacted the work of technologists and sonographers. Practice has changed significantly due to modifications to the work environment (e.g., protocols associated with waiting rooms, change rooms, and patient interactions), the additional cleaning required between patients, and the requirement to wear personal protective equipment at all times. Through discussions with membership, CAMRT has identified anecdotal evidence which suggests that some facilities are extending hours to compensate for patient throughput.

In some departments, staff were cohorted to prevent the spread of infection in the case of an outbreak. A CAMRT survey in April 2020 found that the pandemic had decreased the number of FTE and casual staff positions within facilities, and that there were no concrete plans to return staffing to pre-pandemic levels. Privately funded facilities were much more likely to decrease staff compared to other funding models.[12] This discrepancy may be caused by concerns regarding the health and safety of staff, and that private clinics generally manage P3 and P4 examinations, which were almost entirely postponed by the pandemic.

> ***"We needed to have better communication between the community hospitals and local clinics. I had to reach out to the hospital department heads to see what they were going to be offering, what they would like to off load out of the hospital (e.g. ob ultrasound). There was no coordination about who was cutting back which services, and how we could work together to prioritize/organize the work. By making the effort to call them and set this up, we each had a manageable role and could keep the clinics open and working at a reduced level. We also worked with the family health teams to stay in the loop and keep them up to date on what they could order and where. This should be standard in a health crisis in a "1st world" health care system- Why did we have to organize this? Why is that not set up through the regional or local health authorities? There could be an app for that!"***
>
> - *Respondent to CAR Resumption and Resilience of Radiology Membership Survey* ***[Appendix C]***

Communication and Coordination

Radiologists are an integral part of patient care. At times, they are required on-site, while at other times remote reading is appropriate. Ensuring that radiologists can work remotely is key to building resilience in the system and increases the availability of radiologists. Remote reading is more than interpreting imaging studies from afar, lines of communication must exist between the radiologists and the care team on site. Creating this capacity will ensure that even in a crisis a local radiologist who knows the local context will be able to provide quality care.

Clear communication to corporate or institutional managers, radiology staff, referring physicians, and other consulting specialists has been highlighted to improve staff cohesion and the ability to cope with the added pressure created by the pandemic.[28] In some jurisdictions, poor communication within departments and between hospitals and clinics led to an uncoordinated approach to service delivery, which hindered resilience and recovery overall.

Better coordination between hospitals and clinics providing imaging could lead to targeted prioritization of which exams are best scheduled for which sites, even in instances where there are service reductions due to outbreaks. There is an opportunity to eliminate redundancy (e.g. patients who have multiple tests ordered independently by multiple care providers) by creating a central scheduling system for all imaging orders, and ensuring that all Canadians have a truly universal electronic health care record that is accessible across jurisdictions.

Within departments, clear lines of communication within interdisciplinary care teams proved essential to maintaining morale and quality care during the first phase of the pandemic. The protection and psychological support for nurses, doctors and all frontline staff is extremely important given the ongoing pandemic.[29] As one survey respondent observed: "Keeping up morale is the key to success as the strain of the situation is ongoing and taking a toll on staff mental health." Another respondent remarked that: "I was still surprised at the level of fear and anxiety among all levels of staff. I believe part of the anxiety was the constant changing of policies and practices in the ever-evolving COVID world and I believe staff were looking for stability more than anything."

Targeted Investment Is Essential

Targeted investment in human health resources, especially to increase the number of technologists and clerical staff, would result in an immediate benefit for the system's ability to tackle the backlog of cases. As mentioned above, investment will be required to address the backlog of patients, particularly those with referrals for non-urgent imaging (P3, P4). The concern of this task force is how many of these patients will transition into a higher level of priority requiring significantly more resources? Or will they suffer needlessly due to a lack of a diagnosis? From an economic perspective, The Conference Board of Canada determined that excessive wait times for radiology services cost the Canadian economy $3.54 billion in lost productivity in 2017,[30] a figure that has undoubtedly been exacerbated by the additional impact of the COVID-19 pandemic.

Current operations are not sufficient to address the backlog of imaging requisitions that predates the COVID-19 induced shutdown. Prior to the pandemic, departments struggled to meet demand for imaging on equipment that needed frequent repairs and downtime for servicing. Replacing older equipment will permit more rapid recovery and enhance the ability of radiology departments to ramp up capacity.

Millions of dollars of health spending were deferred by postponing imaging exams and other health services during the first phase of the pandemic; it needs to invest that money strategically, use existing equipment more effectively, procure additional equipment to replace aging units, and to hire and retain more highly-trained technologists. Even prior to the pandemic, the Canadian radiology sector was ill-equipped to meet patient demand for imaging; replacement costs to modernize Canada's medical imaging equipment are $4.4 billion between now and 2040.[30]

Radiology is most effective when it has updated, functional equipment. Efficacy and efficiency contribute to radiology resilience, and the ability to recover ground lost during COVID-19. The "Golden Rules" for medical imaging equipment replacement and maintenance are clear: at least 60% of installed equipment should be less than five years old, no more than 30% of the installed equipment base should be between six and ten years old, and no more than 10% of the age profile should be more than ten years old.[31] Canadian radiologists are using equipment that is mostly (66%) over five years old, a fact which also runs counter to the Canadian guidelines for equipment replacement and lifecycle maintenance.[32] It is worth highlighting that 27% of equipment in the radiology sector is 11 years old or more [**Figure 10**]. For patient care, this is concerning because older equipment does not function with the latest technological advances creating the potential for inferior diagnostic testing, and machines that are more prone to failure and downtime for repairs. Beyond being faster, requiring less service and increasing image quality, newer medical imaging equipment utilizes less radiation than older equipment. Best estimates show a reduction in radiation exposure of 10-30% for a new system over one that is 5 years old.[33]

Unfortunately, capital equipment procurement is often reliant on the benevolence of foundations and ad hoc sources of funding. A stable source of funding for medical imaging equipment, paired with a data-driven strategy for the installation of that equipment in jurisdictions that need it most would be of huge benefit as Canada recovers from the pandemic and prepares for the future.

Canada's Aging Medical Imaging Fleet

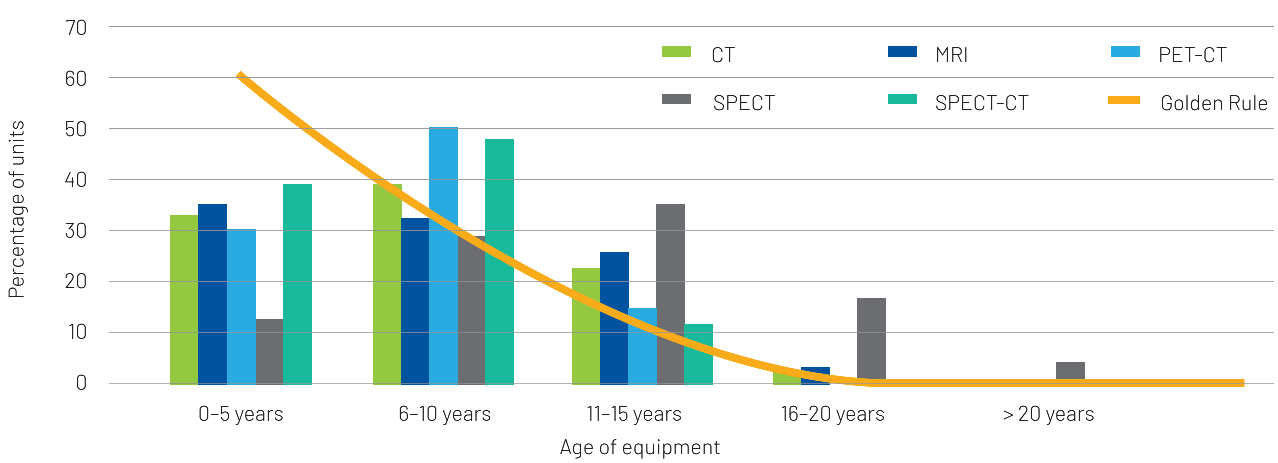


***Figure 10**: Canada's Aging Medical Imaging Fleet. Number of pieces of CT, MRI, PET-CT, SPECT, SPECT-CT by age of the equipment.*

Source: Conference Board of Canada, Value of Radiology Report, Part II (2019).

Radiology Perspectives on the Pandemic from the CAR Survey

1

On adapting to change:
"Remote reading, teaching and virtual meetings does not mean that radiologists are not engaged in active patient care, teaching and effective consultation. These can be just as effective as being on site. Radiologists can provide value from a remote location if necessary although a core group needs to remain in hospital to support our technologists and perform procedures. We can adapt to change and are extremely resilient."

2

On universal health records:
"Patients have multiple tests ordered independently by multiple health care providers leading to redundancy – the lack of coordinated health care and knowledge of what tests have already been done has been highlighted by the current sense of urgency due to the delay and increased wait times caused by the COVID pandemic – a more universal health record would help resolve some of these issues and I feel would lead to decreased wait lists."

3

On inappropriate referrals and need for CDS:
"I often have the impression or the sense that I am doing tests that patients have requested themselves, which their physician did not know how to refuse, that are inappropriate."

4

On balancing safety concerns with operational realities:
"I think it was not the best strategy to ramp down so much at the start of COVID, better pandemic preparedness plans should have been in place to allow continued operations to the maximum possible as we are now doing. Routine work levels should be more in lock step with COVID resource demands rather than trying to anticipate possible upticks due to the pandemic."

5

On balancing administrative responsibilities with clinical work:
"I work within a university setting group practice. Up until a month ago, a few radiologists in leadership roles worked very hard from an administrative point of view to manage the group (schedule, safety etc.). These radiologists were under daily atypical duress making decisions that in some cases were beyond their skill set etc. In future pandemics, radiologists in these roles should form identifiable working groups and focus primarily on the administrative requirements during a pandemic and step back from the clinical work temporarily as, in my experience, it was nearly impossible to juggle both without making errors. These radiologists need support from each other and the group as a whole."

Status of Radiology in Canada in Fall 2020

Table 1: Overview of Strengths, Weaknesses, Opportunities, and Threats for Medical Imaging during COVID-19

	Helpful	Harmful
Internal	**Strengths** • Resourcefulness of radiology groups • Ability of radiologists to adapt to remote reporting • Rapid adoption of infection control measures and safety protocols • Ability to analyse and rectify any air exchange limitations throughout departments, particularly in rooms/areas that require rapid air turnover rates	**Weaknesses** • Mindset and inertia of leadership/administration in some instances • Inflexible health human resource management for supporting staff including technologists • Lack of PPE, or fears about perceived lack of PPE • Paucity of negative pressure rooms in many departments • Existing backlog of non-urgent imaging studies (P3, P4) for all modalities made deferral of cases even more challenging • Available staff, especially highly skilled technologists to perform US, CT, and MRI, remains a limiting factor to catching up
External	**Opportunities** • Investment in human health resources to use existing equipment more efficiently and for longer hours • Capital equipment procurement is required in many of the provinces and territories • Jurisdictions are actively pursuing and implementing appropriateness criteria to reduce unnecessary backlog cases and prioritize resources • Better coordination between hospitals and clinics would lead to more strategic use of resources • Proactive communication with patients and the public can ensure that patients know they can come in for urgent care, even during a pandemic or other crisis[34]	**Threats** • Lack of a coherent national strategy for equipment purchasing • Without supplements to budgets, ramping up services will be very slow, and the backlog may never be fully addressed • Screening programs were severely affected due to the postponement of non-urgent imaging this had a major effect on patient care and mental health

Section 3: Recovery, Improvement, and Optimization of Radiology in Canada After COVID-19

Radiology departments and clinics were challenged by the COVID-19 pandemic and have also risen to the occasion by adapting workflows and working to meet the demand for imaging amid evolving circumstances. Collective action is necessary to drive process improvement, and must include referring physicians, radiologists, administrators, hospital leadership, radiology staff, scheduling, nursing, and transport. There are myriad models to follow; every clinic, institution, and health region needs to determine which method will work best for its unique circumstances. Ultimately, process improvement is about changing a culture, it is not a singular event or flipped switch.

Given the anticipated increase in demand for imaging, existing strain on radiology departments from a variety of metrics, the following section of this report provides guidance for how radiology departments and clinics can improve service times without sacrificing quality. Radiologists, technologists, administrators, and policymakers have a stake in continuous quality improvement that is perpetually focused on patient care and outcomes.

Tackling Wait Lists by Optimizing Performance

Data on the performance of radiology services focuses largely on the time it takes patients to access their scan (wait time to be scanned or waiting for results). Within an individual facility assessing their capacity and utilization, different metrics will be utilized at the equipment and FTE level. The details of radiology operations are complex and are rarely fully examined by senior hospital leadership. The lack of equipment capacity becomes an easy explanation for all problems facing radiology.[35] Increasing demand for CT and MRI compels expansion of radiology departments and calls to procure more equipment. We know that capacity in radiology does need to increase, and that building additional equipment capacity into the system will help build a more resilient radiology system. However, equipment procurement and renewal are a single, cost-prohibitive, medium/long-term solution to an immediate problem. Improving and optimizing other metrics that can improve patient throughput can decrease wait times and drive capacity improvements now.

Measuring Capacity and Determining Throughput

Determining the true capacity of radiology departments and clinics to meet demand for imaging at current and future levels is essential. Radiology capacity is defined by the number of scanners and availability of people to run them, along with the availability of radiologists to read, interpret, and report on the resulting images. We do not have granular enough information to determine precise capacity of the radiology sector because variables such as access override other data points. As discussed in the first section, it appears as though staffing is a limiting factor in terms of CT utilization and likely a large contributor towards optimal MRI utilization. Barring an increase in CT, MRI, and ultrasound capacity, the only way to increase throughput with staff being a limiting factor is to decrease the length of time that it takes to scan a single patient.

MRI category	One technologist	Two technologists
Neuroradiology	1.54	1.8
Abdominal	1.16	1.4
Musculoskeletal	1.46	1.48
Breast	1.48	1.9
Cardiac	0.73	0.87
Vascular	1.6	1.67
Breast biopsy	—	0.8

Table 1: *Average number of patients treated per hour, adapted from Bentayeb et al. 2020*

There are a variety of methods to determine the throughput of a medical imaging system. Accurate local data including availability of staff, scanners, exam time, scheduling blocks, and utilization is the best way to determine capacity and throughput. Adding to the complexity of utilization, a CT or MRI scanner can be operated by a single technologist, but two are required for certain procedures. Moreover, having two technologists assigned to a single imaging system can speed up room turn around time – one technologist can clean, while the other prepares or discharges the patient.[36] By the same logic, bringing in more staff to assist and clean can speed up turnaround time by freeing up technologists to do the skilled, patient-oriented work that they are trained for.

Optimizing Block Scheduling Frameworks

Imaging volumes in Canada have consistently outpaced staffing and imaging system purchasing – leading to wait times. Technologists are consistently trying to meet the combined expectations of patients, management, and radiologists. Joffe et al (2007) said it best: "Why would the staff members support additional growth, when the choice that they perceive is either delivering the highest quality of service to all of their constituents, which they want to do, or becoming overburdened supporting higher volumes?"[35] What motivation is there for the medical imaging community to increase utilization and potentially overwork themselves?

The obvious answer to the criticism of staff productivity metrics is to move towards measurement of throughput on a broader scale. Achieving the lowest possible turnaround time and throughput can have the unintended effect of lowering quality. A better approach is to use metrics that work for radiology staff and the patient population in a balance, considering the perspective of all stakeholders. There are a variety of methods to increase throughput while maintaining quality of care: some facilities have implemented CT coordinators,[37] applied systems engineering practices to reduce patient transport times,[38] and applied a variety of operational practices such as LEAN or Six Sigma.[39–41] All of these have to some degree been effective at local levels, but have not been scaled and spread to the health systems within regional health networks and beyond. These processes are about prompting a culture change, which is essential to create lasting system-wide improvements for real system improvements.

Staffing and the Burnout Factor

Optimization of our current imaging capacity will mean scanning more patients per year without increasing the amount of available equipment. Obviously, completing more scans will require additional human resources (staff, technologists, nursing, cleaning, radiologists), and will necessitate appropriate investment in those resources. The 2020 CAR Survey on the Resumption and Resilience of Radiology Services found that 75% of respondents felt that additional technologists are required to address the current backlog of requisitions [**Figure 11**]. According to CIHI in 2018 there were a total of 25,033 technologists across Canada in all MRT disciplines including radiation therapy. Of that number, only a small percentage perform CT and MRIs (respectively, estimated at 15% and 10%).[42] As CT and MRI examinations are in high demand, most of these scanners are being operated at maximum staff capacity, with units operating beyond traditional model at (from 12 to 24 hours daily). Looking ahead in the pandemic, adding to technologists' and sonographers; current workloads will have significant physical and psychological affects on a workforce already being challenged before the onset of COVID-19 pandemic.

In theory, it is possible to optimize our existing capacity through improved scheduling. Scheduling and exam time are the most easily adjusted variables in the equation. However, increased scheduling density and intensity can lead very rapidly to burnout of staff, technologists, and radiologists. Radiology is already a specialty at a high-risk of burnout, due to heavy workloads and the ceaseless demand for medical imaging.[43-51]

A 2018 mental health study conducted for technologists and sonographers found high levels of emotional exhaustion, in additional to other indicators of burnout. Specifically, 42% of Sonography Canada's membership and 36% of CAMRT's membership had surpassed this critical threshold of emotional exhaustion, as defined by the Maslach Burnout Inventory.[51,52] In response to this data, these organizations have recognized the mental health needs of their memberships and started to work towards national initiatives to support their professionals in the workplace. The pandemic has added another layer of psychological effects on the workforce that is not well understood to date, but evidence is emerging to show the increased burden on health professionals.[53]

Increasing the number of technologists will have several benefits including reduced wait times, reduced burden on existing staff, and more flexibility in the staffing. Additional infection prevention and control (cleaning) staff were also identified as priorities, as were additional administrative staff. In cases where technologists are pulled into infection control or administrative roles and away from patient care, staffing challenges are magnified. It is essential that departments and institutions be aware of how assigned responsibilities align with the goal of effective patient care. Metrics and data should be collected to capture time spent on patient care vs. administrative vs. other duties, so that quality improvements can be data driven. It should be noted that initiatives aimed at quality assurance and quality improvement should be considered patient care not administrative – within reason.

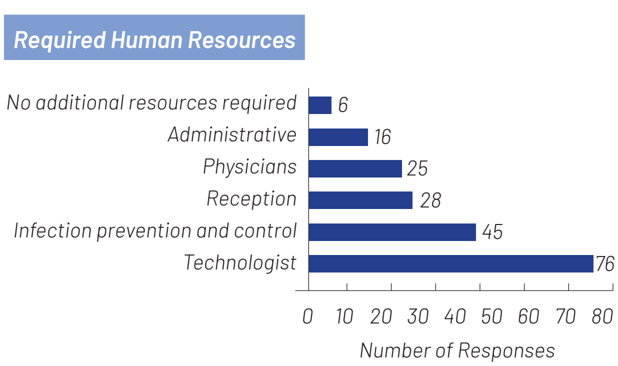


***Figure 11**: Additional human resources required to meet demand and address backlog of imaging requests*

Source: CAR Resumption and Resilience of Radiology Membership Survey [Appendix C]

Collectively, we need to recognize the true threat of working staff until they are overburdened for the sake of improving productivity metrics. As valued medical professionals, the collective wellbeing of an imaging care team will directly translate into patient wellbeing. The prospect of working professionals until they "break" is undesirable from a patient perspective. In some cases, adding additional capacity (more scanners) is preferable over maximizing the utilization of existing systems in the interest of preventing burnout. Radiology professionals put patients first, this means recognizing that radiology professionals are people with limitations.

Improving the Patient Experience

COVID-19 disrupted the day-to-day running of radiology services. The silver lining of that disruption is an opportunity to streamline and improve the patient experience going forward.

Appropriateness of Referrals

The first step any patient takes to access radiology services is to receive a referral. The complexity of the referral process cannot be underestimated; there a multitude of imaging options available and increasing specialization within medicine and radiology can be cause for confusion for referring physicians about which test to request.

Choosing Wisely Canada
Radiology Recommendations

Don't do imaging for lower-back pain unless red flags are present

Don't do imaging for minor head trauma unless red flags are present

Don't do imaging for uncomplicated headache unless red flags are present

Don't do CT for the evaluation of suspected appendicitis in children until after ultrasound has been considered

Don't do an ankle x-ray series in adults for minor injuries.

Appropriate referrals ensure that patients get the right test done first; the test that provides the greatest amount of information to move to the next step in their journey. One method to drive appropriateness is to apply appropriateness criteria for medical imaging and encourage high quality history provision in the imaging requisition. Changes to improve standardization would improve efficiency and accuracy of protocoling while contributing to the quality of the imaging report. In the ideal scenario, these criteria are provided as part of the regular workflow of a referring clinician. For patients being referred for imaging for a suspected or ongoing cancer diagnosis, standardized inputs for clinical information like initial primary malignancy, current status (staging, active therapy, complication, suspected progression, surveillance), previous relevant interventions (surgery, chemo, radiation, etc.), and clinical question would help radiologists provide clinically-relevant and useful information back to the referring physician and patient.

Clinical Decision Support (CDS) tools are already being implemented in a few select locations in Canada and we would encourage other hospitals and health systems to explore the feasibility of integrating a CDS system to enhance appropriateness.[54] In order to decrease referrals for low-value imaging studies, referring physicians should familiarize themselves with Choosing Wisely Canada's recommendations.[55,56]

Consultative Approaches to Patient Management

Enhanced communication between primary care providers and radiologists has been shown to alter patient management and provide valuable opportunities for education. For example, the e-Consult (Champlain BASE in Ontario) electronic consultation platform was developed to provide a secure method to connect primary care providers who have patient-specific questions with specialists including radiologists. It has been shown to reduce unnecessary consultations, decrease wait times and result in more efficient use of resources with an overall cost savings of $11.00 per case even after accounting for the cost of the service.[57-60]

A retrospective analysis of e-Consult in radiology found that median time to complete a consult was 10 minutes.[61] Most consultations pertained to patient workup, surveillance of imaging findings and provider education. Patient management was altered in 55% of 302 consultations and unnecessary testing was avoided in 28%. One third of consultations were related to questions regarding appropriate follow-up as this was not specified in the radiology report, highlighting the importance for radiologists to provide best-evidence follow-up suggestions if appropriate imaging is to be attained.

Electronic platforms may not be suitable for acute care situations. Working with local radiologists to enhance communication with referring physicians may be a more feasible solution in the short-term, with important secondary benefits derived from greater collaboration within patient care teams. In a recent JACR publication, Menezes et al. evaluated the use of a Medical Imaging Call Centre in the Toronto region that provides radiological consultations to community-based primary care physicians.[62] The majority of calls to radiologists focused on the need for urgent imaging and appropriateness consultation for work-up or follow-up of imaging findings. Using this service, 98% (215/220) of Emergency Department referrals for urgent imaging were avoided. Call volumes increased significantly over time and the number of primary care physicians who registered with the service also increased. On average, each radiologist spent five minutes on each call and received two calls per day.

Improving the Queuing Process

When patients are referred to radiology for an exam that has ample capacity, like X-ray, they often book their own appointment and get the imaging done when convenient for them. When being referred to an advanced modality such as CT or MRI where capacity is more limited and strained, patients are triaged and placed in queue (outpatients).

Patients are currently categorized according to priority levels which vary across all provinces. It is a strong recommendation of this Task Force to have all provinces adopt the same prioritization categories and timelines. The prioritization of an imaging request is usually assigned by a radiologist who reviews all incoming referrals and determines the appropriate category based on the information on the requisition.

Improving the queuing process needs input from the referring physician: the priority level is assigned by a radiologist, based on the clinical condition, which is inferred from the history provided on the requisition. In other words, the more detailed and up-to-date information is provided on the requisition, the more accurate the priority assignment. Unfortunately, the information provided is often very limited, incomplete, or frankly incorrect. Radiologists are only able to make use of the data points that they are provided to properly queue and protocol patients. Standardization and improvements to the clinical notes and inputs on the requisition, as discussed above, would vastly improve this workflow.

After being assigned a priority level, the patient experience diverges depending on where someone lives:

- Referred to an individual facility which puts you on their queue
- Patient can have the requisition forwarded to more than one facility to ensure they are on the shortest wait list
- Referral goes to a central queue where they are sent to the first open slot from multiple facilities

Table 2:
Consultation interactions facilitated through e-Consult platforms (Champlain BASE). A and B, two examples of interactions.

A.	B.
Primary Care Physician: This 50-year-old asymptomatic ex-smoker with normal pulmonary function tests was found to have a 5 mm nodule in his right upper lobe. The nodule has been stable, and he was given the impression that it was a calcified granuloma. Would you consider following this up with a chest x-ray or would you recommend a CT?	**Primary Care Physicians:** This 34-year-old man with urinary symptoms had a recent abdominal ultrasound that revealed several small liver cysts with the largest measuring 1.1 cm and a 5 mm polyp in the gallbladder. Is there any follow-up you would recommend if the patient is asymptomatic?
Radiologist: Thank you for the consultation. If the nodule has been stable over 2 years on chest x-ray, then it is compatible with a benign nodule and does not require follow-up imaging. If there is less than 2-year follow-up on chest x-ray, and the report is not definite for calcification, a CT would be useful to ascertain that the nodule is indeed calcified and therefore completely benign and requires no imaging follow-up	**Radiologist:** No follow-up is required for small simple liver cysts less than 4 cm or gallbladder polyps less than 6 mm with no gallstones.

Much work has been done to address wait lists and how to queue patients.[63] There is published evidence that a centralized intake is an efficient patient management strategy. This is especially true for referrals originating in primary care settings. A central intake ensures there are no duplicates and distributes the exams over all available imaging systems in the catchment.[64] One potential downside is that examinations may require reading by subspecialists; sometimes the examinations performed in a secondary care facility require a second reading at a tertiary care imaging centre. In the example of the Ottawa MRI intake,[65] some examinations go through the central intake but are automatically forwarded to academic centres because they require the expertise of subspecialized radiologists. The actual implementation of a centralized intake system is incredibly dependent on buy-in from local administrative and clinical leaders, and the successful integration of the system into existing workflows and referral patterns.

Due to the COVID-19 pandemic, wait lists for radiology are growing at an unknown rate. As the CAR recommended in the Resumption of Radiology Services report, patients on outstanding wait lists should be reassessed after a set period of time, to determine the appropriateness of the referral, and to update as necessary.[6] Resources to perform such a reassessment should be made available as some of the patients may no longer require imaging, or be eligible for a new priority status. Amid these pressured and demanding circumstances, it is increasingly important to communicate with patients about their appointment, the safety of that appointment, the importance of that appointment for their care and to ask them if they have already had the scan done elsewhere.[6]

Patient Scheduling

As discussed above, optimizing the scheduling within a particular department or for an individual scanner can have a significant impact on total throughput. If the underlying assumption driving that type of process improvement is that patient satisfaction will be increased by reduced wait times and more timely imaging results, then it stands to reason that any improvements to scheduling efficiency will have a positive overall effect on patient care. There are a number of scheduling optimization protocols and algorithms, and the literature yields many simulation models about how to optimize patient throughput. In a recent review, approximately 25% of studies applied the process improvements they outlined in simulation into practice.[66] The process improvements outlined in research studies may not be readily applicable to a particular institution. However, there is sufficient evidence that if local data are run through a discrete event simulation model, the outcomes will be relevant and actionable improving external validity.[66] Whether a hospital or department works with a modelling specialist, or follows a more traditional change management approach, the fundamental principle driving quality and timeliness of imaging is to control variability as much as possible.

Intake, Waiting Rooms, Patient Fears About Exposure

COVID-19 has made the idea of waiting rooms practically impossible, not to mention undesirable. Going forward, waiting rooms are likely to be viewed as especially risky if they lack negative airflow. Airborne pathogens such as COVID-19 are particularly difficult to deal with.[67,68] To ensure that patients are not disrupted in the future, we should take every reasonable precaution to prevent the spread of disease and to enhance patient confidence in the safety measures being taken. Further examination about the ideal setup and layout of waiting rooms, patient intake zones, and imaging suites continues in the next section of this report.

Studies of the 2003 SARS epidemic have shown that people's fears of the epidemic had a strong influence on their willingness to seek care.[69,70] Adverse health outcomes resulting from accessibility barriers posed by the fear of contracting COVID-19 should not be underestimated. One of the most significant secondary effects of COVID-19 for the healthcare system is the impact on patients who do not have COVID-19, especially those who delay seeking care for conditions out of fear.[71-74] Studies have already shown that patients have delayed or avoided seeking care altogether during the pandemic,[74] including for diseases requiring urgent care[72] which will have significant downstream effects on morbidity and mortality rates for certain conditions.[14,15] Proactive communication is necessary to ensure that patients are informed about the importance of seeking urgent care when needed,even during a pandemic.[34]

Patient Preparation and Image Acquisition

If we consider patient throughput for an imaging system, there are 4 broad categories of time:

1. Pre-scan: the time between when a patient is sitting in a waiting room until the imaging system begins acquiring images.
2. Scan time: the time the patient is in the scanner.
3. Post scan time: the time between when the scanning is done, and the patient leaves the room.
4. Empty room time: when the room is being prepared for the next patient until the next patient arrives.

The four categories together make up a block of time. If the variability of each component of the block can be reduced, that scheduling can decrease the average block time and throughput of patients can be increased resulting in increased utilization.

Pre-Scan activities can include as few as a couple of questions to placing an IV for contrast. Ensuring that pre-scan activities are done outside of the imaging suite ensures that these are being utilized efficiently. In order to improve patient outcomes and promote quality assurance, a database of standard, synoptic radiology reporting templates should be created in consultation with clinicians and surgeons to ensure that key questions are answered and appropriate data points are added to the patient record for particular

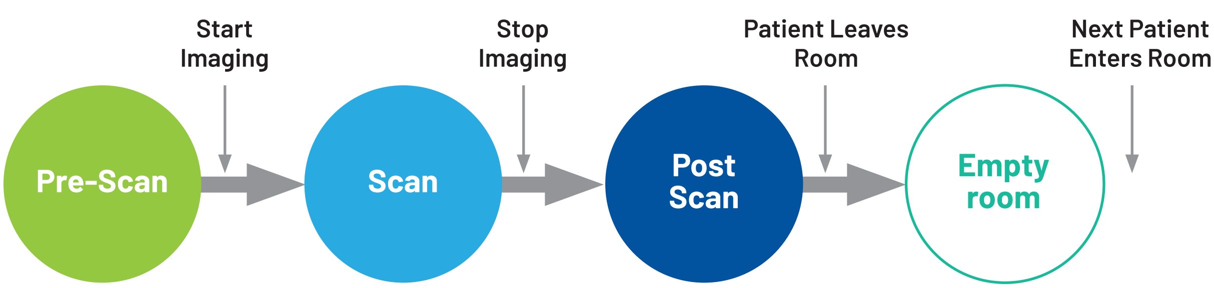


Figure 12: Patient Preparation and Image Acquisition Flowchart

indications. For example, a 2020 Ontario Renal Transplant Donor CT template was created in a collaboration between radiologists and urologists at each Ontario transplant center. This very specific synoptic template ensures that radiologists include in their reports, the key imaging information which is essential for urologists to safely plan living donor renal transplants. Similar synoptic templates exist for rectal cancer staging.

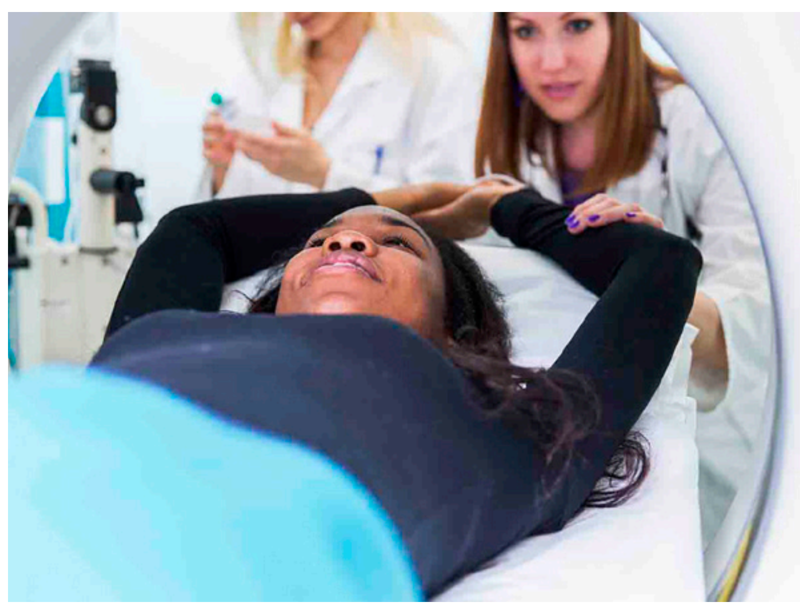
Scan time or acquisition time is often dependent on the technology itself. New scanners are almost always faster than older scanners. For modalities such as CT with an average acquisition time of between three and seven minutes, improving acquisition time by 10% will only provide marginal value if the scheduling blocks are set at 15 minutes. Modalities such as MRI and ultrasound have long acquisition times with a high degree of variability. There have been efforts to reduce MRI acquisition times which have been relatively successful. Unfortunately, the altered protocols are not easily transferred from one MRI system to the next due to the strength of the magnetic field (0.5, 1.5 or 3 Tesla) and imaging gradients.

With MRI there is a balance between optimal and acceptable diagnostic quality. Current protocols are geared towards optimal diagnostic quality. One method to shorten MRI acquisition time and potentially increase capacity is to move towards acceptable image quality (i.e. good enough for a diagnosis but not what the radiologist would prefer to interpret from). Implementing this on a broad scale involves additional research and validation studies on individual scans which we cannot recommend due to the backlog of patients waiting for MRI. Lastly, there has been significant enhancement to applying artificial intelligence (AI) algorithms to decrease MRI acquisition times.[75-77] These algorithms are not yet ready for commercial use and would likely only apply to the newest of MRI systems when ready.

The last step in the patient journey is their discharge, along with the radiologist reporting the results back to the referring physician. As with pre-scan activities, post scan activities should be done as much as possible outside of the imaging suite to allow for a faster turn around time of the room. With additional cleaning protocols in place across the country there is no need to belabour the issue.

Improving the Patient Journey and Preparing for a Better Future

The patient journey through and patient interaction with radiology is complex and institution-specific but can be streamlined through the targeted application and adoption of technology, as will be explored further in the following section. There is substantial operational research about optimal change management, but ultimately any changes to the patient experience must begin and end with the preferences and needs of the patients. At most major institutions, CT and MRI systems have likely already gone through process improvement cycles. Given the disruption and system-wide upheaval that COVID-19 has prompted, it is worth revisiting process improvement projects to find a way forward in the "new normal." Such efforts will only succeed if everyone in the radiology continuum is involved and open and supportive of change. The next section explores some new and existing ideas around defining a new normal in radiology services. Some of these ideas are a few years away; however, we should not revert to backward-looking processes that will prevent us from defining a better future for radiology.



Section 4: Re-Imagining Radiology for the Future, Looking Through the Lenses

The COVID-19 pandemic fundamentally disrupted the delivery of healthcare services across the continuum of patient care; radiology services were no exception. Earlier sections of this report have explained the ways in which service delivery and patient outcomes were affected by the pandemic, and have delved into what the reorientation and reorganization of radiology departments and networks of care will mean for both patients and medical imaging professionals.

This final section of the report examines what the delivery of medical imaging services may look like on a longer time horizon through four lenses: patient, imaging department, local health network, and national healthcare system, and makes recommendations for changes to the way that we think about and practically deliver patient care. By examining the big picture structural and systemic changes wrought by the pandemic through these distinct lenses, we can begin to design and prepare for the future of radiology. While many of these recommendations are based in current evidence and best practices, they are also an exercise in imaging and envisioning what could be.

Patient Lens

Patient- and family-centered care encourages the active collaboration between patients, families, and providers to ensure that care is tailored for the individual patient's needs and preferences.[78] Central to this approach is ensuring that patients are part of the conversation, not consulted afterwards. "A routine request of patients is to have access to their own medical records of which they are custodians and legal owner.[79] They can choose to share it or not, but a lot of the duplication and hunting for data (past scans as well as diagnoses) could be eliminated if there was more effort put into empowering and equipping patients to be the masters of their own information.

Technology "Appification"

Appification is the creation or replacement of website and web pages with programs that operate on mobile operating systems and mobile devices.[80,81] Appification is about providing a user interface for users which is easily accessible in a mobile world. As we transition past getting the Canadian healthcare system to fully digital, appification and usability will be the new primary concerns.

In the future, "appification" may become commonplace within healthcare to allow easier patient access and integration with radiology departments, bringing the patient experience in the radiology department into the 21st century. This will require reinventing the delivery and communication related to medical imaging. In addition to reducing idle time and eliminating the need for crowded waiting rooms, patients, in consultation with referring physicians, may be able to:

- Access necessary imaging services through the web or an app
- Make notes and requests about needs (e.g. allergies, claustrophobia, restricted mobility, scheduling conflicts)
- Allow referring to match level of examination priority with the scheduling availability of the department based on wait times
- View the impact of special requests on availability – like when you request a direct flight and see the trade-off on price and travel time

- Receive notifications and status updates by phone, in the event of a schedule change (e.g. in the case of MRI delay due to ICU emergency)
- Access information on parking or how to reach the radiology department
- Real-time updates on the progress and reporting status of their imaging study – like the tracking updates received for a package

Ultimately, appification will allow patients to remain informed and empowered throughout the entirety of their engagement with the radiology department. If a patient's scheduled examination is bumped by someone more gravely ill, and thus at a higher priority for imaging, they can be informed of delays, the general reason behind those delays, and adapt their schedules accordingly while avoiding unnecessary presence in a waiting room. The implementation of tools that provide more updated information and demystify a needlessly complex patchwork of services, providers, and protocols will greatly improve the patient experience, addressing weaknesses in our current system. In the future, patients need not be subject to overbooking, lack of granularity in scheduling, or the disempowerment and anxiety that result from a lack of information and ownership of their care. A sketch of a Radiology Appointment phone application is shown in **Figure 13**.

***Figure 13**: Mock-up of patient-focused Radiology Appointment App showing booking options, fields for needs and requests, map to hospital, transit or parking information, guidance to reach radiology department, screening questionnaire, preparation instructions, and real-time updates. ©2020, An Tang, CHUM.*

Patient Experience

The patient journey through a radiology department involves several steps that includes referral for an imaging examination (in consultation with a radiologist or run through clinical decision support), protocoling, booking, preparation, navigation, image acquisition, image interpretation, and reporting. For historical reasons, the workflow of some of these steps (such as paper requisitions for outpatients and printed preparation instructions) are still reliant on paper or faxed copies even when the information is available in digital formats. **Figure 14** illustrates the existing patient journey and opportunities for improvement of the image acquisition experience, reception and understanding of radiology reports, and integration with multi-disciplinary care.

Complete digitization of the patient workflow has the potential to shorten delays between each step, facilitate automation of repetitive tasks, reduce clerical errors, and enable the use of optimization algorithms and artificial intelligence for image analysis. From the patient's perspective, digitization of healthcare has the potential to improve the patient experience, engagement, and satisfaction. For example, patients will be able to share their needs and requests, complete screening questionnaires, and read preparation instructions remotely and ahead of their examinations. These steps are important to prevent the late discovery of a contraindication to an imaging examination that may further delay appropriate imaging.

With cell phone applications, patients may receive geolocated information (such as guidance on waiting location to reduce patient density according to social distancing requirements) and real-time updates (such as potential delays due to medical emergencies).

Imaging will be combined with other specialist appointments and next-step referrals to streamline the patient experience. Doing so will also expedite imaging for screening and follow-up. The current organization of service delivery and the isolation/disintegration of imaging departments between hospital systems, or between hospitals and community clinics means that results and data which should be easily shared between radiologists, referring physicians, other specialists, and patients is needlessly slow and complicated. For patients who fit into screening guidelines (e.g., breast mammograms, ultrasound screening of the liver in patients at risk for hepatocellular carcinoma, low dose CT screening for lung cancer), reminders to book their imaging appointments can be made. These reminders may be sent by email, text messaging, notifications via the phone application, or by access through the patient results portal.

In the future, patients will be at the centre of the feedback loop, and will be able to access all results, including their medical images and reports, from a single portal that is also portable from clinic to clinic, hospital to hospital, and between provinces. Establishing appropriate data protection and safety nets is an essential aspect of this evolution, so that parents/guardians can access results on behalf of their dependents where necessary, and to ensure patients receive their results in an environment where they have the opportunity to ask follow-up questions and receive guidance from their physician.

Interdisciplinary Cancer Care Model

A patient referred with a given clinical problem, such as a palpable breast mass, may be referred to a breast centre and be booked for their diagnostic imaging (e.g. mammogram and ultrasound). Once the imaging appointment is booked, they may be booked for an accompanying clinical visit with a breast surgeon or clinician, coordinated to allow for the completion of the imaging study. Coordination of the imaging with the clinical booking appointments minimizes delays in assessment and improves patient and referring physician satisfaction. It also reduces unnecessary duplication of imaging tests, increases the standard of the imaging studies, and enhances multidisciplinary approach to various clinical problems, which improves the quality of patient care. This system exists in many multi-disciplinary centres for lung, prostate, colorectal, hepatic, and other cancers, and could be further engrained as standard practice for the workup of any suspected malignancy.

Simplified Patient Journey

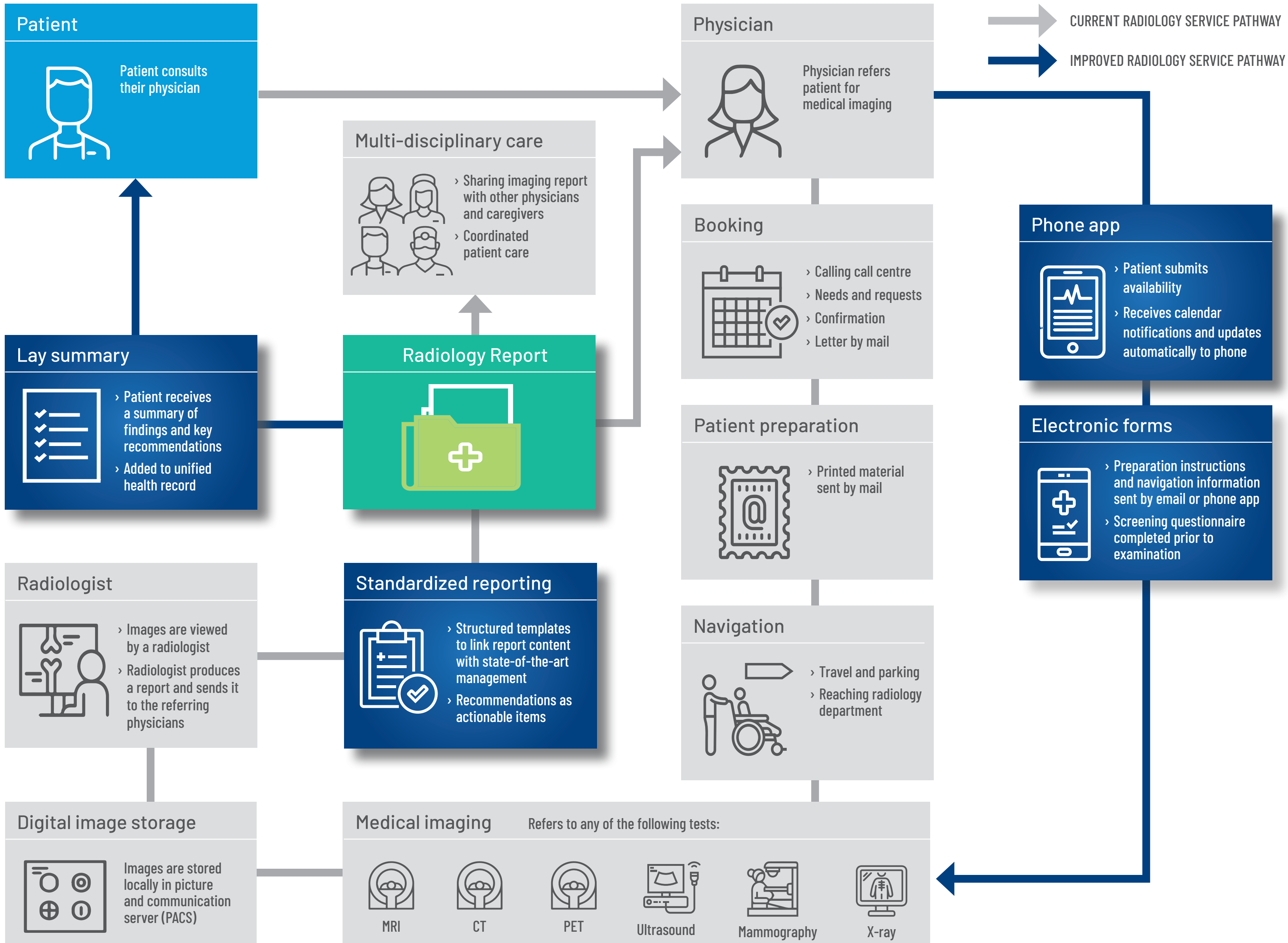


Figure 14: *Patient journey through a radiology department. Current pathway is illustrated in black. Opportunities to improve patient well being, quality of care, patient engagement, and patient satisfaction with modern web, phone, scheduling, and mapping software are shown in* ***blue****. ©2020, An Tang, CHUM.*

Department Lens

Space and Equipment

With the enhancements made to patient scheduling, examination workflow, and communication, the radiology department will look and feel markedly different from its current form. Moreover, the changes to physical space brought about by the COVID-19 pandemic are unlikely to be reversed – reductions to patient density, protocols to keep inpatients separated from outpatients at all times, and improvements to traffic flow will become permanent. Reporting areas will also be set up to promote social distancing, while still providing on-site support by radiologists to technologists and for teaching residents.

Figure 15 depicts a floorplan of a radiology department that has gone fully virtual for scheduling and prioritization. For the sake of mutual protection for inpatients and outpatients in the event of an outbreak of infectious disease, where space permits, CT scanners may be installed in emergency departments. In smaller hospitals, the CT and radiology department could be located as close as possible to the emergency department or other departments that rely heavily on imaging.

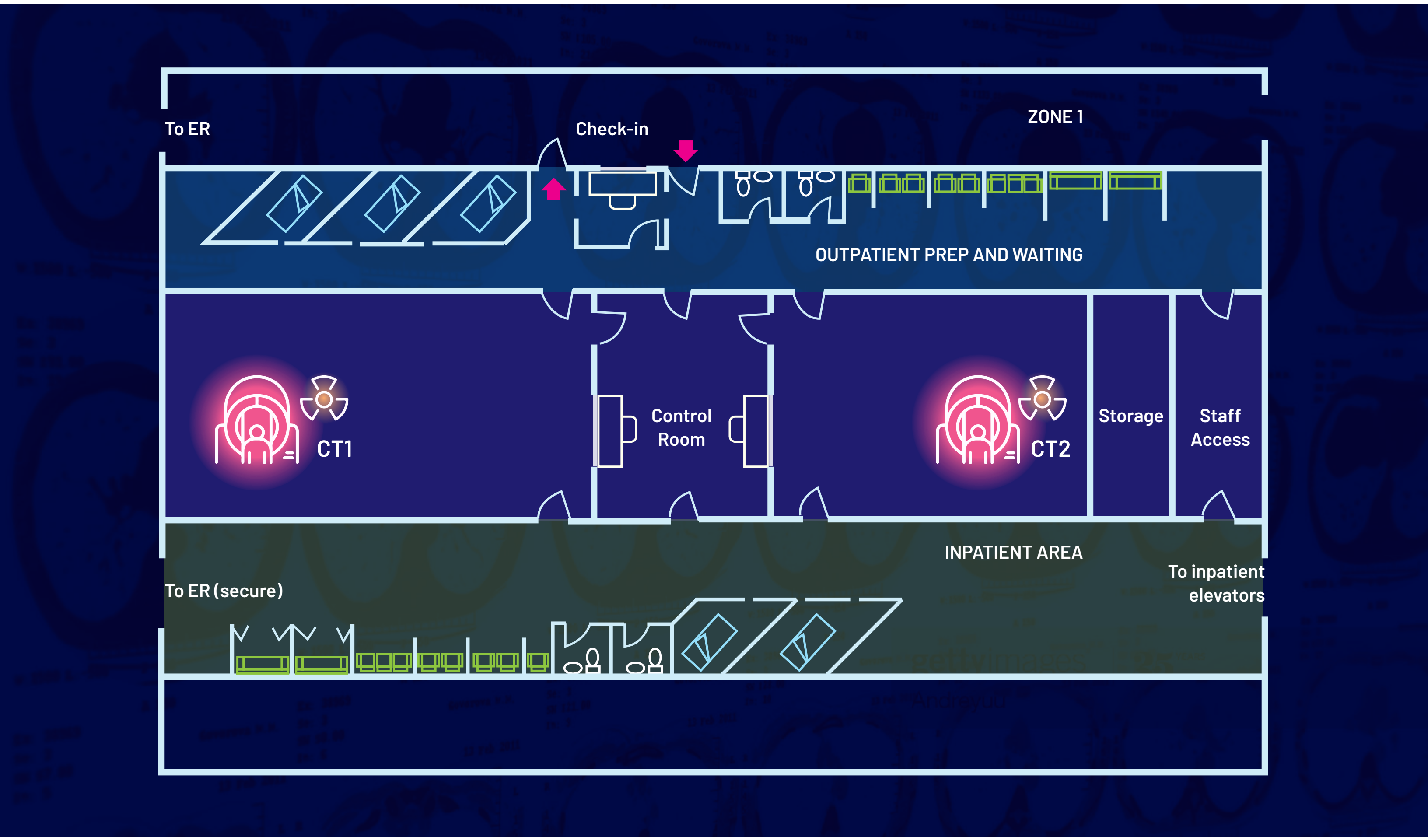


Figure 15: *Map of a virtual radiology department illustrating patient separation and flow. This model is designed to keep outpatients and inpatients in separate areas, for mutual protection. It is also designed to streamline movement through the various areas.*

Protocoling

AI-assisted protocoling based on clinical indications will become increasingly sophisticated. A transition from rules-based protocols (e.g. If R/O kidney stones THEN unenhanced low-dose CT urography if <40 years old) to context-based protocols. In the example of the patient being imaged to rule out kidney stones, these context-based protocols would be informed by fetching mean time interval between previous follow-up exams, pre-filling of protocol based on recurrent examinations ordered at similar time intervals, notifications for declining renal function, and analysis of radiologists' specific recommendations from previous reports. These data points can be harmonized to build protocols on a patient-by-patient basis, contributing to the overall trend towards personalized medicine.

Scheduling and Enhanced Patient Management

Deeper integration of automation technology into patient management and record-keeping will contribute to greater efficiency, improved throughput, and a more streamlined experience for patients who need medical imaging. Referring physicians will use clinical decision support tools to ensure that all patients receive the most appropriate imaging study. Automated optimization algorithms, based on operational research, will dynamically update scheduling to match demand for medical imaging equipment with available supply and waitlists. Outpatients with similar MRI protocols will be automatically scheduled in batches (e.g. all knee MRIs one evening per week; all breast or prostate screening MRIs book in 2-3 hour blocks) to increase throughput by reducing the need for technologists to change imaging coils and protocols. Clinicians will be able to request recurrent imaging more easily, such as screening for hepatocellular carcinoma, or follow-up indications from oncology. Currently, these recurrent requests are managed manually. Greater efficiency and improved patient care will result from harnessing basic algorithms that allow physicians to input changes to a centralized patient record which then prompt a series of outputs to automatically update imaging requests and request additional workup, or to cancel requests entirely, based on clinical indications.

Artificial Intelligence

To improve patient care and shorten time to diagnosis and appropriate management, artificial intelligence (AI) software may be integrated to different steps of the existing clinical pathways.[82] Triage applications may be used to prioritize the review of imaging examinations by radiologists based on automated detection of urgent findings (such as pneumothorax or ruptured abdominal aortic aneurysm) or significant findings (such as breast cancer). Replacement applications may automate tasks traditionally performed by radiologists such as measurement of metastases on follow-up examinations. Add-on applications may be used to enrich the report of radiologists by providing quantitative biomarkers (such as assessment of brain volume in patients with dementia) that are very time-consuming or difficult to obtain even by motivated experts.

Reporting and Communication

To facilitate clear communication of results while facilitating data sharing, radiology will continue to move towards structured reporting templates where appropriate.[83] Structured reporting has been shown to improve reporting times while making results easier to interpret for referring physicians.[84-86] Moreover, the integration of standardized reporting systems (e.g. LI-RADS®, TI-RADS®, BI-RADS®, Lung-RADS®)[87] will enable radiologists to use evidence-based reporting. These templates can be connected to central repositories that ensure that updates and advancements in the medical literature are reflected in "-RADS" category calculations, thereby ensuring that all reporting structures are seamlessly connected to the most recent and relevant scientific evidence.

Tools and apps will allow efficient communication with referring physicians about clinically acute or unexpected results, with a consistent communication loop closure and automatic documentation when the message has been received by the requesting physician. Improved integration with other data points, including genomics and pathology, will help inform the best care pathway for the patient. Additionally, we can expect seamless ability to view studies from other centers, and for those to be available when reporting on current imaging studies.

Beyond the benefit for physicians and other care providers, these advancements will ensure efficient care for patients.

The capacity to view imaging studies from anywhere will also enable more remote imaging, allowing for uninterrupted and safe environments for reporting imaging for both inpatients and outpatients. The pandemic has demonstrated the necessity of developing rigorous and robust platforms for virtual learning. By leveraging these same technologies, including online platforms for reviewing cases with residents at teaching centers, the training paradigm will incorporate more virtual, interactive teaching. Approaches now considered innovative, like the flipped classroom, are more likely to be the norm.[88–90]

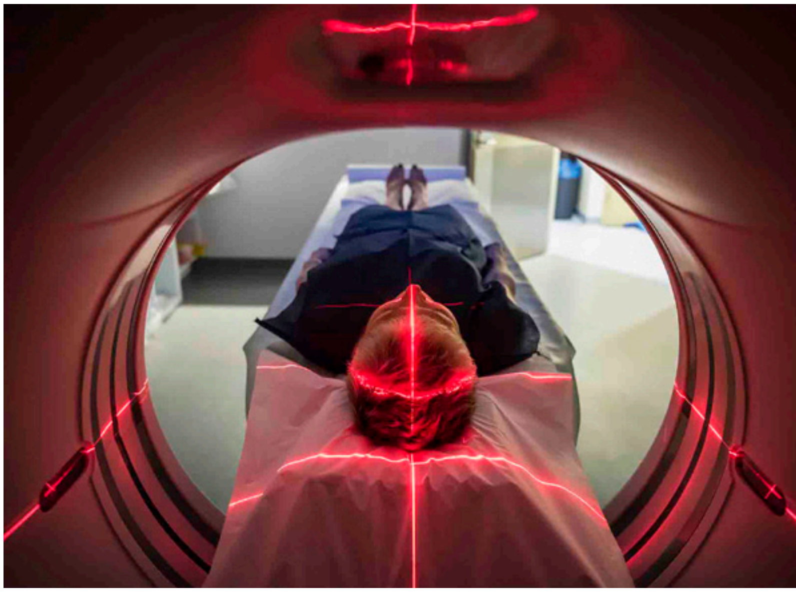
To tackle worklists and imaging volume, imaging studies for some referrals or suspected morbidities will be run through an algorithm as a first-line interpretive and reporting tool, with the findings being confirmed by a radiologist. In the example of a chest radiograph to confirm suspected tuberculosis, the algorithm would produce a report that the patient's imaging was consistent with a TB diagnosis (or not), and identify the associated features of that diagnosis on the images, to be confirmed by a radiologist.[91,92] By eliminating the backlog of studies needing basic interpretation that can just as easily be performed or streamlined by AI, radiologists can evolve further into their role as expert diagnosticians and members of collaborative, consultative patient care teams.

Reporting of imaging findings back to the referring physician via the patient record may also evolve to be more patient friendly. In an environment where more information about diagnosis and treatment is made available to patients via apps or other digital platforms, it will be important that radiologists develop a comfort with sharing a summary of results and their implications in plain language. Training to develop familiarity with this lexicon could begin during residency and would go a long way to integrating radiologists' expertise into the patient experience of their own care.

Resilience of Medical Imaging Teams

The heavy workload of radiology departments means that collaboration and communication between radiologists and other imaging team members is required to meet patient need. As explained in Section 3, burnout is an ongoing issue across medicine and is particularly acute in radiology, for both radiologists and technologists. Work isolation and barriers to effective interpersonal communication can exacerbate and accelerate burnout.[43–51]

To create a resilient and supportive professional community, within the department itself, communication between team members must be prioritized. Strong communication will promote and improve resilience, by ensuring that agreed upon protocols, approaches to patient management, and teamwork are recognized and respected. If remote work arrangements are necessitated by a pandemic or other service disruption, it is essential that radiologists and other team members be supported in maintaining a community even at a distance. It is not the responsibility of the individual radiologist or technologist to build resilience for a radiology department or clinic. Rather, a culture change may be necessary to ensure that team members are given the tools and operational supports necessary to flourish in their roles.



Supporting radiologists and technologists to allow ongoing professional development, networking and the exchange of ideas and best practices is also essential to the optimal functioning of medical imaging teams. Technologists must not be sidelined in the learning and teaching environments; their inclusion can provide a platform for quality assurance projects and quality initiative changes spearheaded by technologists. This type of activity could improve the work environment for technologists, encouraging staff retention in all imaging modalities, and lead to increased resilience among technologists when sudden changes in the workflow occur in the event of future pandemics or service disruptions.

Multidisciplinary Collaboration and Communication

Medical imaging will remain integral to the diagnostic pathway for patients across all demographics. The ongoing integration of AI and informatics-driven tools will serve to increase the reliance of healthcare teams on imaging results. As such, radiologists must be closely integrated into care teams. Ongoing efforts to implement technology that allows for seamless, multidisciplinary discussion of cases and communication of clinically relevant information will be key. Such access includes the ability to pull imaging and pathology information from multiple hospital sites for patient care multidisciplinary rounds. Similarly, advancements in communication and collaboration tools will allow physicians from other centers to participate in case review for patients who would benefit from subspecialized consultation while receiving care closer to home.

Radiologists can also make use of innovative online platforms to provide Grand Rounds, lead educational sessions for other clinicians, surgeons and allied health professionals in a health center or local region. The establishment and normalizing of such programs would facilitate the dissemination of best practices for imaging requests, identify new needs from clinicians and provide insight into new imaging techniques that other physicians may find helpful. New practice models would also be considered for interventional radiologists, whereby patient-centered clinics could be run in conjunction with other clinicians and surgeons working together to provide more integrated patient care. Each of these modifications and adjustments to existing practice patterns will serve to integrate radiologists more fully into inpatient and outpatient service delivery, resulting in reduced administrative burden and higher quality care for patients.

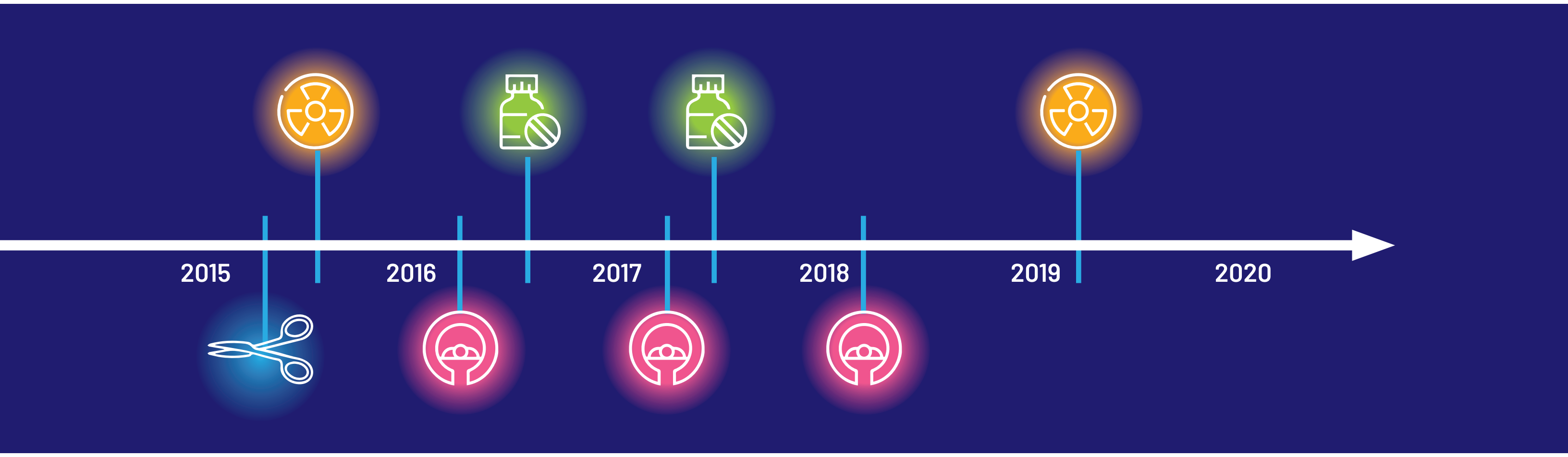
Local Lens

Centralized Booking and Imaging Repositories

As observed in Section 3, coordinated booking has the potential to reduce duplicate examinations by eliminating blanket booking while mitigating unnecessary cancellations. Similarly, centralized imaging repositories will facilitate more seamless patient care between facilities and health networks. These same repositories can be harnessed by data scientists working in concert with radiologists and other clinicians to develop AI applications that integrate back into the continuum of care. Ideally, these imaging repositories will be part of a larger system of patient data that is accessible across hospital systems and provincial jurisdictions. The objective of centralizing patient data into regional or provincial repositories is to streamline the patient experience within the healthcare system, while providing opportunities for collaboration between clinicians to improve patient care. Imaging data does not need to be archived in a single national repository; Canada established interoperability standards for file formats and protocols for PACS at the regional and provincial level.[93] The essential innovation within the existing system is the ability to retrieve imaging data regardless of provincial jurisdiction. In other words, to offer appropriate healthcare, medical imaging data should follow patient mobility across provinces.

Universal electronic patient records and the patient journey

Universal electronic patient records that are tied into a centralized patient data repository will facilitate more automation of referrals and requisitions for medical imaging and other diagnostic testing. For example, entering positive findings into the patient record during a surveillance examination for suspected cancer would prompt actionable items for the physician – to order a given diagnostic examination ± biopsy. This form of clinical decision support, which is powered by imaging referral guidelines developed by radiologists, should lead to a pre-filled requisition, level of priority, and scheduling based on the suspicion of cancer. Communication should be made by the radiologist as to what actions are being taken by the hospital/clinic and what actions are required by the referring physician: e.g. the center/clinic will arrange for the follow-up or biopsy, or that it is the responsibility of the referring physician to submit the request for the additional imaging. Moreover, communication about how the actionable items are being managed is an essential component of the report. Every patient record could include a timeline with markers to denote imaging, surgeries, and treatments received over the course of a given diagnosis or disease trajectory [**Figure 16**]. Such a record could also integrate a radiation passport, detailing the patient's history of radiation exposure to facilitate informed decision-making about further exposure to radiation.



Imaging – includes type and report when hovered over

Surgery –links to surgical and pathology reports

Chemotherapy –includes type, dose and duration

Radiation therapy – includes dose and duration

Figure 16*: Sample timeline contained in unified patient record, denoting imaging, surgeries, and treatments received for a particular diagnosis. Timeline would be visible to all healthcare providers interacting with the patient and would be especially useful for reviewing prior imaging reports.*

Mobile Imaging Equipment

Providing high-quality imaging and time-sensitive reporting for patients in remote areas will be easier in the future, even in areas where having full time installation of cross-sectional imaging may not be economically viable. For example, mobile CT or MRI on trucks that regularly visit different remote communities to meet their imaging needs. Such vehicles exists with screening mammography in mobile vans in several provinces and can be added to for an increase in population health, for instance when combined with cervical cancer screening.[94] These mobile imaging units reduce the need for patients to travel elsewhere, because they can receive high-quality care close to home. This evolution in the provision of imaging services will help to reduce disparities and inequities in healthcare across Canada.

COVID-19 has generated renewed interest in mobile imaging.[95] Modular chest imaging pods can be constructed that could be deployed at field hospitals as needed. Such units have been created out of shipping containers.[96] In this scenario, the patient enters into a separate translucent booth designed to keep the patient airflow separate from staff. The patient is isolated from staff the whole time with a physical barrier, which will save on PPE and cleaning. Mobile and modular imaging equipment could be built and deployed in parking lots or other locations to facilitate the separation of inpatient and outpatient imaging, or to adhere to containment protocols in the case of an outbreak of an infectious disease like COVID-19.

National Lens

National Guidelines and Protocols

Canadians must be able to receive the same standard and quality of care no matter where they live. Platforms that include national guidelines and protocols, and which integrate seamlessly into clinical workflows can drive this evolution. These tools help to improve quality and standardization, while contributing to cost savings derived from every patient receiving the right test or treatment at the right time. Enacting national, standardized, evidence-based protocols can also drive quality improvement and make imaging departments more efficient in their use of existing resources. Such protocols may include decreased use of oral contrast for CT, abbreviated or shortened MRI protocols (e.g. biparametric prostate, non-contrast pancreas follow-up for cystic lesions, breast cancer screening, HCC screening on delayed hepatobiliary phase contrast enhanced MRI, and administration of gadolinium-based contrast agents in kidney disease).[97,98]

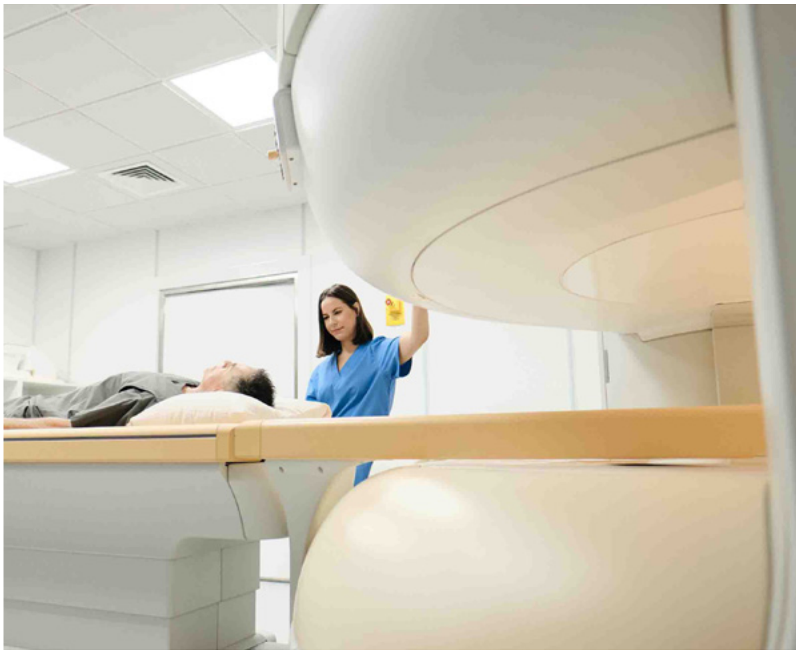
Research and Development

Government investment in research and development for medical imaging could lead to giant leaps forward in our ability to care for patients. This investment should both support existing programs and encourage innovation to keep the radiology sector moving forward. Portable and accessible technology that would allow for patients to be evaluated at home at the time of their symptoms to determine the cause of their concern and whether acute care is necessary. For example, automatic ultrasound or ultrasmall non-ionizing imaging technologies could acquire imaging data, integrate it with additional patient data such as vital signs and allow remote radiologic diagnosis. Federated or distributed learning based on large datasets aggregated across Canadian hospitals has the potential to improve the performance and robustness of AI software trained on a wide spectrum of imaging. These types of innovations would ideally be supported by stable, sustainable federal investment in medical research, geared at harnessing technology for the sake of the health and well-being of all Canadians.

A Vision for the Future

Ultimately, COVID-19 has brought the existing challenges, inadequacies, inefficiencies, and idiosyncrasies of our healthcare system into sharp relief. None of the findings in this report are likely to come as a surprise to anyone with knowledge of or experience working in medical imaging departments or in healthcare generally. The silver lining of the pandemic may be the recognition of pinch points, barriers, and unnecessary hurdles in the system, and the subsequent building of political will to enact system-wide change. We are trying to plan for the future of medical imaging that will result in the highest quality and best organized care for patients, without causing undue harm or stress to practitioners that provide that care. Unfortunately, our current thinking and system are somewhat limited by the patchwork of policies and programs that have brought us to this point.

Consistently centering the needs of the patient will naturally lead to the development of data-driven applications and platforms to streamline care pathways, improvements in records management, the reasonable exchange of patient data in a jurisdiction-agnostic way, and a commitment to making optimal use of physical, technological and human resources available in the system. We have an opportunity to get back to basics and reimagine the way that we use and deliver medical imaging care; our abiding goal must be the betterment of patient health and experience in the healthcare system.



Recommendations

1. ***Invest in better infrastructure to collect better data.*** *The CAR, Canadian Institute for Health Information (CIHI) and provincial Ministries of Health should collaborate to augment the current national and provincial medical imaging wait time databases to ensure there is standardized reporting of wait times on a regular basis across the country.*

2. ***Adopt standardized imaging prioritization categories and benchmarks across all provinces and territories.*** *We cannot improve what we do not measure, and we cannot properly assess the situation without consistent metrics*

3. ***Invest in human resources****, to hire more technologists, sonographers, and clerical staff, to use existing equipment and capital resources more efficiently and for longer hours.*

4. ***Let data drive procurement and investment in capital equipment.*** *Enact a coherent national strategy for targeted, data-driven capital equipment procurement.*

5. ***Institute clinical decision support tools*** *to drive appropriateness while curtailing low-value examinations.*

6. ***Create centralized intake systems for CT and MRI****, at the provincial or regional level that allow for seamless booking of exams and access to wait time data.*

7. ***Reorganize clinical space****, where possible, to facilitate continuation of service delivery during active outbreaks.*

8. ***Reassess the metrics being used to measure radiology performance****; ensure that the metrics are aligned to the needs of patients, rather than the raw productivity of individuals and departments.*

9. ***Harness AI applications*** *to improve the patient experience, clinical workflows, and health care administration. Let technology help to streamline systems while eliminating unnecessary redundancies and inefficiencies.*

10. ***Develop a disaster preparedness plan*** *to ensure that there is less of an impact on service delivery in the event of another outbreak; prioritize maintaining operations and human resources at the maximum possible level rather than ramping down service in fear of a surge.*

Areas for Further Research

1. ***Data Collection Strategies and Platforms*** *– what elements comprise the ideal dashboard for imaging data collection and curation, what barriers exist to collecting, managing, and sharing this data?*

2. ***Impact of the Pandemic on Training and Education*** *– what is the new way forward, how can programs adapt to remote learning, how can competence be encouraged and measured in remote learning environments, what about interventional radiology?*

3. ***Preparedness Framework for Pandemics and Mass Casualty Incidents*** *– how can our health systems prepare for mass casualty incidents with their acute, short-term effects versus events like the COVID-19 pandemic which have widespread, sustained disruptive impacts? These two types of incidents require differing preparedness frameworks, and we need national, provincial, and local level plans for each.*

4. ***Rural, Remote, and Indigenous Communities*** *– how can we ensure equitable access to medical imaging services in rural and remote communities; which aspects of our existing care models will have to be adjusted in order to meet the particular demands inherent with delivering care in those communities?*

References

1. Canada H. Canada Health Act. *aem*, https://www.canada.ca/en/health-canada/services/health-care-system/canada-health-care-system-medicare/canada-health-act.html (2004, accessed 22 September 2020).

2. Canada TCB of. Canada's recovery continues at a slower pace. *The Conference Board of Canada*, https://www.conferenceboard.ca/insights/featured/canadian-economics/canadas-recovery-continues-at-a-slower-pace (accessed 11 September 2020).

3. Ford prepared to ask surgeons to work weekend to clear backlog | Globalnews.ca, http://globalnews.ca/news/7326976/ford-ontario-doctors-work-weekends-surgery-backlog/ (accessed 11 September 2020).

4. Wait Times, http://waittimes.cihi.ca/?_ga=2.70146320.1614892285.1599660015-703135947.1599144257 (accessed 9 September 2020).

5. Kringos D, Carinci F, Barbazza E, et al. Managing COVID-19 within and across health systems: why we need performance intelligence to coordinate a global response. *Health Res Policy Syst* 2020; 18: 80.

6. Canadian Association of Radiologists. *Radiology Resumption of Clinical Services*. Ottawa, ON, https://car.ca/wp-content/uploads/2020/05/CAR-Radiology-Resumption-of-Clinical-Services-Report-May-En-Final-May-13.pdf (8 May 2020, accessed 9 September 2020).

7. Canadian Association of Radiologists. *National Maximum Wait Time Access Targets For Medical Imaging (MRI and CT)*, https://car.ca/wp-content/uploads/car-national-maximum-waittime-targets-mri-and-ct.pdf (January 2013).

8. Norbash AM, Moore AV, Recht MP, et al. Early-Stage Radiology Volume Effects and Considerations with the Coronavirus Disease 2019 (COVID-19) Pandemic: Adaptations, Risks, and Lessons Learned. *J Am Coll Radiol JACR* 2020; 17: 1086–1095.

9. Naidich JJ, Boltyenkov A, Wang JJ, et al. Coronavirus Disease 2019 (COVID-19) Pandemic Shifts Inpatient Imaging Utilization. *J Am Coll Radiol JACR*. Epub ahead of print 18 June 2020. DOI: 10.1016/j.jacr.2020.06.011.

10. Siegal DS, Wessman B, Zadorozny J, et al. Operational Radiology Recovery in Academic Radiology Departments After the COVID-19 Pandemic: Moving Toward Normalcy. *J Am Coll Radiol JACR 2020*; 17: 1101–1107.

11. Canadian Association of Radiologists. CAR National and International Radiology Resumption and Resilience Survey Data [unpublished].

12. CAMRT. *COVID-19 – Health Human Resources Survey*. Ottawa, ON: Canadian Association of Medical Radiation Technologists, https://www.camrt.ca/wp-content/uploads/2020/06/COVID-19-HHR-Survey-Survey_1-Highlights.pdf (April 2020, accessed 15 September 2020).

13. Chen-See S. Disruption of cancer care in Canada during COVID-19. *Lancet Oncol* 2020; 21: e374.

14. Hamilton W. Cancer diagnostic delay in the COVID-19 era: what happens next? *Lancet Oncol* 2020; 21: 1000–1002.

15. Maringe C, Spicer J, Morris M, et al. The impact of the COVID-19 pandemic on cancer deaths due to delays in diagnosis in England, UK: a national, population-based, modelling study. *Lancet Oncol* 2020; 21: 1023–1034.

16. CADTH. *Canadian Medical Imaging Inventory*, 2017. Ottawa, ON, https://www.cadth.ca/sites/default/files/pdf/canadian_medical_imaging_inventory_2017.pdf (March 2018, accessed 18 September 2020).

17. Stogiannos N, Fotopoulos D, Woznitza N, et al. COVID-19 in the radiology department: What radiographers need to know. *Radiogr Lond Engl* 1995 2020; 26: 254–263.

18. Evan D. The great PPE panic: How the pandemic caught Canada with its stockpiles down | CBC News. *CBC News*, 11 July 2020, https://www.cbc.ca/news/politics/ppe-pandemic-covid-coronavirus-masks-1.5645120 (11 July 2020, accessed 14 September 2020).

19. Laing S, Westervelt E. Canada's National Emergency Stockpile System: time for a new long-term strategy. *CMAJ 2020*; 192: E810–E811.

20. Patel NR, El-Karim GA, Mujoomdar A, et al. Overall Impact of the COVID-19 Pandemic on Interventional Radiology Services: A Canadian Perspective. *Can Assoc Radiol J* 2020; 0846537120951960.

21. Chen RC, Tan TT, Chan LP. Adapting to a new normal? 5 key operational principles for a radiology service facing the COVID-19 pandemic. *Eur Radiol* 2020; 30: 4964–4967.

22. Dennie C, Hague C, Lim RS, et al. The Canadian Society of Thoracic Radiology (CSTR) and Canadian Association of Radiologists (CAR) Consensus Statement Regarding Chest Imaging in Suspected and Confirmed COVID-19. 2020; 23.

23. Sonography Canada. Sonography Canada statement COVID-19. *Sonography Canada*, https://sonographycanada.ca/covid-19-statements-resources-and-information-for-diagnostic-medical-sonographers-in-canada/sonography-canada-statement-sonographers-and-covid-19 (accessed 4 May 2020).

24. Seely, Jean, Barry, Michael. Canadian Society of Breast Imaging and Canadian Association of Radiologists Joint Position Statement on COVID-19, https://csbi.ca/wp-content/uploads/2020/03/Covid-19-statement-CSBI_CAR-1.pdf (2020, accessed 14 September 2020).

25. Mossa-Basha M, Medverd J, Linnau K, et al. Policies and Guidelines for COVID-19 Preparedness: Experiences from the University of Washington. *Radiology* 2020; 201326.

26. Wan Y-L, Schoepf UJ, Wu CC, et al. Preparedness and Best Practice in Radiology Department for COVID-19 and Other Future Pandemics of Severe Acute Respiratory Infection. *J Thorac Imaging* 2020; 35: 239–245.

27. Rai A, Ditkofsky N, Hunt B, et al. Portable Chest Radiography Through Glass During COVID-19 Pandemic-Initial Experience in a Tertiary Care Center. *Can Assoc Radiol J J Assoc Can Radiol* 2020; 846537120942885.

28. Snow A, Taylor GA. Coronavirus Disease 2019 (COVID-19) Imaging Austerity: Coming Back From the Pandemic. *J Am Coll Radiol* 2020; 17: 903–905.

29. Zaka A, Shamloo SE, Fiorente P, et al. COVID-19 pandemic as a watershed moment: A call for systematic psychological health care for frontline medical staff. *J Health Psychol* 2020; 25: 883–887.

30. Sutherland G, Gibbard R, Russell, Nigel, et al. *The Value of Radiology, Part II*. Ottawa, ON: The Conference Board of Canada, https://www.conferenceboard.ca/e-library/abstract.aspx?did=10328 (2019, accessed 14 September 2020).

31. COCIR. *Medical Imaging Equipment Age Profile & Density: 2016 Edition. Brussels, Belgium*: European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry, https://www.cocir.org/uploads/media/16052_COC_AGE_PROFILE_web_01.pdf (May 2016, accessed 15 September 2020).

32. CADTH. Diagnostic Imaging Equipment Replacement and Upgrade in Canada. 2016; 32.

33. European Society of Radiology (ESR). Renewal of radiological equipment. *Insights Imaging* 2014; 5: 543–546.

34. O'Brien CM, Jung K, Dang W, et al. Collateral Damage: The Impact of the COVID-19 Pandemic on Acute Abdominal Emergency Presentations. *J Am Coll Radiol*; 0. Epub ahead of print 20 August 2020. DOI: 10.1016/j.jacr.2020.08.010.

35. Joffe S, Drew D, Bansal M, et al. Radiology Operations: What You Don't Know Could Be Costing You Millions. *Radiol Manage* 2007; 8.

36. Bentayeb D, Lahrichi N, Rousseau L-M. Simultaneous Optimization of Appointment Grid and Technologist Scheduling in a Radiology Center. In: Bélanger V, Lahrichi N, Lanzarone E, et al. (eds) *Health Care Systems Engineering*. Cham: Springer International Publishing, 2020, pp. 231–240.

37. Johnson K, Johnson CE, Porter L, et al. Streamlining Throughput with the Implementation of a CT Coordinator. 56.

38. White BA, Yun BJ, Lev MH, et al. Applying Systems Engineering Reduces Radiology Transport Cycle Times in the Emergency Department. *West J Emerg Med* 2017; 18: 410–418.

39. Boland GW, Duszak R. Modality Access: Strategies for Optimizing Throughput. *J Am Coll Radiol* 2015; 12: 1073–1075.

40. Kruskal JB, Reedy A, Pascal L, et al. Quality Initiatives: Lean Approach to Improving Performance and Efficiency in a Radiology Department. *RadioGraphics* 2012; 32: 573–587.

41. Amaratunga T, Dobranowski J. Systematic Review of the Application of Lean and Six Sigma Quality Improvement Methodologies in Radiology. *J Am Coll Radiol* 2016; 13: 1088-1095.e7.

42. CIHI. Canada's Health workforce | Data Tables, https://www.cihi.ca/en/health-workforce (accessed 17 September 2020).

43. Giess CS, Ip IK, Cochon LR, et al. Predictors of Self-Reported Burnout Among Radiology Faculty at a Large Academic Medical Center. *J Am Coll Radiol JACR*. Epub ahead of print 4 July 2020. DOI: 10.1016/j.jacr.2020.01.047.

44. Ferguson C, Low G, Shiau G. Burnout in Canadian Radiology Residency: A National Assessment of Prevalence and Underlying Contributory Factors. *Can Assoc Radiol* J 2020; 71: 40–47.

45. Zha N, Patlas MN, Neuheimer N, et al. Prevalence of Burnout among Canadian Radiologists and Radiology Trainees. *Can Assoc Radiol J* 2018; 69: 367–372.

46. Zha N, Neuheimer N, Patlas MN. Etiology of Burnout in Canadian Radiologists and Trainees. *Can Assoc Radiol J* 2020; 0846537120904452.

47. Tawfik DS, Scheid A, Profit J, et al. Evidence Relating Health Care Provider Burnout and Quality of Care: A Systematic Review and Meta-analysis. *Ann Intern Med* 2019; 171: 555.

48. Guerra J, Patrício M. Burnout in radiation therapists: Systematic review with meta-analysis. *Eur J Cancer Care* (Engl); 28. Epub ahead of print May 2019. DOI: 10.1111/ecc.12938.

49. Hall LH, Johnson J, Watt I, et al. Healthcare Staff Wellbeing, Burnout, and Patient Safety: A Systematic Review. *PLOS ONE* 2016; 11: e0159015.

50. Dewa CS, Loong D, Bonato S, et al. The relationship between physician burnout and quality of healthcare in terms of safety and acceptability: a systematic review. *BMJ Open 2017*; 7: e015141.

51. Canadian Association of Medical Radiation Technologists | A Look Into The CAMRT Mental Health Survey Results, https://www.camrt.ca/blog/2020/01/29/a-look-into-the-camrt-mental-health-survey-results/ (accessed 14 September 2020).

52. Zychla L. State of the Profession: Mental health. Presented to Sonography Canada's 37th Annual Conference, May 24, 2019.

53. Spoorthy MS, Pratapa SK, Mahant S. Mental health problems faced by healthcare workers due to the COVID-19 pandemic–A review. *Asian J Psychiatry* 2020; 51: 102119.

54. CADTH. *Clinical Decision Support Systems for Appropriate Medical Imaging: Clinical Evidence and Cost-Effectiveness*. RC1061-000, Ottawa, ON: CADTH, https://cadth.ca/clinical-decision-support-systems-appropriate-medical-imaging-clinical-evidence-and-cost-0 (14 January 2019, accessed 16 September 2020).

55. CAMRT. Five Things Medical Radiation Technologists and Patients Should Question. *Choosing Wisely Canada*, https://choosingwiselycanada.org/medical-radiation-technology/ (2018, accessed 16 September 2020).

56. Canadian Association of Radiologists. Five things physicians and patients should question in radiology. *Choosing Wisely Canada*, https://choosingwiselycanada.org/radiology/ (2019, accessed 16 September 2020).

57. Caffery LJ, Farjian M, Smith AC. Telehealth interventions for reducing waiting lists and waiting times for specialist outpatient services: A scoping review. *J Telemed Telecare* 2016; 22: 504–512.

58. Shehata F, Posner G, Afkham A, et al. Evaluation of an Electronic Consultation Service in Obstetrics and Gynecology in Ontario. *Obstet Gynecol* 2016; 127: 1033–1038.

59. Bradi AC, Sitwell L, Liddy C, et al. Ask a neurologist: What primary care providers ask, and reducing referrals through eConsults. *Neurol Clin Pract* 2018; 8: 186–191.

60. Liddy C, Drosinis P, Deri Armstrong C, et al. What are the cost savings associated with providing access to specialist care through the Champlain BASE eConsult service? A costing evaluation. *BMJ Open* 2016; 6: e010920.

61. Walker D, Macdonald DB, Dennie C, et al. Electronic Consultation Between Primary Care Providers and Radiologists. *Am J Roentgeno*l 2020; 1–5.

62. Menezes RJ, Kavanagh J, Latif E, et al. Bridging the Gap Between Radiology and Primary Care: Expansion and Sustainability of a Medical Imaging Call Center Model. *J Am Coll Radiol* 2020; S1546144020307857.

63. Wait Time Alliance. *Canadian still waiting too long for health care*, https://www.waittimealliance.ca/wp-content/uploads/2014/05/2013_Report_Card.pdf (accessed 11 September 2020).

64. Improving Access to MRI through Central Intake – Vancouver Coastal Health, http://www.vch.ca/for-health-professionals/resources-updates/mri-central-intake (accessed 17 September 2020).

65. MRI Central Intake | The Ottawa Hospital, https://www.ottawahospital.on.ca/en/mricentralintake/ (accessed 23 September 2020).

66. van Sambeek JRC. *Smarter imaging management: operations management for radiology*. PhD, University of Twente. Epub ahead of print 4 May 2018. DOI: 10.3990/1.9789402810134.

67. Morawska L, Milton DK. It is Time to Address Airborne Transmission of COVID-19. *Clin Infect Dis*. DOI: 10.1093/cid/ciaa939.

68. Guo Z-D, Wang Z-Y, Zhang S-F, et al. Aerosol and Surface Distribution of Severe Acute Respiratory Syndrome Coronavirus 2 in Hospital Wards, Wuhan, China, 2020 – Volume 26, Number 7—July 2020 – Emerging Infectious Diseases journal – CDC. DOI: 10.3201/eid2607.200885.

69. Huang H-H, Yen DH-T, Kao W-F, et al. Declining Emergency Department Visits and Costs During the Severe Acute Respiratory Syndrome (SARS) Outbreak. *J Formos Med Assoc* 2006; 105: 31–37.

70. Chang H-J, Huang N, Lee C-H, et al. The Impact of the SARS Epidemic on the Utilization of Medical Services: SARS and the Fear of SARS. *Am J Public Health* 2004; 94: 562–564.

71. Rosenbaum L. The Untold Toll — The Pandemic's Effects on Patients without Covid-19. *N Engl J Med*. Epub ahead of print 17 April 2020. DOI: 10.1056/NEJMms2009984.

72. Agarwal M, Udare A, Patlas M, et al. Effect of COVID-19 on computed tomography usage and critical test results in the emergency department: an observational study. *CMAJ Open* 2020; 8: E568–E576.

73. Deerberg-Wittram J, Knothe C. Do Not Stay at Home: We Are Ready for You. *NEJM Catal Innov Care Deliv*, https://catalyst.nejm.org/doi/abs/10.1056/CAT.20.0146 (2020, accessed 16 September 2020).

74. Wong L, Hawkins J, Langness S, et al. Where Are All the Patients? Addressing Covid-19 Fear to Encourage Sick Patients to Seek Emergency Care. *NEJM Catal Innov Care Deliv*, https://catalyst.nejm.org/doi/abs/10.1056/CAT.20.0193 (2020, accessed 14 September 2020).

75. Schlemper J, Caballero J, Hajnal JV, et al. A Deep Cascade of Convolutional Neural Networks for Dynamic MR Image Reconstruction. *IEEE Trans Med Imaging* 2018; 37: 491–503.

76. Lee D, Yoo J, Tak S, et al. Deep Residual Learning for Accelerated MRI Using Magnitude and Phase Networks. *IEEE Trans Biomed Eng* 2018; 65: 1985–1995.

77. Zhang Z, Romero A, Muckley MJ, et al. Reducing Uncertainty in Undersampled MRI Reconstruction with Active Acquisition. *ArXiv190203051 Cs*, http://arxiv.org/abs/1902.03051 (2019, accessed 23 September 2020).

78. Catalyst N. What Is Patient-Centered Care? *NEJM Catal*, https://catalyst.nejm.org/doi/abs/10.1056/CAT.17.0559 (2017, accessed 23 September 2020).

79. CMPA Good Practices Guide – Who owns the medical record?, https://www.cmpa-acpm.ca/serve/docs/ela/goodpracticesguide/pages/communication/Documentation/who_owns_the_medical_record-e.html (accessed 23 September 2020).

80. Paschou M, Sakkopoulos E, Tsakalidis A. APPification of hospital healthcare and data management using QRcodes. *IISA 2013*. Epub ahead of print 2013. DOI: 10.1109/IISA.2013.6623716.

81. What is Appification | IGI Global, https://www.igi-global.com/dictionary/the-appification-of-literacy/50128 (accessed 16 September 2020).

82. Tang A, Tam R, Cadrin-Chênevert A, et al. Canadian Association of Radiologists White Paper on Artificial Intelligence in Radiology. *Can Assoc Radiol J* 2018; 69: 120–135.

83. Goel AK, DiLella D, Dotsikas G, et al. Unlocking Radiology Reporting Data: an Implementation of Synoptic Radiology Reporting in Low-Dose CT Cancer Screening. *J Digit Imaging* 2019; 32: 1044–1051.

84. Schwartz LH, Panicek DM, Berk AR, et al. Improving Communication of Diagnostic Radiology Findings through Structured Reporting. *Radiology* 2011; 260: 174–181.

85. Wetterauer C, Winkel DJ, Federer-Gsponer JR, et al. Structured reporting of prostate magnetic resonance imaging has the potential to improve interdisciplinary communication. *PLoS ONE*; 14. Epub ahead of print 19 February 2019. DOI: 10.1371/journal.pone.0212444.

86. Sala E, Freeman S. Structured reporting of pelvic MRI leads to better treatment planning of uterine leiomyomas. *Eur Radiol* 2018; 28: 3007–3008.

87. Reporting and Data Systems, https://www.acr.org/Clinical-Resources/Reporting-and-Data-Systems (accessed 17 September 2020).

88. Tan N, Bavadian N, Lyons P, et al. Flipped Classroom Approach to Teaching a Radiology Medical Student Clerkship. J *Am Coll Radiol* 2018; 15: 1768–1770.

89. O'Connor EE, Fried J, McNulty N, et al. Flipping Radiology Education Right Side Up. *Acad Radiol* 2016; 23: 810–822.

90. Darras KE, Spouge RJ, de Bruin ABH, et al. Undergraduate Radiology Education During the COVID-19 Pandemic: A Review of Teaching and Learning Strategies. *Can Assoc Radiol J* 2020; 0846537120944821.

91. Kulkarni S, Jha S. Artificial Intelligence, Radiology, and Tuberculosis: A Review. *Acad Radio*l 2020; 27: 71–75.

92. Lakhani P, Sundaram B. Deep Learning at Chest Radiography: Automated Classification of Pulmonary Tuberculosis by Using Convolutional Neural Networks. *Radiology* 2017; 284: 574–582.

93. Jaremko JL, Azar M, Bromwich R, et al. Canadian Association of Radiologists White Paper on Ethical and Legal Issues Related to Artificial Intelligence in Radiology. *Can Assoc Radiol J J Assoc Can Radiol* 2019; 70: 107–118.

94. Mobile Mammography Service, http://www.bccancer.bc.ca/screening/breast/find-a-clinic/mobile-mammography-service (accessed 11 September 2020).

95. Sampa MB, Hoque MR, Islam R, et al. Redesigning Portable Health Clinic Platform as a Remote Healthcare System to Tackle COVID-19 Pandemic Situation in Unreached Communities. *Int J Environ Res Public Health*; 17. Epub ahead of print 30 2020. DOI: 10.3390/ijerph17134709.

96. Chia AQX, Cheng LT-E, Wijaya L, et al. Chest Radiographs and CTs in the Era of COVID-19: Indications, Operational Safety Considerations and Alternative Imaging Practices. *Acad Radiol* 2020; 27: 1193–1203.

97. Schieda N, Maralani PJ, Hurrell C, et al. Updated Clinical Practice Guideline on Use of Gadolinium-Based Contrast Agents in Kidney Disease Issued by the Canadian Association of Radiologists. *Can Assoc Radiol J* 2019; 70: 226–232.

98. Schieda N, Blaichman JI, Costa AF, et al. Gadolinium-Based Contrast Agents in Kidney Disease: Comprehensive Review and Clinical Practice Guideline Issued by the Canadian Association of Radiologists: *Can Assoc Radiol J*. Epub ahead of print 1 May 2018. DOI: 10.1016/j.carj.2017.11.002.

99. CADTH. *Canadian Medical Imaging Inventory Survey Data, 2019-2020 [unpublished]*. Ottawa, ON, August 2020.

Appendix A – Data Sources

The Radiology Resilience Task Force collected data on what we have learned, and what we know about the status of radiology services in a new COVID-19 environment. We used the following data sources for the development of our report.

CAR Provincial and Regional Wait Time Data Survey

From June – August 2020, we surveyed radiology administrative directors across Canada to collect provincial wait time data. For some provinces we were able to collect a centralized inventory of wait lists or number of examinations performed (AB, SK, MB, NS, PEI). For provinces without a centralized inventory (BC, QC, ON, NL), the survey was addressed directly to administrative directors of imaging departments for a specific region or hospital. We collected data for the following modalities: CT, MRI, ultrasound (US), and mammography. Our data analysis was validated by experts. To mitigate the lack of complete data, we pooled the available data by averaging it by the proportion of habitants in each province and using only relative values. One assumption is that the relative values which we apply to all of Canada may be weighted towards centres which did provide data, likely larger academic centres.

We opted to not include the mammography data as it seemed weighted toward high priority level patients and did not provide an accurate representation on the status of mammography in Canada. One assumption is that the relative values which we apply to all of Canada may be weighted towards centres which did provide data – likely larger academic centers.

National and International Radiology Directors Survey

(Participation rate ≈ 49%; n = 29)

From June – July 2020 we sent a survey using Microsoft forms to the Canadian Administrative Directors Group (n = 18) to collect information in the following key areas: CT and MRI equipment productivity (output per hour, or similar measures); Physical space modification of radiology departments/services; Responsiveness on new COVID-19 related safety and workflow; Remote work and access to information technology (March 2019 compared to March 2020). The same survey questions were translated and sent to a list of radiology directors in Quebec (n = 35) and to a list of international radiology colleagues of the CAR (n = 6).

CAR Resumption and Resilience of Radiology Membership Survey

(Participation rate ≈ 9%; n = 103)

In August 2020, the CAR sent a survey using Microsoft forms to its membership to collect feedback on the impact that COVID-19 has had on radiologists across Canada.

CAMRT survey on Personal Protection Equipment for MRTs during the COVID-19 Crisis

(n = 2991)

CAMRT conducted a survey on Personal Protective Equipment for MRTs during the COVID-19 Crisis.

CAMRT COVID-19 Health Human Resources Survey

(n = 40)

CAMRT conduced a survey to their membership and the purpose was to understand any changes to policy, workload, and patient care from the perspective of management.

Canadian Medical Imaging Inventory (CMII) 2020

The Canadian Medical Imaging Inventory (CMII) collects data, via a web-based survey, from all health care facilities across Canada that operate advance imaging equipment including: CT, MRI, single-photon emission computed tomography (SPECT), PET-CT, PET-MRI, single-photon emission computed tomography–computed tomography (SPECT-CT). An up-to-date inventory of medical imaging equipment can help with planning for upgrades, installations, replacements, and decommissioning. It can also provide valuable insights into usage trends over time, patient access, appropriateness, and service delivery. In 2015, CADTH assumed the task of conducting a biennial survey of medical imaging providers in Canada, following the Canadian Institute for Health Information's (CIHI's) data collection until 2012. Our report used some of the results from the 2019 data collection with permission from CADTH.[99] The CMII 2020 will be published later in 2020. https://cadth.ca/imaginginventory

Appendix B – National and International Radiology Directors Survey Questions

Background

1. What is your province?
2. Did you experience any delays with your nuclear medicine imaging (I.e. PET/CT Scans)?
    a. Yes
    b. No
    c. If yes, explain the main issue(s) concerning the delay with your nuclear medicine imaging.

Physical Space Modifications

3. Have you made any significant physical space or utilization modifications for your institution(s) due to COVID-19?
    a. Yes
    b. No

4. If yes, specify the physical space or utilization modifications you have made (check all that apply).
    a. Installing physical barriers (i.e. Plexiglas)
    b. Enhanced use of mobile X-Ray systems
    c. Divide areas to accommodate the different categories of patients (i.e. confirmed, suspected)
    d. Dedicated entrance, passages and waiting rooms
    e. Decrease foot traffic in radiology reading rooms
    f. Addition of negative pressure devices
    g. Acquire additional reading rooms or offices for radiologists
    h. Using virtual tools (e.g. Teams) for reading out with trainees, and going over images with referring physicians
    i. Other

5. What has worked well regarding physical space or utilization modifications to manage patient flow for your institution(s)?

Responsiveness on Safety, Scheduling and Workflow

6. Rate the usefulness of the following COVID-19 Radiology Guidelines [Extremely useful, very useful, moderately useful, slightly useful, not useful at all, no opinion].
    a. Institutional radiology COVID-19 guidelines
    b. Provincial Ministries of Health COVID-19 guidelines
    c. CAR COVID-19 guidelines
    d. Other (please specify below).

7. Have you needed to re-task or hire additional staff to adapt to the COVID-19 specific workflow requirements?
    a. Yes
    b. No

8. If yes, please identify the type of position individuals have been re-tasked or hired into (check all that apply)?
    c. Infection prevention and control (e.g. cleaning)
    d. Administrative
    e. Reception
    f. Technologists
    g. Physicians
    h. Other

9. What has worked well in terms of schedule and/or workflow modifications to drive safe patient throughput (check all that apply)?
    - Extended hours of imaging equipment
    - Extended hours of staff
    - Changing scheduling template to allow more time and/or exams
    - Grouping patients according to COVID-19 status (I.e. optimized scheduling)
    - Increase capacity for remote interpretations
    - Other

Budget

10. Did you receive any additional budget specifically for COVID-19 related expenditures?
    a. Yes
    b. No

11. If yes, specify how you have used or plan to use the additional COVID-19 related budget (check all that apply)?
    a. Personal protective equipment (PPE)
    b. Physical distancing measures
    c. Cleaning protocols
    d. Imaging equipment
    e. Staff training
    f. Other

Remote work

12. Specify the estimated proportion of remote work for radiology staff during the following conditions: pre-COVID-19, current state, future projections?

Proportion of remote work	**Pre- COVID-19**	**Current state**	**Future Projections**
0-25%			
25-50%			
50-75%			
75-100%			

Overall Lessons Learned

13. Do you have any important lessons learned that you would like to share with our Canadian radiology community?

Appendix C – CAR Resumption and Resilience of Radiology Membership Survey Questions

1. Did you read the CAR Radiology Resumption of Clinical Services Report?
    a. Yes
    b. No

2. What current level of imaging volume are you experiencing compared to this time last year (or just pre-COVID-19)
    a. Over 100%
    b. 80-100%
    c. 60-80%
    d. 40-60%
    e. 20-40%

3. Has your daily practice returned to stable operations? Meaning, things are different (or not) but relatively stable.
    a. Yes
    b. No
    c. Getting there

4. Has your practice/health authority accommodated your ability to work from home, or are you able to work in areas of the hospital that allows social distancing?
    a. Yes
    b. No

5. Identify any physical space or utilization modifications that have occurred in your practice (check all that apply).
    a. Installing physical barriers (i.e. Plexiglas)
    b. Enhanced use of mobile X-Ray systems
    c. Divide areas to accommodate the different categories of patients (i.e. confirmed, suspected)
    d. Dedicated entrance, passages and waiting rooms
    e. Decrease foot traffic in radiology reading rooms
    f. Addition of negative pressure devices
    g. Acquire additional reading rooms or offices for radiologists
    h. Using virtual tools (e.g. Teams) for reading out with trainees, and going over images with referring physicians
    i. Other

6. Is your practice/health authority making efforts to address the backlog of radiology imaging caused by COVID-19?
    a. Yes
    b. No
    c. Uncertain

7. Do you have confidence in the plan that is been put forward to address the needs of your patient population?
    a. Yes
    b. No

8. What percent of pre-COVID patient throughput is your practice/health authority able to achieve under new measures related to cleaning and social distancing?
    a. 0–19%
    b. 20–39%
    c. 40–59%
    d. 60–79%
    e. 80– 00%

9. Which new piece of imaging equipment would most positively impact the capacity to meet patient need at your department/hospital/clinic?
    a. A new MRI
    b. A new CT
    c. A portable X-ray
    d. An ultrasound

10. Which additional human resources are needed to meet the current demand and address the backlog of imaging requests (check all that apply)?
    a. Infection prevention and control (e.g. cleaning)
    b. Administrative
    c. Reception
    d. Technologists
    e. Physicians
    f. No additional human resources are required

11. Which new and/or improved IT system would most positively impact the ability of your department/hospital/clinic to meet current demand and address the backlog of imaging requests?
    a. PACS (to optimize image management and facilitate WFH/remote reading)
    b. Unified EHR (to facilitate sharing of imaging studies and reports outside of hospital/health system)
    c. Clinical Decision Support (CDS) tool (to ensure appropriateness of referrals)

12. Will the development and deployment of AI-based tools positively impact your ability (and the ability of your department or clinic) to meet the current demand and address the backlog of imaging requests? Examples could include: patient scheduling apps, throughput optimization tools, assistive protocolling based on clinical indications, assistive reporting tools.
    a. Yes
    b. No

13. What type of AI-based tool or informatics project do you anticipate will have the greatest impact on your practice?

14. What timeline do you anticipate that AI tools will be implemented and/or have an effect on your practice?
    a. Within the next 12 months
    b. 12-24 months from now
    c. 24-36 months from now
    d. More than 36 months from now
    e. I do not think that AI tools will be implemented or have an effect on my practice

15. Do you have any important lessons learned that you would like to share with our Canadian radiology community?