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Original article

## Survival of SARS-CoV-2 and Other Pathogens in the Environment of a University Hospital and a Thai-Malaysia Border Control Post: A Cross-sectional Study

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### Abstract

The rapid global spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) since December 2019 has highlighted the importance of understanding its modes of transmission, including through large droplets, contact with contaminated surfaces (fomites), and airborne aerosols. Environmental factors such as ventilation conditions can influence SARS-CoV-2 transmission rates. The objective of this study was to investigate airborne transmission of SARS-CoV-2 and other respiratory pathogens in hospital and customs environments in Songkhla, Thailand, amidst the COVID-19 pandemic. Air monitoring was conducted at various locations, including hospital wards and customs offices, using multiple bioaerosol samplers. Two phases of sampling were carried out in August-September 2020 and in June-September 2021. Bioaerosol sampling was conducted using four types of samplers: N6 Single Stage Andersen Cascade Impactor, midjet impinger, liquid impinger, and polyvinyl chloride (PVC) filters. Additionally, a biosampler was utilized for measuring viable microbial load. Respiratory pathogens were identified using real-time RT-PCR assays. Frequencies, percentages, Pearson's correlation coefficient ( $r$ ), and linear regression were used for data analysis. Pathogen results were reported qualitatively (detected/non-detectable) and as percentages. No airborne transmission of SARS-CoV-2 or other respiratory pathogens was detected in the monitored environments during the study period. There were 3 potential risk areas of SARS-CoV-2 survival conditions with the relative humidity (45-50%RH) and temperate (24-25 °C), especially the isolation rooms did fall in the range allowing SARS-CoV-2 survival. There was no evidence of transmission of SARS-CoV-2 or other airborne pathogens in the

hospital or the Customs and Immigration environments. However, the relative humidity and temperature of ICU and isolation rooms were fit for SARS-CoV-2 survival. Therefore, the setting of ventilation system in both enclosed office and hospital should be considered the transmission of airborne pathogens.

**Keywords:** SARS-CoV-2; airborne transmission; university hospital; customs offices; air monitoring

## Introduction

Since 2019, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) quickly spread worldwide. Human-to-human transmission of SARS-CoV-2 occurs through large droplets from infected individuals talking, breathing, sneezing, or coughing nearby, or by contact transmission via contaminated surfaces or objects (fomites), and by aerosol particle transmission in poorly ventilated enclosed spaces<sup>(1,2)</sup>. Aerosols, with droplet diameter < 5 µm, can remain airborne for extended periods and travel beyond 6 feet (1.83 m), posing a risk as they can reach the lower respiratory tract<sup>(3,4)</sup>. Normal breathing generates droplets of 0.1–5.0 µm in size<sup>(5,6)</sup>, whereas speech in closed air environments generates droplet nuclei of 4 µm size or 12–21 µm droplets before dehydration<sup>(7)</sup>.

Airborne aerosol transmission of SARS-CoV-2 can occur in enclosed spaces with inadequate ventilation, such as hospitals. Studies have found the presence of SARS-CoV-2 in hospitals, and the intensive care units in Wuhan, China, were more contaminated than general wards. The virus was detected on various surfaces in hospitals, and in the air approximately 4 m away from patients<sup>(8)</sup>. In the United States, emergency departments had the highest concentration of SARS-CoV-2 RNA in aerosol particles ≤2.5 µm, and the nurse's station in the non-COVID-19 ward had the highest concentrations of aerosol particles >10 µm<sup>(9)</sup>. However, the human movement such as the

movement of people between countries at the border trade area during this crisis situation was important to monitor the airborne transmission of SARS-CoV-2 both indoor and outdoor and mostly previous studies were performed in the laboratory setting<sup>(10,11)</sup>.

To prevent the transmission of SARS-CoV-2 in the hospital, hospital management procedures were observed. However, there were some gaps in knowledge of SARS-CoV-2 airborne transmission. In addition, Songkhla Province has a long border section between Thailand and Malaysia, which is an important border trade area. Therefore, a large number of cases of COVID-19 might enter along this border segment. This study aimed to assess the airborne transmission of SARS-CoV-2 by investigating both viable and non-viable particles, as well as other respiratory pathogens within the work environments of a university hospital and customs and immigration checkpoints.

## Methods

Air monitoring was conducted at various locations, including hospital wards and customs offices, using multiple bioaerosol samplers as part of this cross-sectional study. The study was conducted in accordance with the Declaration of Helsinki and was approved by the University Human Research Ethics Committee (Approving Institutional Review Board Name: Faculty of Medicine, Prince of Songkla University,

IRB Reference Number: REC No. 63-255-9-2). All participants provided informed consent for participation.

#### Air Monitoring Sites

Air monitoring was carried out in two phases by specified the potential areas for airborne disease and easy to transmission people to people. Therefore, the OPDs and ICUs at the hospital and the Thai-Malaysia Border Control Post were purposive sampling, The first phase was carried out in August and September 2020 and involved monitoring at the COVID-19 intensive care unit (COVID-19-ICU) and the person under investigation (PUI) ward of a university hospital, and at the Sadao Immigration office and Customs check-point in Thailand. The relative humidity (%) and temperature (°C) were simultaneously measured along with air monitoring by using a direct-reading instrument (VelociCal, TSI, Germany).

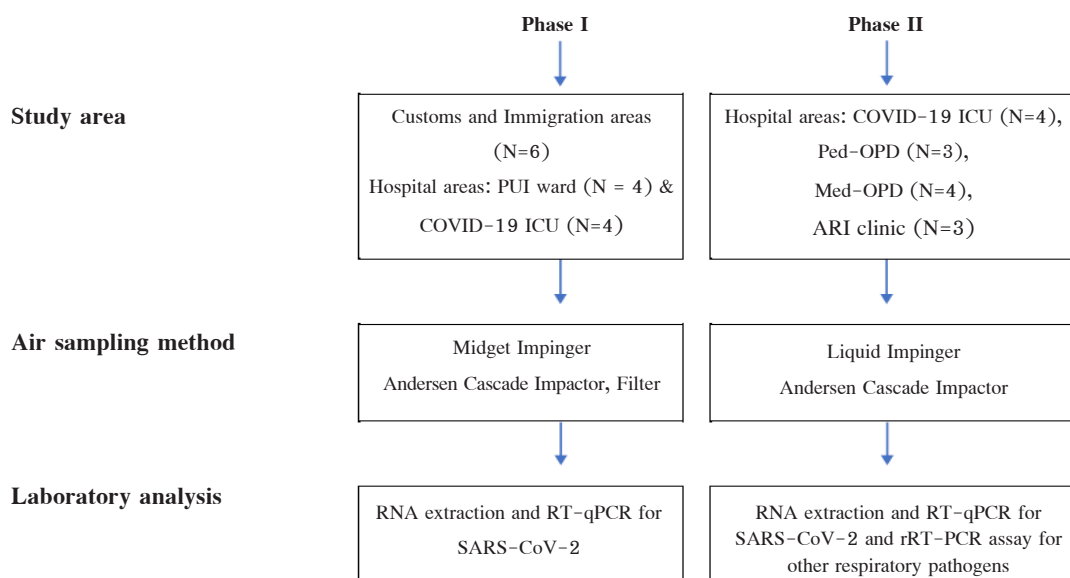
The second phase took place from June to Sep-

tember 2021, with air monitoring at the Internal Medicine Outpatient Department (Med-OPD), Paediatric Outpatient Department (Ped-OPD), Acute Respiratory Infection (ARI) clinic, and COVID-19-ICU of the university hospital (Figure 1). The relative humidity and temperature were reported in a previous study<sup>(12)</sup>.

#### Bioaerosol Sampling Technique

To comprehensively study bioaerosol sampler efficiencies, four types of bioaerosol samplers were used: (1) N6 Single Stage Andersen Cascade Impactor (Thermo Fisher Scientific, MA, USA) with the flow rate set at 28.3 L/min, (2) Impinger connected to a personal pump (Sensidyne, Inc., St Petersburg, FL, USA; SKC Inc., Eighty Four, PA, USA) with a design flow rate of 2 L/min, (3) Polyvinyl chloride (PVC) filters were attached in a 3-piece cassette holder and connected to a personal pump (Sensidyne, Inc., SKC Inc.) with a design flow rate of 2 L/min.

Figure 1. The flow chart of study design, air sampling and laboratory analysis



Abbreviations: ARI, acute respiratory infection; COVID-19, coronavirus disease; ICU, intensive care unit; IPD, inpatient department; Med-OPD, medical outpatient department; OPD, outpatient department; Ped-OPD, paediatric outpatient department; PUI, person under investigation; PVC, polyvinyl chloride; rRT-PCR, real-time reverse transcription polymerase chain reaction; RT-qPCR, reverse transcription-quantitative polymerase chain reaction; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2

and finally (4) a biosampler (SKC Inc.), with the flow rate set at 12 L/min, was used for measuring the viable microbial load. All sampling pumps were pre and post calibration and the field blanks were prepared for at least 10% of samples. The sampling time for all samplers were set at 1 hour while the Andersen Cascade Impactor was set at 5 minutes to avoid overloading the plates. All samples were kept in an icebox and transferred directly to the Immunology and Virology Unit for SARS-CoV-2 and other respiratory virus testing.

#### **RNA Extraction and RT-qPCR for SARS-CoV-2 Diagnosis**

Automated nucleic acid extraction was performed on all UTM samples using the MagDEA Dx system (Precision System Science Co., Ltd., Japan) according to the manufacturer's instructions. An aliquot of 50  $\mu$ L of RNA extract was obtained from 200  $\mu$ L of UTM sample, with the remaining UTM stored at -80 °C. RNA extractions were tested using the 2019 - nCoV nucleic acid diagnostic kit (Sansure Biotech Inc., Changsha, China). Furthermore, ORF1ab and N genes were used as the target regions, and human RNase P was used as an internal control (IC). The assay was designed to detect N on FAM, ORF1ab on ROX, and IC on the CY5 channel. According to the manufacturer, the lower detection limit of the test is 200 copies/mL.

Real-time RT-PCR procedures were conducted using the MA6000 real-time qPCR thermal cycler system (Sansure Biotech Inc.) with 10  $\mu$ L of the RNA extract under the following conditions: reverse transcription at 50°C for 30 min, followed by denaturation at 95°C for 1 min, 45 cycles at 95°C for 15 s for denaturation, and 60°C for 31 s for

annealing. Finally, the instrument was cooled at 25°C for 10 s. Positive SARS-CoV-2 results were reported when the standard curves of FAM, ROX, or CY5 channel showed an S-shape with Ct values of 40 or less. To avoid RNA degradation, samples were processed on the same day that they were extracted.

#### **Other Respiratory Pathogen Detection**

The Allplex Respiratory Panel (Seegene, Seoul, South Korea) was used in this study. It comprised four different panels in a multiplex one-step rRT-PCR assay based on MuDT technology. The platform allowed visualisation of the amplification curves and Ct values. Nucleic acid extracts from all UTM samples were tested using the Allplex for the detection of various respiratory pathogens as per the manufacturer's instructions.

The same RNA extracts from all UTM samples were tested using the Allplex following the manufacturer's instructions. Panel 1 was used to detect Flu A, Flu B, RSV A, RSV B, and Flu A subtypes H1, H1pdm09, and H3. Panel 2 was used to detect PIV-1, PIV-2, PIV-3, PIV-4, AdV, hMPV, and HEV. Panel 3 was used to detect RV, human coronavirus OC43, 229E, and NL63, and HBoV. Seven respiratory bacteria (BPP, BP, CP, HI, LP, MP, and SP) were detected by amplifying nucleic acid extracts from sample suspensions using Allplex Detection for Panel 4. The results were analysed using Seegene viewer software ver. 3.17 type A. The negative result or non-detectable indicates the result was no typical S-shape or amplification curves detected at Ct >40. While ORF1ab and N genes are SARS-CoV-2 genes, and the RNase P gene (human housekeeping gene) was used as an internal control (IC).

### Data Analysis

Descriptive statistics included frequency and percentage. To determine the relationship between relative humidity and temperature, the Pearson correlation coefficient (r) and linear regression was used. Laboratory analysis of pathogens was presented in qualitative manner as either detected or non-detectable, and a percentage to describe the overall results.

## Results

### Bioaerosol Monitoring

In this study there were four groups of respiratory pathogens other than SARS-CoV-2 were identified in Phase II of this study: Group 1: influenza A virus (Flu A), influenza A-H1 (Flu A-H1), influenza A-H1pdm09 (Flu A-H1pdm09), influenza A-H3 (Flu A-H3), influenza B virus (Flu B), respiratory syncytial virus A (RSV A), and respiratory syncytial virus B (RSV B). Group 2: adenovirus (AdV), human enterovirus (HEV), metapneumovirus (MPV), parainfluenza virus 1 (PIV-1), parainfluenza virus 2

(PIV-2), parainfluenza virus 3 (PIV-3), and parainfluenza virus 4 (PIV-4). Group 3: human bocavirus 1/2/3/4 (HBoV), coronavirus 229E (229E), coronavirus NL63 (NL63), coronavirus OC43 (OC43), and human rhinovirus (HRV). And Group 4: *Bordetella parapertussis* (BPP), *Bordetella pertussis* (BP), *Chlamydomphila pneumoniae* (CP), *Haemophilus influenzae* (HI), *Legionella pneumophila* (LP), *Mycoplasma pneumoniae* (MP), and *Streptococcus pneumoniae* (SP) were identified. However, all bioaerosol samples showed negative results (100%).

During Phase I, only 3 of 42 samples (7%) had detectable human housekeeping gene but no typical S-shape or amplification curves detected at Ct > 40. These 3 potential risk areas included: (1) the documentation check (truck) point, (2) the temperature screening point of the customs and immigration area at the Sadao border where primarily using a general ventilation system in a crowded area (truck drivers and passengers) and (3) PUI where a limited space around the patient beds (Table 1). During Phase II, monitoring of airborne pathogens was intensified, but

**Table 1 Comparison of bioaerosol sampling techniques for COVID-19 detection (Phase 1)**

Location	Sampling point	ORF1ab gene <sup>1</sup>			N gene <sup>2</sup>			IC (RNase P gene)			Interpreting report
		Filtration	Impinger	Impaction	Filtration	Impinger	Impaction	Filtration	Impinger	Impaction	
PUI ward	Isolation room no. 4	not detected			negative			not detected			Undetectable
	Nurse counter	not detected			negative			not detected			Undetectable
	Patient bed No. 2	not detected			negative			ND	ND	40.93	Undetectable
	PUI ward entrance	not detected			negative			not detected			Undetectable
Customs and Immigration office	Immigrant registration	not detected			negative			not detected			Undetectable
	Health desk screening point	not detected			negative			not detected			Undetectable
	Documentation check point	not detected			negative			ND	40.28	ND	Undetectable
	Stamping passport	not detected			negative			not detected			Undetectable
	Temperature screening point	not detected			negative			ND	ND	40.23	Undetectable
	Empty truck check-point	not detected			negative			not detected			Undetectable

Note: 1. ORF1ab and N genes are SARS-CoV-2 genes, and the RNase P gene (human housekeeping gene) was used as an internal control (IC).

2. Amplification curves detected at Ct >40 were reported as negative.

ND (not detected) indicates the result was considered as not detected because no typical S-shape amplification curve was detected.

no SARS-CoV-2 or other airborne pathogens were detected.

**Relative humidity and temperature**

The average relative humidity percentages of the Customs checkpoint, PUI, and COVID-19-ICU were  $77.10 \pm 3.05$ ,  $63.29 \pm 8.76$  and  $71.90 \pm 6.70$ , respectively. The average temperatures of them were  $28.99 \pm 0.62$ ,  $25.68 \pm 2.58$  and  $25.40 \pm 1.54$  Celsius degree, in the same order. However, the relative humidity and temperature were not strongly correlated ( $R^2=0.2875$ ) but should be considered at the closed area environments that fit for SAR-CoV-2 survival (Figure 2).

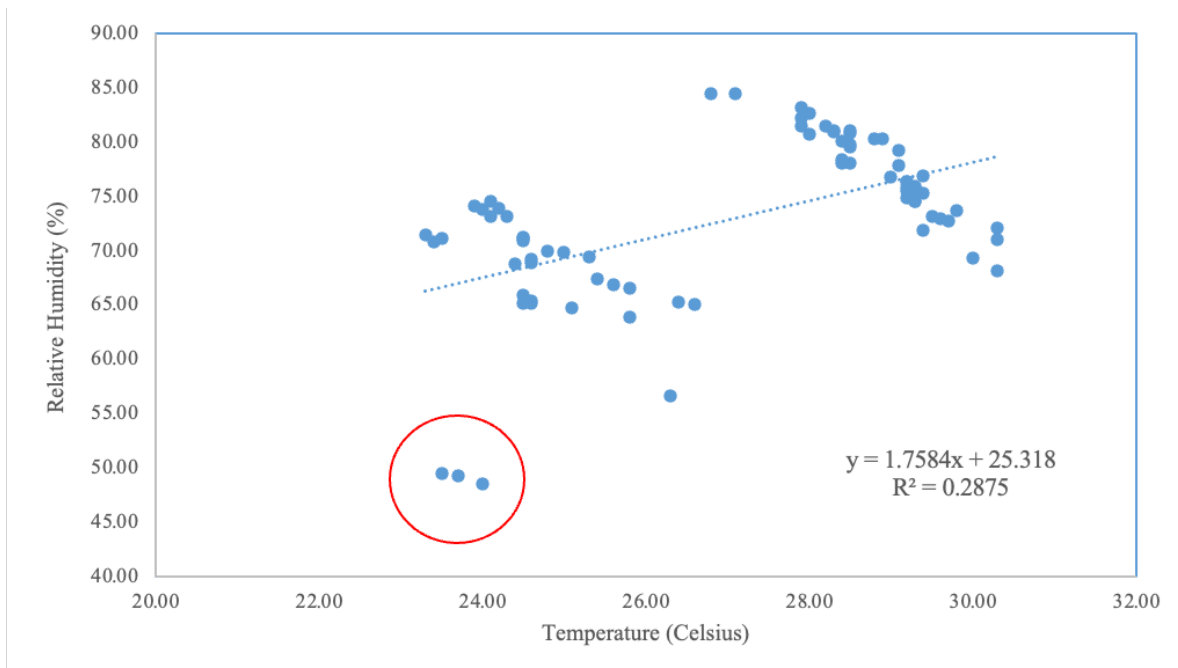
**Discussion**

**Air sampling and environmental conditions**

In our study, no SARS-CoV-2 was detected in air samples collected from various areas of the hospital and Customs and Immigration offices,

consistent with a report from Singapore<sup>(13)</sup>. Swabs taken from air exhaust outlets tested positive, indicating the displacement of small virus droplets by airflows and their deposition on equipment. Studies from Hong Kong, Korea, and China have also suggested that airborne transmission of SARS-CoV-2 is uncommon in the absence of aerosol-generating procedures, and good ventilation and disinfection protocols effectively reduce detectable viral concentrations<sup>(14-16)</sup>. However, van Doremalen et al<sup>(17)</sup>. reported viable SARS-CoV-2 detection in laboratory-generated aerosols up to 3 hours post-aerosolization, raising the possibility of aerosol transmission in relatively closed spaces with prolonged exposure to high concentrations of SARS-CoV-2 aerosol. Studies conducted in Wuhan, where COVID-19 had a higher reproductive number, found measurable aerosol concentrations of SARS-CoV-2 in isolation or ICU wards, but the viral loads were still low<sup>(8)</sup>.

**Figure 2** The relationship between relative humidity and temperature among customs checkpoint and a university hospital



Remarks: the circled cases are for PUI (isolation room)

Inconsistencies in findings among the studies warrant further research to determine factors contributing to variations, such as air sampler types, flow rates, duration of aerosol sampling, distance from patients, and height from the floor<sup>(14,18)</sup>. Standardised methods for collecting air samples for virological investigation are lacking<sup>(19)</sup>. Solid impactors appear to be more effective than liquid impactors or filters, and a combination of methods may be recommended depending on the setting<sup>(18)</sup>. In our study, different air samplers, including impactor, impinger, and filters, were used in two sampling phases. No detection of SARS-CoV-2 was reported, suggesting that strict disinfection and room ventilation may keep airborne SARS-CoV-2 concentrations low<sup>(14-16)</sup>. However, the challenge lies in the low concentration of the virus in the air compared with other microorganisms, necessitating sampling of a relatively large air volume for reliable analysis<sup>(18)</sup>. High flow rate air samplers (e.g., 150 L/min) improve success in airborne SARS-CoV-2 surveillance<sup>(20)</sup>. Previous studies have successfully used lower flowrate air samplers in environments with high viral loads<sup>(21-22)</sup>. Thus, prolonged sampling time is crucial for airborne bioaerosol sampling in clean or low bioaerosol concentration settings.

Chan et al. (2011)<sup>(23)</sup> reported the survival of SARS-CoV-2 at 40-50% relative humidity and temperature of 22-25 Celsius. These conditions were a match with the setting of ICU and isolation rooms in a university hospital in this study and in a previous study<sup>14</sup>. However, the outdoor environment of Malaysia, Indonesia and Thailand may not support major outbreaks of SARS-CoV-2. Our study found the relative humidity (77.10±3.05%) and tempera-

ture (28.99±0.62 °C) at Customs checkpoint (outdoor sampling) to be in comparison high.

However, the detection of human RNase P gene with high Ct values at the Sadao border and PUI ward (Bed No. 2) serves as an internal control, confirming the efficiency of the sampling and RNA extraction processes. Although these results were considered negative for SARS-CoV-2, they indicate that the bioaerosol samplers successfully captured human-derived particles in high-traffic or confined areas. This underscores the potential for pathogen detection if viral loads were present in the environment.

#### **Air monitoring limitations**

This study has several limitations, including the small number of air samples collected from each location and the predominance of area sampling. In the part of air sampling, the duration of air monitoring, the dry media of sampling plate should be concerned if the longer period of air monitor was conducted. However, the varied air sampling method, followed their sampling guidelines were performed in this study to find the suitable of filed air sampling and avoided viral degradation. The Andersen impactor enabled direct microbial cultivation but was limited to a 5-minute duration to avoid plate overloading. In contrast, liquid-based samplers and PVC filters allowed for extended one-hour monitoring, though their efficacy may be reduced in environments with low viral concentrations compared to high-flow systems. Further research with larger sample sizes, sampling times, and a variety of air sampling methods such as high-flow sampler is required to obtain more comprehensive data on airborne SARS-CoV-2 concentration and transmission risk.

**Hospital, custom and immigration office management and transmission of SARS-CoV-2**

No airborne viral infections were found despite a variety of air sampling techniques being used at the Customs and Immigration office area as well as at a hospital. Effective management techniques, including patient identification and isolation, PPE management, and well-defined COVID-19 rules, have been emphasized in an earlier report<sup>(24)</sup>. Hospitals were found to benefit from the crisis management application of the PDCA Deming cycle in order to stop the spread of SARS-CoV-2 and other contagious diseases. This strategy was demonstrated by a university hospital, which made sure that all patients, family members, and healthcare workers (HCWs) always wore face masks in accordance with CDC guidelines. Appropriate use was made of several mask types, such as surgical masks to prevent droplet transmission and N95 respirators to guard against aerosols. PPE was provided for HCWs in accordance with different

scenarios, with a focus on surface disinfection, social distancing, ventilation, and hand hygiene, as ways to reduce the risk of transmission<sup>(24)</sup>.

At the Immigration and Customs office in response to the COVID-19 pandemic, effective measures were put in place, such as requiring staff members to wear face masks. With the exception of Thai lorry drivers and people going home, travel restrictions were put in place to stop the importation of new COVID-19 cases. Drivers of other countries and Malaysians were prohibited from crossing the border, and vehicle exchange with cleaning overseen by DDC personnel was necessary (Table 2).

**Conclusion**

There was no evidence of transmission of SARS-CoV-2 or other airborne pathogens in the hospital or in the Customs and Immigration environments, which followed good practices in COVID-19 management. Consequently, in order to stop the spread of SARS-CoV-2, hospitals and other offices should implement

**Table 2 COVID-19 ‘KEYS’ management procedure for staff and stakeholders**

Study area	COVID-19 ‘KEYS’ management procedure		
	In-house management procedure for all stakeholders	Available PPE for employees	Ventilation system
Customs and Immigration office	<ul style="list-style-type: none"> <li>• Verify passengers’ 7-hour entry form (name, address, passport, cell phone number) and immigration approval of entry time to control the entry of Malaysian visitors.</li> <li>• Passengers with the PUI: PUI contacts Disease Prevention and Control (DDC) 12th Songkhla Province.</li> <li>• An ASEAN company vehicle travelling to Singapore will exchange drivers under the supervision of the DDC officers; documents of personal information and operator documentation are required. All foreign drivers will have a thermal screening and quarantine.</li> <li>• In case of driver exchanges, the DDC officers will approve the personal information of the driver, a place of accommodation provided by the operators, and the second is at the container yard.</li> </ul>	Face mask	General and mechanical ventilation

## การอยู่รอดของเชื้อไวรัสโคโรนาสายพันธุ์ใหม่ (SARS-CoV-2) และเชื้อก่อโรคอื่น ๆ ในสภาพแวดล้อมของโรงพยาบาล

**Table 2 COVID-19 ‘KEYs’ management procedure for staff and stakeholders (cont.)**

Study area	COVID-19 ‘KEYs’ management procedure		
	In-house management procedure for all stakeholders	Available PPE for employees	Ventilation system
University hospital	<ul style="list-style-type: none"> <li>Establishing the ARI clinic to reduce patients with nasal congestion from entering the hospital</li> <li>Establish PUI clinic, IPD, and ICU COVID-19 ward, which included the proving rooms, shower, and changing rooms for the COVID-19 Operation Teams.</li> <li>Training of don PPE (putting on PPE) and doff PPE (taking off PPE) for HCWs by Infectious Control units</li> <li>Limiting inpatients</li> <li>Providing telephone consultation service, delivering drugs at home to patients with chronic conditions, rescheduling and extending the appointments of the patients</li> <li>Providing protective face masks and sealing materials and alcohol hand washing and implementing a social distancing campaign</li> </ul>	<ul style="list-style-type: none"> <li>Medical OPD: Mask, glove, face shield</li> <li>Paediatric OPD: Mask, glove, face shield</li> <li>ARI: All above plus gown</li> <li>PUI: All above plus coverall</li> <li>COVID-19-ICU: all above plus air-purified power respirator (PAPR)</li> </ul>	<ul style="list-style-type: none"> <li>Mechanical ventilation</li> <li>Air handling unit</li> <li>General and mechanical ventilation</li> <li>Air handling unit</li> </ul>

Abbreviations: ARI, acute respiratory infection; ASEAN, Association of Southeast Asian Nations; DDC, Disease Prevention and Control; HCW, healthcare worker; OPD, outpatient department; PPE, personal protective equipment; PUI, person under investigation

crisis management using the P-D-C-A Deming cycle. In addition, to minimise the risk of SARS-CoV-2 transmission in a hospital, it is important to adhere to standards of ventilation, especially in ICUs and isolation rooms.

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## การอยู่รอดของเชื้อไวรัสโคโรนาสายพันธุ์ใหม่ (SARS-CoV-2) และเชื้อก่อโรคอื่น ๆ ในสภาพแวดล้อมของโรงพยาบาล

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### การอยู่รอดของเชื้อไวรัสโคโรนาสายพันธุ์ใหม่ (SARS-CoV-2) และเชื้อก่อโรคอื่น ๆ ในสภาพแวดล้อมของโรงพยาบาลมหาวิทยาลัยและด่านควบคุมชายแดนไทย-มาเลเซีย: การศึกษาแบบภาคตัดขวาง

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**บทคัดย่อ:** การแพร่ระบาดอย่างรวดเร็วของเชื้อไวรัสโคโรนาสายพันธุ์ใหม่ (SARS-CoV-2) ตั้งแต่เดือนธันวาคม พ.ศ. 2562 แสดงให้เห็นถึงความสำคัญของการทำความเข้าใจวิธีการแพร่เชื้อ ทั้งทางละอองฝอยขนาดใหญ่ การสัมผัสพื้นผิวที่ปนเปื้อน และละอองลอยในอากาศ ซึ่งปัจจัยด้านสิ่งแวดล้อม เช่น การระบายอากาศ ส่งผลต่ออัตราการแพร่กระจายของ SARS-CoV-2 การศึกษานี้มีวัตถุประสงค์เพื่อสำรวจการแพร่กระจายทางอากาศของ SARS-CoV-2 และเชื้อก่อโรคทางเดินหายใจอื่น ๆ ในสภาพแวดล้อมของโรงพยาบาลและด่านศุลกากรในจังหวัดสงขลา ประเทศไทย ในช่วงการแพร่ระบาดของ COVID-19 การเก็บตัวอย่างอากาศดำเนินการในหอผู้ป่วยและสำนักงานศุลกากรในสองช่วง คือ เดือนสิงหาคม-กันยายน พ.ศ. 2563 และเดือนมิถุนายน-กันยายน พ.ศ. 2564 เครื่องเก็บตัวอย่างอากาศทางชีวภาพที่นำมาใช้มี 4 ประเภท ได้แก่ N6 Single Stage Andersen Cascade Impactor, midjet impinger, liquid impinger, กระจาดทรง polyvinyl chloride (PVC) รวมทั้ง Biosampler ซึ่งใช้ในการวัดปริมาณจุลชีพที่ยังมีชีวิตอยู่ วิเคราะห์เชื้อก่อโรคทางเดินหายใจด้วยวิธี real-time RT-PCR ผลการศึกษา ไม่พบการแพร่กระจายของ SARS-CoV-2 หรือเชื้อก่อโรคทางเดินหายใจอื่น ๆ ในสภาพแวดล้อมที่ทำการเก็บตัวอย่าง อย่างไรก็ตาม พบจำนวน 3 พื้นที่ที่มีสถานะเสี่ยงต่อการอยู่รอดของเชื้อ SARS-CoV-2 คือ บริเวณที่มีความชื้นสัมพัทธ์ร้อยละ 45-50 และอุณหภูมิ 24-25 องศาเซลเซียส โดยเฉพาะในห้องแยกโรค และหอผู้ป่วยวิกฤต ที่มีสถานะเอื้อต่อการคงอยู่ของเชื้อ ดังนั้น การติดตั้งระบบระบายอากาศทั้งในสำนักงานที่เป็นระบบปิดและในโรงพยาบาล จึงเป็นปัจจัยสำคัญที่ควรคำนึงถึงเพื่อป้องกันการแพร่กระจายของเชื้อก่อโรคทางอากาศ

**คำสำคัญ:** เชื้อ SARS-CoV-2; การแพร่กระจายทางอากาศ; โรงพยาบาลมหาวิทยาลัย; สำนักงานศุลกากร; การเก็บตัวอย่างอากาศ