Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Clinical Perspective

The bug stops with me: Prevention of COVID-19 nosocomial transmission during radiographic procedures

Ai Ling Heng a*, Chin Chin Ooi abc, Benjamin Jun Wen Eu a, Yen San Kiew a, Agnes Sau Kheng Wong d and Kun Da Zhuang d

a Radiography Unit, Division of Radiological Sciences, Singapore General Hospital, Singapore
b Duke-NUS Medical School, Singapore
c Singapore Institute of Technology (SIT), Health and Social Sciences Cluster, 10 Dover Drive, 138683, Singapore
d Division of Radiological Sciences, Department of Vascular and Interventional Radiology, Singapore General Hospital, Singapore

ABSTRACT

Introduction: Nosocomial transmission of Coronavirus Disease 2019 (COVID-19) is a preventable risk to the patient population and radiographer workforce. This article aims to describe the prevention of COVID-19 nosocomial transmission during radiographic procedures by the utilization of stringent infection prevention measures at a leading tertiary hospital in Singapore.

Methods: The implemented measures are the appropriate use of personal protective equipment, staff education, infection controls measures such as equipment disinfection, physical distancing and segregation of staff and patients.

Results: Despite the handling of 1637 COVID-19 cases as of July 25, 2020, there has not been a single case of known nosocomial transmission of the disease in the institution.

Discussion: The absence of nosocomial transmission suggests that the implemented measures are adequate. These measures will need to be sustainable for the long term in order to ensure continued success.

Conclusion: Radiographers are a crucial part of the team in the fight against COVID-19 and are at risk of contracting COVID-19. Strict adherence to appropriate infection control measures is essential for the safety of Radiology staff and their patients, and the successful control of this pandemic.

RÉSUMÉ

Introduction : La transmission nosocomiale de la maladie à coronavirus de 2019 (COVID-19) est un risque qui peut être prévenu pour les patients et le personnel de radiographie. Cet article vise à décrire la prévention de la transmission nosocomiale de la COVID-19 durant les procédures de radiographie par l’utilisation de mesures strictes de prévention de la transmission nosocomiale dans un grand hôpital de soins tertiaires à Singapour.

Méthodologie : Les mesures appliquées sont l’utilisation appropriée de l’équipement de protection, l’éducation du personnel, les mesures de contrôle des infections comme la désinfection de l’équipement, la distanciation physique et la ségrégation du personnel et des patients.

Résultats : Malgré le fait que 1 637 patients atteints de la COVID-19 aient été traités en date du 25 juillet 2020, il n’y a pas eu un seul cas connu de transmission nosocomiale de la maladie dans cet établissement.

Discussion : L’absence de transmission nosocomiale permet de penser que les mesures appliquées sont suffisantes. Ces mesures devront être durables à long terme pour assurer un succès continu.

Conclusion : Les radiographes sont une partie cruciale de l’équipe de lutte contre la COVID-19 et courent le risque de contracter la maladie. Un respect strict des mesures de contrôle des infections appropriées est essentiel pour la sécurité des radiographes et de leurs patients, ainsi qu’au contrôle fructueux de cette pandémie.
Introduction

Nosocomial transmission during the Coronavirus Disease 2019 (COVID-19) global pandemic, which has since surpassed the severe acute respiratory syndrome (SARS) outbreak in 2003 in terms of spread and mortality, is an undesirable outcome that no healthcare institution would welcome. Not only does it expose the vulnerable population in the healthcare setting, it also places the healthcare workers (HCWs) who are greatly needed to fight this pandemic at risk. The World Health Organization (WHO) - China Joint Mission on COVID-19 reported that 2055 HCWs from 476 hospitals across China were infected with the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as of February 20, 2020.1 This number is expected to rise not just in China but likely in other parts of the world as well.

SARS-CoV-2 is capable of human-to-human transmission and is spread via respiratory droplets and fomites during close unprotected contact.1 Viable viral particles have been isolated from surfaces up to 72 h after inoculation.2 Appropriate infection prevention and control measures taking into consideration staff protection and patient safety are required to contain and prevent the spread of COVID-19.

Radiographers may be exposed to SARS-CoV-2 during procedures such as radiography and Computed Tomography (CT) of the chest that are performed routinely to assess severity and progression of disease. However, the greatest risks likely occur during procedures such as ultrasound (US) and interventional radiology (IR) due to the prolonged patient contact. Protocols are therefore necessary to mitigate the risk of radiographers being infected to protect the other HCWs, patients and public. With these goals in mind, this paper aims to describe the prevention of COVID-19 nosocomial transmission during radiographic procedures utilizing stringent infection prevention and control at a leading tertiary hospital in Singapore.

Measures of infection prevention and control for radiographic procedures during COVID-19

Staff education

The experience with the 2003 SARS outbreak in which Singapore was one of the hardest hit countries has shown the importance of acquiring expert advice to refine procedures and review practices. These steps were vital to close any potential gaps and reinforce proper infection control techniques.3 Hospital staff have learned that it was critical to invest in staff education after the SARS outbreak in order to contain the spread of disease.

An infection control team consisting of representatives from each modality is tasked to educate, update and ensure adherence to hospital approved COVID-19 protocols at all times. At the onset of the outbreak, the team worked with the hospital’s Infection Prevention and Epidemiology unit to create specific instructions and protocols for each modality. These instructions and protocols are readily available on the hospital intranet for ease of access. Apart from the previous efforts in conducting the compulsory annual hand hygiene and infection prevention online module, mandatory hands-on refresher courses on personal protective equipment (PPE) are also conducted for all employees including housekeeping and administrative staff.

Hand hygiene

Proper hand hygiene is critical to prevent nosocomial transmission as the hands are the most frequent vector for transmission during radiographic procedures. In line with WHO recommendations, the hospital advocates4:

1. Washing with soap and water for hands that are visibly soiled
2. Using an alcohol-based hand rub (ABHR) for hands that are not visibly soiled
3. The five moments of hand hygiene which includes before touching a patient, before a clean or aseptic procedure, after body fluid exposure or risk, after touching a patient and after touching patient surroundings

To facilitate hand hygiene, ABHRs are provided in all procedure rooms, waiting area and along hospital corridors. The hospital was endorsed by WHO as one of the Global Hand Hygiene Expert Centre in 2011 following Singapore’s signing of the pledge to the “Clean Care is Safer Care” program.5

Table 1

Personal protective equipment used by the radiographers during the COVID-19 outbreak.

| Personal protective equipment                              | Routine general radiography, ultrasound and CT (computed tomography) scan procedures | Routine interventional radiology procedure | General radiography, ultrasound, CT (computed tomography) scan and interventional radiology procedures for suspect or positive COVID-19 patient |
|-------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------|---------------------------------------------------------------------------------------------|
| Surgical mask                                              | Yes                                                                                  | Yes                                      | No                                                                                          |
| N95                                                         | No                                                                                   | No                                       | Yes                                                                                          |
| Disposable fluid-resistant isolation gown                   | No                                                                                   | Yes                                      | Yes                                                                                          |
| Disposable surgical gloves                                  | Yes                                                                                  | Yes                                      | Yes                                                                                          |
| Goggles or face mask with visor                             | No                                                                                   | Yes                                      | Yes                                                                                          |
| Hair cap                                                    | No                                                                                   | Yes                                      | Yes                                                                                          |

Table 1

Personal protective equipment used by radiographers during COVID-19 outbreak.
**Personal protective equipment**

Inadequate personal protection was one of the main contributing factors leading to the high number of infected HCWs in China.\textsuperscript{6} PPE is necessary to diminish the risk of disease transmission.\textsuperscript{7}

Both the surgical mask and the N95 will protect the wearer from large droplets of blood or body fluids and the patient from the wearer’s respiratory emissions. Compared to the surgical mask, the N95 however, is capable of reducing wearer’s exposure to minute particles such as fine aerosolised droplets produced by coughing.\textsuperscript{8}

Eye protection such as goggles or face mask with visor is worn when performing procedures that may generate splashes or sprays of body fluids, or when the procedure is performed within 1.5 m of a coughing patient.\textsuperscript{9} Personalised goggles are distributed to radiographers in high risk area handling suspect or positive COVID-19 patients.

PPEs are stored in boxes as a one-stop storage solution for easy and convenient access. The location of the boxes is made known to all staff and the items are replenished each time they are used. As HCWs, all radiographers are trained in the proper steps to don and doff PPE with annual audits in place to ensure compliance. Table 1 summarizes the PPE used by radiographers during the COVID-19 outbreak.

In the radiology department, a baseline of 10 days’ worth of supplies is kept in the store to ensure PPE stocks are adequate to meet the hospital demand. Active monitoring of the PPE supplies on a daily basis is aided by the creation of a chart by the logistics section of the department.

At the time of writing this article, no shortage of PPE stocks has been reported. PPE stock is obtained directly from the national stockpile. According to the 2014 Ministry of Health (MOH) pandemic readiness and response plan from the national stockpile. According to the 2014 Ministry of Health (MOH) pandemic readiness and response plan for influenza and other acute respiratory diseases, a 3–6 month of PPE stock is maintained for the national hospitals and clinics. Resupply of PPE occurs when the PPE stockpiles fall below 90% of the baseline stock.\textsuperscript{10}

**Specific infection control protocol**

Prior to admission, PPE in the form of surgical masks are provided to patients suspected of having the COVID-19 infection once they fulfill the screening criteria set by the hospital. These patients are isolated and any accompanying persons and visitors who demonstrate any respiratory symptoms or have returned from overseas in the past 14 days are not allowed to enter the hospital’s premises. These patients will have their chest radiographs conducted on admission in the designated negative pressure rooms.

Subsequent general radiography (GR) and US imaging are obtained at the bedside where possible with designated imaging equipment to avoid transfer of patients. Radiographers work in pairs to handle COVID-19 patients, such that radiographers handling equipment will not be in contact with the patient and vice versa. After each procedure, the equipment is wiped down with the appropriate disinfectant wipes and terminal cleaning is performed. In our hospital, Medipal \textsuperscript{®} Disinfectant Wipes and Sodium hypochlorite 1000 ppm are used for surface and terminal cleaning respectively. These designated imaging equipment are parked in the isolation ward to prevent fomite transmission.

For studies that cannot be conducted bedside such as CT scan and certain IR procedures, the patient will be scheduled such that there is temporal segregation (for instance, scheduling COVID-19 cases to the afternoon, after the non-infected morning cases). The transport route will be via a planned specified route to minimize contact with other patients or HCW. Table 2 summarizes the infection control protocol for radiographic procedures during the COVID-19 outbreak.

A study conducted in the Huoshenshan Hospital in Wuhan, China has shown that the environment of the health care setting with COVID-19 patients represented a potentially high infection risk area for both HCWs and other close contacts.\textsuperscript{11} Enhanced cleaning as part of infection control is therefore critical in preventing nosocomial transmission. Terminal and ultraviolet (UV) cleaning are mandatory after completion of CT and IR procedures. During the cleaning procedure, doors to the procedure room are closed to allow efficient exchange of air in the negative pressure room which exchanges air at a minimum of 12 air changes per hour as recommended by MOH.\textsuperscript{9} After UV cleaning is completed, the room is closed for a further 20 min to ensure that room air is exchanged before it is open for routine procedures.

**Managing radiographers**

Measures are also in place to ensure that radiographers are fit for duty. It is mandatory for radiographers to undergo N95 mask fitting session. Radiographers who are pregnant, have asthma or chronic obstructive pulmonary disease or are certified unfit to wear the N95 mask by an Occupational Medicine Physician will be reassigned to low-risk areas requiring only surgical mask. These radiographers will also avoid participating in aerosol-generating procedures.

Radiographers are required to report their temperatures twice daily, even on off-duty days, via the online staff health surveillance system. Radiographers with respiratory symptoms are required to seek medical attention at the staff clinic to facilitate contact tracing should the need arises. Unwell radiographers with either travel or contact history or who has worked at a high-risk area will be isolated with swabs tests performed. In contrast, unwell radiographers without travel or contact history and has not worked at any high-risk area will be issued 5 days of medical leave to ensure full recovery before returning to duty (Fig. 1).

**Leveraging on technology**

In line with the national recommendations, the hospital has leveraged on the use of technology with the implementation of SafeEntry and TraceTogether. When used simultaneously, both SafeEntry and TraceTogether will furnish critical information required for contact tracing. SafeEntry, a national digital system which record entries and exits, is
Table 2
Infection control protocol for radiographic procedures during COVID-19 outbreak.

| Radiographic procedures | Routine protocol | Protocol for suspect or positive COVID-19 patient |
|-------------------------|------------------|--------------------------------------------------|
|                         | Performing location | Protocol after each scan | Performing location | Pre-procedural protocol | Post-procedural protocol |
| Ultrasound              | Ultrasound suite   | 1. Disinfectant wipes are used to clean the machine, probe, couch and door handles | Isolation ward | 1. Portable machine is covered with disposable transparent plastic cover | 1. The transparent plastic cover of machine is turned inside out before disposal |
|                         |                   | 1. Portable machine is covered with disposable transparent plastic cover |           | 2. Sterile disposable gel is applied onto the probe before covering it with a disposable probe sleeve | 2. The probe sleeve is removed |
|                         |                   | 2. Sterile disposable gel is applied onto the probe before covering it with a disposable probe sleeve |           | 3. The machine and probe are cleaned with disinfectant wipes | 3. The machine and probe are cleaned with disinfectant wipes |
|                         |                   | 3. The machine and probe are cleaned with disinfectant wipes |           | 4. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin | 4. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin |
|                         |                   | 4. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin |           | a Disposal is via the general bin if there is no blood spillage and visible stains have been wiped down with the disinfectant wipes as the waste is incinerated at 800 °C which would have destroyed the virus. |
| General radiography     | General radiography suite | 1. Disinfectant wipes are used to clean the x-ray tube, couch, control panel, vertical bucky and door handles | Isolation ward | 1. Portable machine and digital radiography detector are covered with disposable transparent plastic cover | 1. The transparent plastic cover of machine is turned inside out before disposal |
|                         |                   | 1. Portable machine and digital radiography detector are covered with disposable transparent plastic cover |           | 2. Portable machine and digital radiography detector are cleaned with disinfectant wipes | 2. The probe sleeve is removed |
|                         |                   | 2. Portable machine and digital radiography detector are cleaned with disinfectant wipes |           | 3. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin | 3. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin |
|                         |                   | 3. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin |           | a Disposal is via the general bin if there is no blood spillage and visible stains have been wiped down with the disinfectant wipes as the waste is incinerated at 800 °C which would have destroyed the virus. |
| CT (computed tomography) scan | CT suite      | 1. Disinfectant wipes are used to clean CT couch, immobilizing straps, mattress, door handle, patient slide and contrast injector | Negative pressure CT suite | 1. Equipment not required for the procedure are shifted to another room to minimize contamination. | 1. The plastic covers of machine are turned inside out before disposal |
|                         |                   | 1. Equipment not required for the procedure are shifted to another room to minimize contamination. |           | 2. The CT table, scan console monitors and contrast media injectors are covered with disposable plastic covers | 2. CT couch, immobilizing straps, mattress, door handle, patient slide and contrast injector are cleaned with disinfectant wipes |
|                         |                   | 2. The CT table, scan console monitors and contrast media injectors are covered with disposable plastic covers |           | 3. A sign indicating “Isolation case” is placed on the door as visual warning | 3. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin |
|                         |                   | 3. A sign indicating “Isolation case” is placed on the door as visual warning |           | a Disposal is via the general bin if there is no blood spillage and visible stains have been wiped down with the disinfectant wipes as the waste is incinerated at 800 °C which would have destroyed the virus. |
| Interventional radiology | Interventional radiology suite | 1. Imaging, clinical monitoring and other equipment are cleaned with disinfectant wipes | Interventional radiology suite | 1. Equipment not required for the procedure are shifted out to minimize contamination. | 1. The plastic covers of machine are turned inside out before disposal |
|                         |                   | 1. Equipment not required for the procedure are shifted out to minimize contamination. |           | 2. Required equipment will be wrapped in plastic covers. | 2. All equipment are cleaned with disinfectant wipes |
|                         |                   | 2. Required equipment will be wrapped in plastic covers. |           | 3. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin | 3. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin |
|                         |                   | 3. The plastic cover, probe sleeve and used disinfectant wipes are discarded into the general waste bin |           | a Disposal is via the general bin if there is no blood spillage and visible stains have been wiped down with the disinfectant wipes as the waste is incinerated at 800 °C which would have destroyed the virus. |
used at the hospital to log the check-in and out of employees and visitors. The TraceTogether app uses Bluetooth signals to record proximity data on phones with the app. This app can estimate the distance between users and how much time they spent in contact. The TraceTogether app complements SafeEntry by diminishing the time taken to identify potential close contacts of COVID-19 cases, which is vital in mitigating new waves of infection.12

Physical distancing

Physical distancing is critical to slow the spread of COVID-19 as it can be infectious before the onset of symptoms. Strict adherence to physical distancing measures will help reduce the risk of transmission and the number of radiographers quarantined should anyone in the team be infected.13 Application of physical distancing includes the segregation of radiographers to work in a consistent but smallest functional team at different locations. Movement of these team of radiographers are restricted within the same campus. Working hours and meal breaks are staggered as well. HCWs are encouraged to pack takeout meals for consumption in designated staff areas. Seats and tables are also arranged to provide a 1 m distance between HCWs during mealtime14 (Fig. 2).

Additionally, meetings and lectures are conducted with teleconferencing applications such as Zoom and WebEx. Interaction between different teams is minimized, especially during change of shift and movement across different work areas. Information and regular updates are posted via emails, chat groups and a dedicated COVID-19 page on the hospital intranet. Any non-critical events involving more than 10 people are cancelled. However, if such events are unavoidable, surgical masks must be worn by all attendees and the meeting duration should be kept as short as possible. Administrative staff who can perform their work by telecommuting from home will be allowed to do so to reduce the need to return to and congregate at the workplace.

Since 2019, patients are encouraged to skip the queue for payment after procedures under the hospital’s e-payment initiative where payment can be made online or via automated payment stations in the community. Crowding and long wait times are thus reduced, facilitating the observation of safe physical distancing.
As of July 25, 2020, there has not been a single case of infection among the radiographers despite the handling of 1637 COVID-19 cases, suggesting that the implemented measures have been adequate to prevent nosocomial transmission.

**Conclusion**

Radiographers are a crucial part of the team in the fight against COVID-19 and will be at risk of being infected in the course of their duty. Strict adherence to appropriate infection control measures is therefore essential both for the safety of HCWs and patients, and the outcome of this ongoing pandemic.

**Acknowledgements**

The authors would like to acknowledge all colleagues from the Division of Radiological Sciences, Singapore General Hospital for their efforts during the COVID-19 pandemic. We would like to thank Aw Lian Ping and Tan Chin Chong for their valuable contribution in the preparation of the manuscript.

**References**

1. World Health Organization. Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19). https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf. Accessed March 25, 2020.
2. van Doremalen N, Bushmaker T, Morris DH, et al. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *N Engl J Med*. 2020;382(16):1564–1567.
3. Lau TN, Teo N, Tay KH, et al. Is your interventional radiology service ready for SARS?: the Singapore experience. *Cardiovasc Intervent Radiol*. 2003;26(5):421–427.
4. World Health Organization. Guidelines on hand hygiene in health care. https://apps.who.int/iris/bitstream/handle/10665/44102/9789241597906_eng.pdf?sequence=1. Accessed July 12, 2020.
5. Ling ML, How KB. Impact of a hospital-wide hand hygiene promotion strategy on healthcare-associated infections. *Antimicrob Resist Infect Contr*. 2012;1(1):13.
6. Wang J, Zhou M, Liu F. Reasons for healthcare workers becoming infected with novel coronavirus disease 2019 (COVID-19) in China. *J Hosp Infect*. 2020;105(1):100–101.
7. Livingston E, Desai A, Berkwits M. Sourcing personal protective equipment during the COVID-19 pandemic. *J Am Med Assoc*. 2020;323:1912–1914. https://jamanetwork.com/journals/jama/fullarticle/2764031. Accessed April 5, 2020.
8. Health Science Authority. Guide to masks and respirators. https://www.hsa.gov.sg/consumer-safety/articles/guide-to-masks-and-respirators. Accessed July 12, 2020.
9. Ministry of Health. *The National Infection Prevention and Control Guidelines for Acute Healthcare Facilities*, 2017. https://www.moh.gov.sg/docs/librariesprovider5/diseases-updates/interim-pandemic-plan-public-ver-_april-2014.pdf. 2014. Accessed April 25, 2020.
10. Ministry of Health. Pandemic readiness and response plan for influenza and other acute respiratory diseases. https://www.moh.gov.sg/docs/librariesprovider5/diseases-updates/interim-pandemic-plan-public-ver-_april-2014.pdf. 2014. Accessed April 25, 2020.
11. Guo ZD, Wang ZY, Zhang SF, et. al. Aerosol and surface distribution of severe acute respiratory syndrome coronavirus 2 in hospital wards, Wuhan, China, 2020. *Emerg Infect Dis*. 2020;26(7):1583–1591.
12. Ministry of Manpower. Requirements for safe management measures at the workplace after circuit breaker period. https://www.mom.gov.sg/covid-19/requirements-for-sale-management-measures. Accessed May 11, 2020.
13. Lewnard JA, Lo NC. Scientific and ethical basis for social-distancing interventions against COVID-19. *Lancet Infect Dis*. 2020;20(6):631–633.
14. Chen RC, Cheng LT, Liang Lim JL, et al. Touch me not: safe distancing in radiology during coronavirus disease 2019 (COVID-19). *J Am Coll Radiol*. 2020;17(6):739–742.