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SARS-CoV-2 detection in hospital indoor environments, NW Iran

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ABSTRACT

This study aimed to investigate the potential contamination of SARS-CoV-2 in indoor settled dust and surfaces of Amir Al-Muminin hospital in Maragheh, Iran. Samples were taken from surfaces and settled dust using a passive approach and particulate matter (PM) using an active approach from different hospital wards. SARS-CoV-2 was detected in 15% of settled dust samples (N = 4/26) and 10% of surface samples (3/30). SARS-CoV-2 has been detected in 13.8% and 9.1% of the dust samples collected at a distance of fewer than 1 m and more than 3 m from the patient bed, respectively. SARS-CoV-2 was found in 11% of surface samples from low-touch surfaces and 8% from high touch surfaces. The relationship between PM$_{2.5}$, PM$_{10}$, humidity, temperature, and positive samples of SARS-CoV-2 was investigated. A positive correlation was observed between relative humidity, PM$_{2.5}$, and positive SARS-CoV-2 samples. Principal component analysis (PCA) suggested positive correlation between positive SARS-CoV-2 samples, relative humidity, and PM$_{2.5}$. Risk assessment results indicated that the annual mean infection risk of SARS-CoV-2 for hospital staff with illness and death was 2.6×10^{-2} and 7.7×10^{-4} per person per year. Current findings will help reduce the permanence of viral particles in the COVID 19 tragedy and future similar pandemics e.g., novel influenza viruses.

1. Introduction

The coronavirus disease 2019 (SARS-CoV-2 or COVID-19) as a pandemic has been the most significant biological disaster of this century. One of COVID-19's side effects is severe acute respiratory syndrome (SARS) and pneumonia (Breslin et al., 2020). The SARS is a lineage of β-coronaviruses (Letko and Munster, 2020; Sauer et al., 2021). MERS-CoV in 2012 in Saudi Arabia and SARS-CoV in China in 2002 led to the respiratory syndrome in emerging form (Meo et al., 2020). The SARS-CoV-2 virus was found to carry a strain that not only can be transmitted through breath by fine droplets from a stricken person but also can travel more than 10 m in the air (Shamsaddin et al., 2020). This updated version of Coronavirus can survive on metal and plastic surfaces for up to 2 days, and 24 h on paper or cardboard (Aboubakr et al., 2021; Corpet, 2021). Aerosols in the indoor environment have been found to

be an additional source of SARS-CoV-2 in respiratory air. Therefore, persons can acquire the virus by inhaling or contacting contaminated surfaces from mucosae or by simply being exposed to an infected individual (Li et al., 2020; West et al., 2020).

Unfortunately, by 2021′, SARS-CoV-2 had caused 6 million infections with 131,000 deaths in IR Iran, also as world health organization (WHO) reported more than 273 million cases infections and more than 5.1 million deaths in 205 countries from the world, which it have serious concern in worldwide and that's rate dramatic increasing (OCHA, 2021; WHO, 2022). In residential and ambient environments, cleaning and disinfection processes have been studied because disinfectants have a critical role in the inactivation or removal of microbes. However, the airborne spread of SARS-CoV-2 needs to give more importance as it is the main route of transmission of the virus (Li et al., 2020; West et al., 2020).

The transmission of SARS-CoV-2 had several demographic and environmental factors, with many unknown and strange correlations (Ma et al., 2020). The center for disease control and prevention (CDC) introduced the important transmission pathway of SARS-Cov-2 including, (1) direct contact by droplet from person to person; (2) indirect contact with contaminated fomite, especially deposition of contaminated aerosol on surfaces; (3) transmission by airborne aerosol (Mousavi et al., 2020). Several studies suggested that the SARS-CoV-2 is airborne and particulate matter (PM) have potential transmission mechanisms of SARS-CoV-2 which increases mortality (Domingo et al., 2020; Hadei et al., 2020; Prather et al., 2020; Zhou et al., 2021). The high per capita health expenditures and lower exposure to unhealthy levels of PM resulted in to decrease in the average COVID-19 fatality rate (Coccia, 2021a). Along with PM there are other important variables (temperature, wind speed, and humidity) that controls the spread of SARS-CoV-2 (Rosario et al., 2020).

It is well proven that the risk of COVID 19 is less in the outdoors than the indoors. In indoor environments most of the study focuses on hospital environments (Baboli et al., 2021; Dunker et al., 2021; Grimalt et al., 2022; Passos et al., 2021a). Most of the studies conducted on hospitals detected the SARS-Cov-2 virus in airborne samples (Domingo et al., 2020; Hadei et al., 2020; Prather et al., 2020) but still few studies did not detect any airborne viral RNA (Faridi et al., 2020; Masoumbeigi et al., 2020; Vosoughi et al., 2021). Comparing the results of different studies is difficult for several reasons due to lack of standard sampling procedure, weakness of the strength of the source, impact of specific mitigation strategies, mechanical ventilation, and the size of the indoor environments (Borges et al., 2021; Conte et al., 2022; Mohammadi-- Moghadam and Hemati, 2021). As people are coming back to work places again, it is important to understand the behavior of SARS-CoV-2 in the air or on surfaces to different indoor environments (i.e., shopping centers, vehicles, restaurants, hair salons, schools, and cinemas) and take proper mitigation strategies to control the spread of COVID 19 (Coccia, 2021c; Yifang et al., 2021).

Iranians are among the most infected people in the Middle East, and they have been the first country in Asia to implement four total lockdowns lasting more than 10 days each. When the country's status was flagged as red, the government imposed widespread restrictions on schools, public housing (such as cafes and restaurants), and only permitted emergencies. Maragheh city in the northwest of Iran is located near Turkey and Iraq. Maragheh city had the highest COVID-19 infection rate in each of Iran's four peaks. To our knowledge no study has previously been done in Middle East hospitals to detect SARS-CoV-2 RNA in the hospital environmental. Therefore, the study was carried out to investigate potential existence of SARS-CoV-2 and that's relationship with environmental factors (PM, wind speed, and humidity) in the indoor environments of a hospital in Maragheh city. In addition, the exposure of nurses and other staff to SARS-CoV-2 on each shift were assessed. The results of this study can be used for more identification, prevention, control, and planning against SARS-CoV-2 and help prepare for the next similar probable epidemic.

2. Materials and methods

2.1. Sample and data

Maragheh as ancient city is in East Azerbaijan province (37°1′–37°45′N, of 46°9′–46°44′E), NW of Iran. This city has a population of 180,000 and a land area of 30 square kilometers. Amir al-Muminin hospital is one of the educational-therapeutic facilities in Maragheh city, with a capacity of 150–200 beds. During the study period (15 September- October 15, 2020), approximately 150 patients with positive COVID-19 test were hospitalized in Amir al-muminin hospital. In this study, Amir al-muminin hospital was selected for the detection of COVID-19 in surfaces and settled dust. Details of study area is shown in Fig. 1.

2.2. Measures of variables

Surface samples were taken with sterile premoistened swabs from 30 points of the wall, including the intensive care unit (ICU), critical care unit (CCU), cell phone, boiling water tank, iPhone cell, water closet (WC), stair hand rail, emergency ward, post CCU, laboratory ward, radiology ward, elevator button and Patients' rooms ward. Before sampling, all instruments and sampling jars (e.g., swabs, falcon's tube, and Petri dishes) were sterilized and disinfected using an autoclave device and 70% ethanol solution. For settled dust samples, 10 samples were collected from a distance of fewer than 1 m and 16 samples from 1 to 3 m distance from the patient bed. For surface samples, 15 points of the hospital (2 samples for each place) were selected with low and high-touch surfaces. For air sampling, one work shift (8 h) was considered for the determination of COVID-19 exposure to nurses and the other hospital staffs. The sampling height was above 1.5 m farm floor to be near breathing area of the corona patients. Air samples were collected containing temperature, percent humidity, and particular matter ($PM_{2.5}$ and PM_{10}) concentration using a portable environmental dust analyzer Fanpaya (IRAN.Fanpaya). Calibration, accuracy and precision of the instrument was checked by Comde-Derenda - Model PNS T-DM.

2.3. RT-PCR

After sampling the self-tube of swab and Petri dish samples contents were separately pre-filled with 5 cc of normal saline solution or 5 cc of Dulbecco's Modified Eagle's Medium solution (DMEM) (Baboli et al., 2021). The solution content of each sample was directly poured to 15 cc in sterilized falcons' tube under prevented condition and kept at 4 °C. Finally, the samples were transferred to a covid-19 detection laboratory and frozen at −80 °C for further analysis. Extraction of SARS-CoV-2 RNA and RT-qPCR was done in Maragheh Cellular-Molecular diagnostics laboratory. First using the RNJia Virus Kit (ROJETechnologies, Yazd, Iran), 200 μL of each sample was harvested for SARS-CoV-2 RNA extraction according to company's protocol. The details of the extraction procedure were summarized by Pourakbar et al. (2022) (Pourakbar et al., 2022). Detection of SARS-CoV-2 genes were done by quantitative polymerase chain reaction (qRT-PCR) assay using COVID-19 ONE-STEP RT-PCR kit (Pishtaz Teb Diagnostics, Tehran, Iran) as described in previous study (Pourakbar et al., 2022).

For the determination of microbial health risk assessment active air sampling was done after the detection of SARS-CoV-2 in settled dust and surface samples. Therefore, again in 4 contamination points, active air samples were collected using portable vacuum pumps connected to an impinger having liquid media (phosphate buffer solution) at a flow rate of 7.5–8.5 L/min at 1.5 m above the ground level. After sampling, samples were directly transferred to the laboratory in an insulated box with cooling packs to detect COVID 19.

2.4. Statistical analysis

The polyserial correlation was used for determining the correlation among SARS-CoV-2 in settled dust and different air parameters using R software version 3.6.2. Also, principal component analysis (PCA) was used for identifying the pattern of correlations between indoor air quality factors including temperature, relative humidity, PM_{10}, and $PM_{2.5}$, and the existence of SARS-CoV-2 in settled dust. The PCA was performed in Stata MP v. 14.

2.5. Quality control of SARS-CoV-2 detection

Samples of settled dust were collected passively in Petri dishes (10 cm diameter) with 10 mL of liquid media (distilled water) and samples from and surfaces, including cotton swabs, were placed in phosphate-buffered saline which was then turned on each sampling site before being placed in the self-tube. Eventually all the samples were
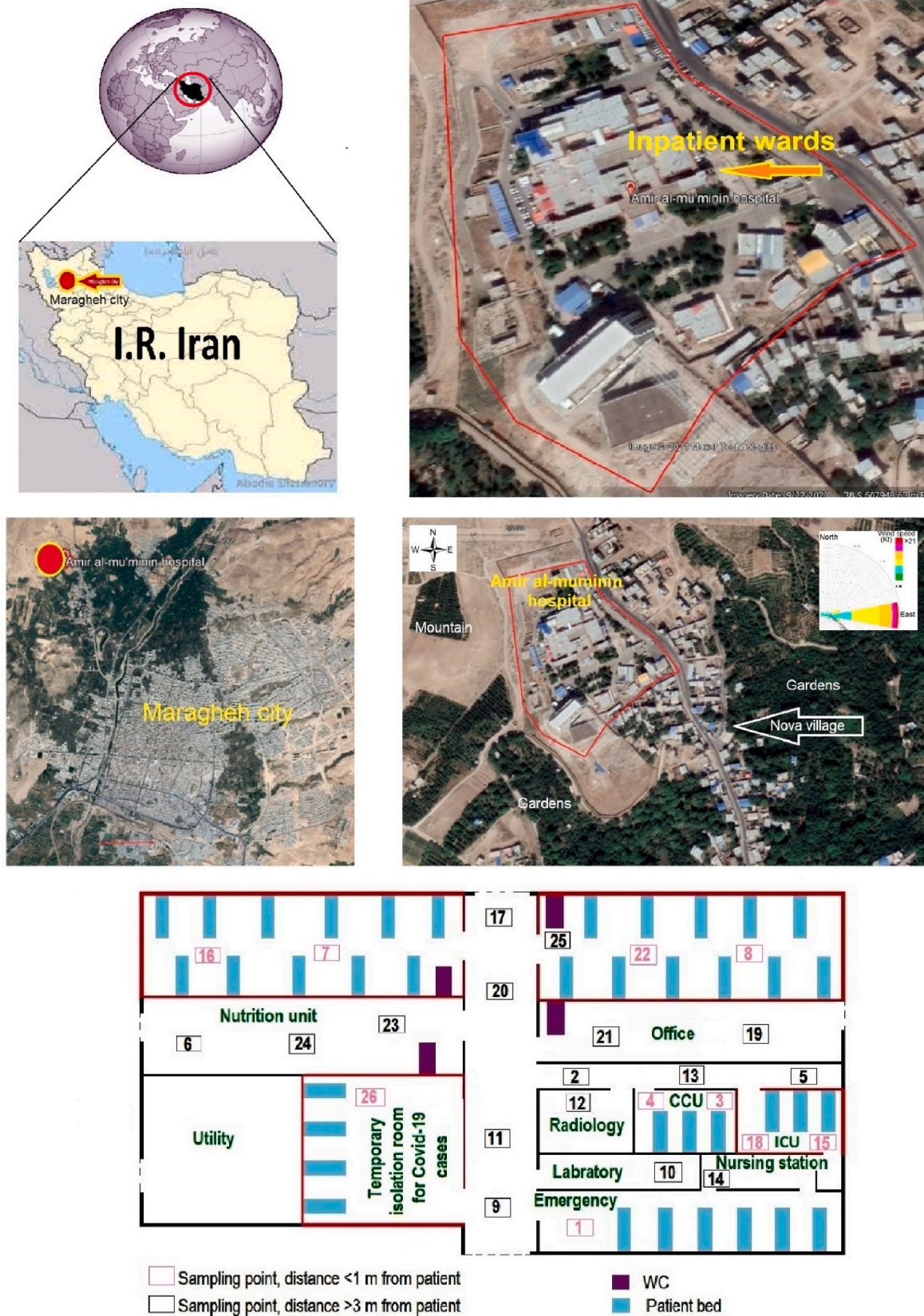
Fig. 1. Maps of study area, wind speed and direction, and schematic diagram of air settled dust sampling location in Amir al-muminin hospital.

transported directly to the COVID-19 detection laboratory. Finally, for quality control of SARS-CoV-2 detection, 2 s detection kits with name the Novel Coronavirus (2019-nCoV) Nucleic Acid Diagnostic Kit (Sansure Biotech, China) was used which targets ORF-1ab and N genes, and another kit with name Novel Coronavirus 2019-nCoV Real Time Multiplex RT-PCR Kit (Liferiver Bio-Tech, US) which targets, E and N genes.

Each sample was assayed in triplicate. RT-qPCR results were interpreted as follows: the gene target (RdRp, N) with a cycle threshold (Ct) value lower or equal to 40 was considered positive.

The Ct is a semi-quantitative amount that is used for the classification of viral genetic material in samples detected by RT PCR as low, medium, and high Ct. Ct approximately revealed the amount of viral genetic material in each sample by numerical values. In the presence of a low Ct (<40), viral genetic compounds are high, and the probability of viral infection is high too. Conversely, a high CT value suggests low viral infection risks (England, 2020). Thus, when at least two of the three replicates were positive, the corresponding sample was considered positive for SARS-CoV-2. For SARS-CoV-2 quantification, standard curves were constructed using 10-fold dilutions of SARS-CoV-2 positive control from the reference kit. RNA extraction and RT-qPCR preparation were carried out in different laboratories to avoid cross-contamination.

Blank samples including field blanks and lab blanks from air and surfaces were taken for negative control samples to be controlled bias in detection steps by RT-qPCR. These samples collected from raw materials from the environment after disinfection indoor lab to obtain sure the procedures were not contaminated.

2.5.1. Quantitative microbial risk assessment

The primary mode of transmission of SARS-CoV-2 is airborne transmission, which may lead to the presence of COVID-19 in medical staff working in hospitals (Mousavi et al., 2020; Passos et al., 2021b). For this reason, it seems necessary to evaluate the risk of virus infection for hospital workers. So, in the present study, the quantitative microbial risk analysis (QMRA) model was used to assess the risk of infection due to inhalation of SARS-CoV-2 for hospital staff. The values of input parameters of the QMRA model in the present study are listed in Table S1.

For calculation of the daily dose (TCID$_{50}$/L) of SARS-CoV-2 aerosols inhaled by the hospital staff was used by following equation (1) as recommended by Gholipour et al. (2021a); and Zaneti et al. (2021) (Gholipour et al., 2021b; Zaneti et al., 2021):

$$d = C_{aero} \ IR \ t_{exp} \ RR \tag{1}$$

where,

C$_{aero}$: concentration of SARS-CoV-2 in aerosols (TCID$_{50}$/L)

IR: average inhalation rate (m^3/h).
t$_{exp}$: staff daily exposure duration (h).
RR: retention rate of aerosol in the lungs which is calculated by following Eq. (2) (Schoen and Ashbolt, 2011):

$$RR = f_i^1 f_i^2 \tag{2}$$

where.
f$_i^1$: fraction of aerosols of size range i
f$_i^2$: fraction of the aerosols of size range I that are deposited in the lower respiratory tract (Gholipour et al., 2021b; Schoen and Ashbolt, 2011). We assumed that hospital atmosphere could generate inhalable-size aerosols (smaller than 10 mm) which may carry the virus.

– The probability of infection is estimated by the dose-response model through the inhaled dose. We used exponential dose-response models which have been suggested by Gholipour et al. (2021a) (Gholipour et al., 2021b).

$$P_i(d) = 1 - e^{-k_{ill}d} \tag{3}$$

$$P_i(d) = 1 - e^{-k_{death}d} \tag{4}$$

Pi(d): risk of infection per daily exposure of hospital staff to aerosols of SARS-CoV-2

d: daily dose (TCID$_{50}$/L).

k$_{ill}$ and k$_{death}$: endpoints of response for equations of 4 (5.39×10^{-2}) and 5 (2.46×10^{-3}), respectively (Watanabe et al., 2010).

Eventually, for estimation of the annual risk of SARS-CoV-2 infection per person (Pi (A)) was used by equation (5) (Gholipour et al., 2021b):

$$P_i(A) = 1 - [1 - P_i(d)]^n \tag{5}$$

where, n: the number of days per year on which a worker may be exposed to SARS-CoV-2 aerosols. We considered 20 working days per each month and an exposure period of 12 months.

3. Result and discussion

Table 1 shows the results of RT-PCR for SARS-CoV-2 virus in settled dust samples. In present study, molecular detection in RNA of SARS-CoV-2 virus was selected for two genes, including RNA-dependent RNA polymerase (RdRp) and nucleocapsid (N) genes. Of course, N gene is first-line in investigation of SARS-CoV-2 because of special characteristics e.g. screening and tracking (Pourakbar et al., 2022). But, the RdRp gene is having more sensitivity and used for more confidence.

From 26 settled dust samples, as shown in Table 1, 23% (N = 6) were positive for the N gene, which may not be positive for the SARS-CoV-2 virus. 15% (N = 4) samples were positive for both the N and RdRp genes, which were interpreted as definitive positive for the presence of the SARS-CoV-2 virus. These positive cases in air samples were taken from high-contamination areas, such as patient'' rooms, laboratories, ICU, and WC.

Several studies have been carried out related to COVID-19 exposure from indoor environment (Ali et al., 2020; Baboli et al., 2021; Biktasheva, 2020; Breslin et al., 2020; Gholipour et al., 2021a; Guo et al., 2020). A hospital in Ahavaz city in Iran, reported more than 22% of air samples with positive SARS-CoV-2 (Baboli et al., 2021). In the current study, SARS-CoV-2 virus was detected in 13.8% and 9.1% of air samples at fewer than 1 m and more than 3 m away from the patient, respectively. Similar study in tertiary hospital in Wuhan, among 300 air and surface samples only one sample was detected positive and the other samples were detected negative for SARS-CoV-2 (Tan et al., 2020). The reason for low detection of SARS-CoV-2 may be due to air exhaust fans with natural ventilation (Lynch and Goring, 2020; Tan et al., 2020). Amir al-muminin hospital also uses air exhaust which might be the reason for getting few positive reports for SARS-CoV-2 virus. However, ventilation could not protect completely in acute care in all wards but can decrease possible risk for COVID-19 spread and transmission.

In an ICU at Wuhan, SARS-CoV-2 was found in deposition samples, suggesting resuspension risk for transmission of SARS-CoV-2 (Wang et al., 2020). In Italy, SARS-CoV-2 was detected in high and low contaminated areas using air samples taken from a hospital and found that highly contaminated areas were positive for viral RNA, but there were no positive results in the low polluted area (Setti et al., 2020). Therefore, droplet, airborne, and settled dust (with resuspension potential) are the main risk factors for transmission of SARS-CoV-2 from respiratory air and need precautions. Several experiments were performed in previous outbreaks of emerging respiratory viruses, such as SARS, MERS, and pandemic influenza H1N1 (Al-Tawfiq and Memish, 2015; Cheng et al., 2010; Holden and Mogck, 2003; Tan et al., 2020).

Two samples (11%) from low-touch surfaces (9 points and 18 swabs) and only one sample (8%) from the high-touch surfaces (6 points and 12 swabs) was positive for SARS-CoV-2 (Table 2).

The two positive sampling points are located in the critical source area (laboratory and patients' room) of the hospital. Tan et al. (2020) reported 2.8% and 0.17% of hospital surface samples in high and low

Table 1

Detection of different target genes in SARS-CoV-2 in settled dust samples with the other indoor air parameters. .

Sampling ward	Sampling number	Target gene in surface sample		SARS-CoV-2 in surface sample
		N	RdRp	
Emergency	1		-	Negative
Lab corridor	2	-	-	Negative
	5	-	-	Negative
	13	-	-	Negative
Critical care unit (CCU)	3		-	Negative
	4	-	-	Negative
Nutrition unit	6	-	-	Negative
	23		-	Negative
	24	-	-	Negative
Patient's rooms (males)	7		-	Negative
	16		-	Negative
Patient's rooms (females)	8			Positive
	22	-	-	Negative
Main corridor	9	-	-	Negative
	11	-	-	Negative
	17	-	-	Negative
	20	-	-	Negative
Laboratory	10			Positive
Radiology	12	-	-	Negative
Nursing station	14	-	-	-
Intensive care unit (ICU)	15			Positive
	18	-	-	Negative
Office parts	19		-	Negative
	21	-	-	Negative
Water closet (WC)	25			Positive
Temporary isolation room	26	-	-	Negative

*Ct scale	29	30	31	34	35	40	not detected: -

*Ct: Cycle threshold

touch field positive for SARS-CoV-2. The reasons mentioned stringent infection prevention and control measures (IPC) actions accepted in the Optics Valley Branch (OVB) of Tongji Hospital (Tan et al., 2020). However, in our study higher contamination percentage was identified between high/low touch sink which strongly recommend using environmental disinfection/decontamination in touch fields. Due to relatively high levels of contamination on certain surfaces, including computer mice, trash cans, sickbed handrails and doorknobs, the study in Wuhan Hospital suggested hand hygiene practices (Guo et al., 2020). In our previous study in 2013, bacterial and fungal contamination were detected from elevator buttons at Isfahan University of medical sciences (Mohammadi et al., 2016). This study (9 years old) reveal the emergency need to approve some strategies for disinfection and cleaning in high-touch sink in health centers (i.e., elevator buttons, cell phone, toys in a pediatric hospital, computer keyboards, computer mousses, shopping cart handle).

Different meteorological parameters (temperature and relative humidity), and PM_{10} and $PM_{2.5}$ values from 13 sampling sites of the hospital are given in Table S2.

The average temperature, relative humidity, PM_{10} and $PM_{2.5}$ were 24 ($\pm$1.85) °C, 53% ($\pm$4.6), 43 ($\pm$11), and 25 ($\pm$12) (µg/m^3), respectively. In accordance with the occupational and environmental health center in Iran's guideline on ventilating hospitals, the recommended temperature and relative humidity for hospitals are 24 °C and 30–60% (Shahsavani, 2014). The recommended value for PM_{10} and $PM_{2.5}$ by the world health organization is 50 µg/m^3 and 25 µg/m^3, respectively for outdoor air quality (Mokhtari et al., 2019; Vardoulakis et al., 2020). Indoor PM_{10} and $PM_{2.5}$ in this study were in the recommended range according to the Iran health ministry and WHO (Mohammadi et al., 2019; Vardoulakis

et al., 2020). In an indoor hospital in Kashan city, Iran, PM_{10} and $PM_{2.5}$ were 162.7 µg/m^3, and 45.5 µg/m^3, respectively which are higher than the present study due to cracks in the structures and covering, and defective ventilation along with dryness of the climate and the influence of natural dust from the ambient air which is adjacent to central deserts in Iran (Mohammadyan et al., 2019; Samadi et al., 2021). In the other studies with same climate as our study area, $PM_{2.5}$ level in hospitals in Madurai city (India), Istanbul (Turkey) and Shijing (China) reported 64, 50, and 99 (µg/m^3) which were higher than our finding (Lawrernce et al., 2018; Wang et al., 2006; Yurtseven et al., 2012). Low level of PM in Amir al-muminin hospital may be due to the use of strong air exhaust ventilation system and good outdoor quality in Maragheh city.

During the study period, the air quality index (AQI: 25 to 40) was fair, the prevalence wind speed (30 m/s) was high, and the wind direction was mostly from the east (AccuWeather, 2022; I.R.meteorological, 2022). These air quality levels are generally acceptable for most individuals. However, sensitive groups may experience minor to moderate symptoms from long-term exposure. Previous studies have shown that higher wind speed could disperse air pollutants and decrease COVID-19 mortality (AccuWeather, 2022; Coccia, 2021b; I.R.meteorological, 2022).

In the present study, relationship among indoor meteorological parameters (temperature and relative humidity), PM_{10}, and $PM_{2.5}$ and existence of SARS-CoV-2 in settled dust was conducted with Polyserial correlation (Fig. 2) and principal component analysis (PCA) (Fig. 3). A good positive correlation was obtained between relative humidity, $PM_{2.5}$ and positive samples by SARS-CoV-2 (r > 0.8, P < 0.05).

Based on the PCA result, two principal components (PCs) contributed most to the positive results of the RT-PCR test. Fig. 3 shows the two-

Table 2
Detection of different target genes in SARS-CoV-2 in indoor surfaces samples..

Sampling ward	Sampling number	Target gene in surface sample		SARS-CoV-2 in surface sample
		N	RdRp	
Intensive care unit (ICU) ward	1	-	-	Negative
	2	-	-	Negative
Critical care unit (CCU) ward	3	-	-	Negative
	4	-	-	Negative
Post CCU ward	5	-		Negative
	6	-	-	Negative
Stair hand rail	7	-	-	Negative
	8	-	-	Negative
Cell phone	9	-	-	Negative
	10	-	-	Negative
Water cooler	11			Positive
	12	-	-	Negative
Boiling water tank	13	-	-	Negative
	14	-	-	Negative
iPhone cell	15	-	-	Negative
	16	-	-	Negative
Water closet (WC) ward	17	-	-	Negative
	18	-	-	Negative
Patients' rooms ward (males)	19	-	-	Negative
	20	-		Negative
Emergency ward	21	-	-	Negative
	22	-	-	Negative
Laboratory ward	23			Positive
	24	-		Negative
Radiology ward	25	-	-	Negative
	26	-	-	Negative
Elevator button	27	-	-	Negative
	28	-	-	Negative
Patients' rooms ward (females)	29			Positive
	30	-		Negative

*Ct scale	35	36	37	38	39	40	not detected: -

*Ct: Cycle threshold
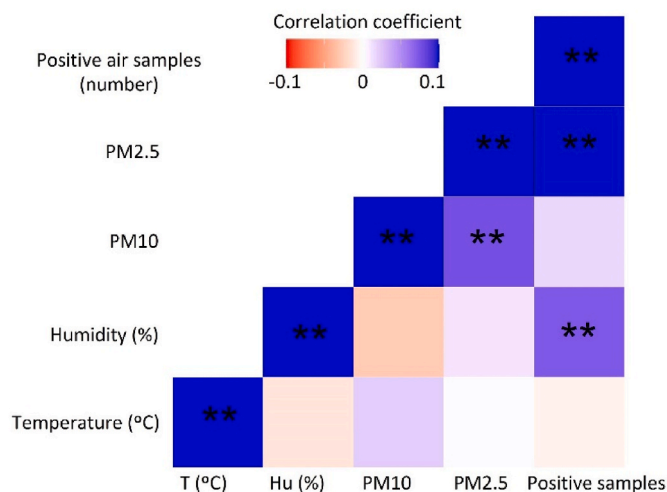
Fig. 2. Polyserial correlation among SARS-CoV-2 in settled dust and different air parameters (**p-value <0.05).

Fig. 3. Principal component analysis Biplot for the two principal components (PC1 vs PC2). SARS-CoV-2 is strongly correlated with humidity and PM$_{2.5}$ (lower red circle), but PM$_{10}$ and temperature are conversely corelated (upper red circle). Variable scores are plotted against the left and bottom axes.

dimensional biplot of PC1 versus PC2 as well as the effect of each of the indoor air parameters on the SARS-Cov-2 results. Each point on the biplot represents a sampling point, and each line represents a study variable. Every point on the biplot represents the sampling points' data,
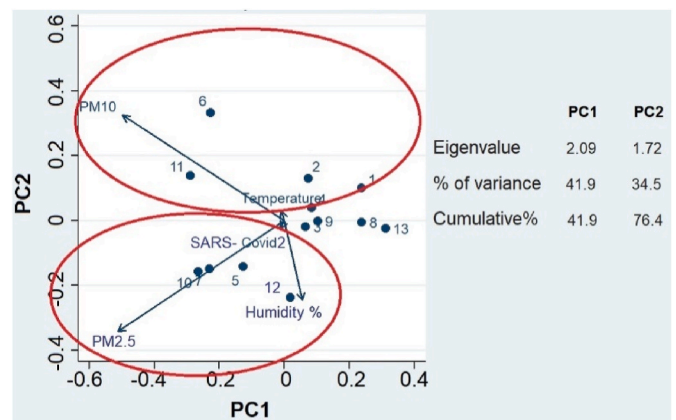
and each line (bar) represents a study variable. From PCA analysis, 76.4% of the total variation can be explained by two components (PC1 and PC2). The first component (PC1) explains 41.9% of the total variance and is positively affected by positive SARS-CoV-2, relative humidity, and PM$_{2.5}$; in other words, SARS-CoV-2 increases with higher

relative humidity and $PM_{2.5}$. The second component (PC2) explains 34.5% of the total variance including PM_{10} and temperature which are conversely related to the positive RT_PCR test, suggesting their negligible effect on the detection of SARS-CoV-2. Doğan et al. (2020) found ssimilar strong correlation of COVID 19 with relative humidity and $PM_{2.5}$ and negative correlation with temperature in outdoor environment in New Jersey, USA (Doğan et al., 2020). On the other hand, Baboli et al. (2021) found highest correlations of COVID 19 for temperature, relative humidity, and PM in indoor hospital environment in Ahvaz, Iran (Baboli et al., 2021).

The amount of SARS-CoV-2 RNA detected in air samples was 4–15 gene copies/L, based on results from active air sampling. Other studies on air samples in wastewater treatment plant for detection of SARS-CoV-2 in aerosols reported 5 to 188 gene copies/L in Isfahan city and 15 to 240 gene copies/L in Maragheh city (Gholipour et al., 2021a; Pourakbar et al., 2022). The low range concentration of SARS-CoV-2 in the outdoor air of wastewater treatment plant is similar to the current findings in the indoor air of the hospital.

Aerosols produced by patients during coughs, sneezes, speaking, and breathing can cause the spread of SARS-CoV-2 respiratory air (Schijven et al., 2021). The airborne transmission is one of the main transmission routes of SARS-CoV-2 that play an important role during the SARS outbreak could also partially account for the high secondary transmission rates to medical and health staff (Passos et al., 2021b). Therefore, it seems necessary to evaluate the risk of virus infection for medical and health staff workers. Hence, in the present study health risks of virus infection for hospital staff were quantified with the QMRA model. The results of the present study showed that annual mean infection risk of SARC-CoV-2 for hospital staff with illness and death as endpoint of response were 2.6×10^{-2} (95% CI: $9.7 \times 10^{-3} – 6.1 \times 10^{-1}$) and 7.7×10^{-4} (95% CI: $2.4 \times 10^{-5} – 2.2 \times 10^{-3}$) per person per year (pppy), respectively. In a similar study, Adhikari et al. (2019) reported that the highest daily mean risk of infection of MERS-CoV induced by aerosols transmission for nurses and healthcare workers was 8.49×10^{-4} and 7.91×10^{-4}, respectively. While, this rate for family visitors and patients staying in the same room was reported as 3.12×10^{-4} and 1.29×10^{-4}, respectively (Adhikari et al., 2019). Also, in another study, the mean infection risk of SARS-CoV-2 induced by the aerosol transmission for the costumers inside the market was 2.2×10^{-2} (95% CI: $1.90 \times 10^{-6} – 2.34 \times 10^{-4}$) pppy, while the infection risk of SARS-CoV-2 for the people outside the market rapidly declined due to dilution by ambient air (Zhang et al., 2020). The benchmark of tolerable infection risk of viruses proposed 10^{-4} and 10^{-3} pppy by EPA (USEPA, 2011) and WHO (Gholipour et al., 2021a), respectively. Comparing the mean annual infection risk of SARS-CoV-2 for hospital staff in the present study was higher than the WHO and EPA recommended value. This can be due to the high concentration of SARS-CoV-2 in the present study that causes the estimated infection risk of SARS-CoV-2 to be higher than the other studies. This high infection risk of SARS-CoV-2 is a serious warning to hospital managers and staff. Following strategies can be recommended to the hospital stuff to reduce the exposure of SARS-CoV-2: Use of ventilation approach and appropriate personal protective equipment (PPE) by workers, including protective outerwear, face shield, face mask (N95), gloves, goggles, regular hand washing after each activity, avoid any unwashed hand touching with eyes, nose, mouth, and reduction of exposure time of SARS-CoV-2 for hospital staff. According to the lack of adequate information about SARS-CoV-2, the estimated infection risk may be over or underestimated. So, more studies are needed to assess the infection risk of SARS-CoV-2 for hospital staff (Ali et al., 2020; WHO, 2020).

3.1. Limitations of the study

To accurately determine the effect of environmental parameters on the transmission of SARS-CoV-2, more air samples are needed in different conditions and locations. In addition, adding more variables (i.

e., number of patients, air velocity, presence or absence of air condition, rate of ventilation, open or close window, $PM_{1.0}$, CO_2, CO) in the PCA test might give us better understating of the relationship between the variables and the positive RT-PCR result.

4. Conclusion

This study showed that the SARS-CoV-2 virus can be present in settled dust which has resuspension potential, thus making it a major risk factor for transmission of SARS-CoV-2 particles in the respiratory air. Detection of SARS-CoV-2 in different surface points of the hospital revealed contaminated touch surfaces located in critical wards (e.g., laboratory and patients' room). Therefore, these environments need to be disinfected/decontaminated on a regular basis. The polyserial correlation showed a positive correlation among relative humidity, $PM_{2.5}$, and positive SARS-CoV-2 which was further confirmed by PCA analysis. The humidity and $PM_{2.5}$ possibly had a high potential for connecting by viral particles and transmitting to the respiratory system or surfaces pollution. Finally, annual mean infection risk of SARC-CoV-2 for hospital staff with illness and death as the endpoint of response were 2.6×10^{-2} (95% CI: $9.7 \times 10^{-3} – 6.1 \times 10^{-1}$) and 7.7×10^{-4} (95% CI: $2.4 \times 10^{-5} – 2.2 \times 10^{-3}$) per person per year (pppy), respectively.

Natural and mechanical air ventilation through dilution and removal of particulate matter (PM) and settled dust can have a positive impact on reducing the permanence of viral particles in the Corona tragedy and future similar pandemics, e.g., novel influenza viruses. A number of factors are key to the management of COVID 19 crises, including preparedness countries, vaccine hesitancy, having enough drugs and other medical equipment, and an increase in health expenditure per capita. Due to several known and unknown intervention factors for COVID risk assessment, more studies in this field with a large number of samples are necessary.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apr.2022.101511.

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