

Article

Studying the effect of particulate matter as SARS-CoV-2 transmitters

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Abstract

Background: Studies of risk factors are especially valuable at this difficult time in the midst of a pandemic. High levels of particulate matter (PM) represent a serious risk factor on health. While this is a direct impact on health, indirect effects are worth considering too.

Design and methods: The aim of this study was to investigate the role of PM in the transmission of viruses, especially SARS-CoV-2. Also, we sought to understand dynamics of PM in still air at high and low altitudes. Historic AQI and physical PM measurements were collected between August and September 2020 using air quality detector. Potential correlations between the number of total confirmed COVID-19 cases and average air quality index (AQI) from varied geographic locations were also assessed.

Results: Airborne PM levels were weakly associated with COVID-19 cases after analysing 77 territories. PM remained longer in the air at high altitudes compared to measurements made at sea level. This suggests that the link between PM and COVID-19 transmission could be aggravated in areas of high altitude.

Conclusions: This article highlights that particulate matter can be involved in SARS-CoV-2 transmission. However, confounding factors may have impacted the association between the two variables. These findings can serve as a foundation for future studies on the effect of air pollutants and fine particulate matter on viral transmission.

Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) emerged on December 2019. On March 11th, 2020, the World Health Organization declared the disease as a global pandemic.¹ During July-August, 2020, the Hajj Pilgrimage was under strict measures to minimize the spread of coronavirus disease 2019 (COVID-19), and Umrah was temporarily suspended.^{2,3} It was proposed that SARS-CoV-2, the causative agent of COVID-19, is transmitted by aerosols.⁴ A one-month study found a significant positive correlation between fine particulate matter (PM)_{2.5} and COVID-19 severity in 110 Italian provinces at the height of the pandemic.⁵ High PM concentration has also been linked with total COVID-19 cases in Milan, Italy in a study performed from January 1st to April 30th, 2020.⁶

When high concentrations of atmospheric PM are inhaled over a long period of time, they can cause health effects such as chronic obstructive pulmonary disease, bronchial asthma, and lung cancer.⁷ PM may also be able to harbour and distribute viruses such as SARS-CoV-2,⁸ but more research on the airborne transmission of respiratory viruses is urgently needed.⁹ Some previous studies found a positive association between PM exposure and COVID-19 mortality risk, but not COVID-19 transmissibility.¹⁰

Therefore, the primary aim of this study was to investigate the dynamics of particulate matters in still air and further characterize their role as transmitters of SARS-CoV-2 virus. Studies on the correlation between PM and COVID-19 will be discussed and compared. Thus, the second objective was to examine the correlation between air pollutants and COVID-19 cases.

Design and methods

Study area

Two Saudi Arabian cities of high and low altitudes were chosen to conduct air quality measurements and that data was compared to total confirmed COVID-19 cases: Abha in the Asir Region (18° N, 42° E, 2700 m elevation, population of 2.2 million), and Gazan city (17° N, 42° E, sea-level, population of 1.6 million).

Outdoor air quality measurements

To gain insights into the quality of air over time, measurements were conducted between August and September, 2020, using air quality detector (BR-8C, Kailishen®, China). The level of outdoor ubiquitous particulate matters was measured in two different Saudi Arabian locations. An average of 15 readings were taken with some exceptions in order to lessen the effect of wind speed on PM measurements. In this global analysis, the average annual air quality of countries and cities were correlated with total confirmed COVID-19 cases.

Particulate matter dynamics

Large particulate matter is believed to settle within 2 meters of its source.^{8,11} To understand how long particulate matter remains

Significance for public health

The impact of high levels of particulate matter on health is well documented. However, growing studies on its indirect effect by transmitting viruses warrant further considerations. In this article, we studied particulate matter in high and low altitudes to better predict the dynamics of particulate matter in still air. Then, correlation between air quality index and COVID-19 cases were made. Backed by some investigations, the positive correlation suggests that particulate matter could play a role in viral transmission including SARS-CoV-2. Therefore, studies of the direct and indirect effect of particulate matters are significant and suggest imposing preventive measures such as air quality monitoring.

airborne in a closed room, an air quality detector (model BR-8C) was used to measure the level of indoor $PM_{2.5}$ and PM_{10} of Bakhour smoke (Arabian incense) over time. A small natural Bakhour woodchip was burnt for 1 min in charcoal. Windows were closed and no fans were used. Since it was not possible to finely control the rate of incense burning, attempts to generate consistent PM concentrations were made. The same weight of Bakhour woodchips were burnt in the Asir Region and in the Gazan Region. In both locations, the room size was approximately 25-square meter and the Bakhour incense burner (Mabkhara) was taken out of the room after 1 min of burning.

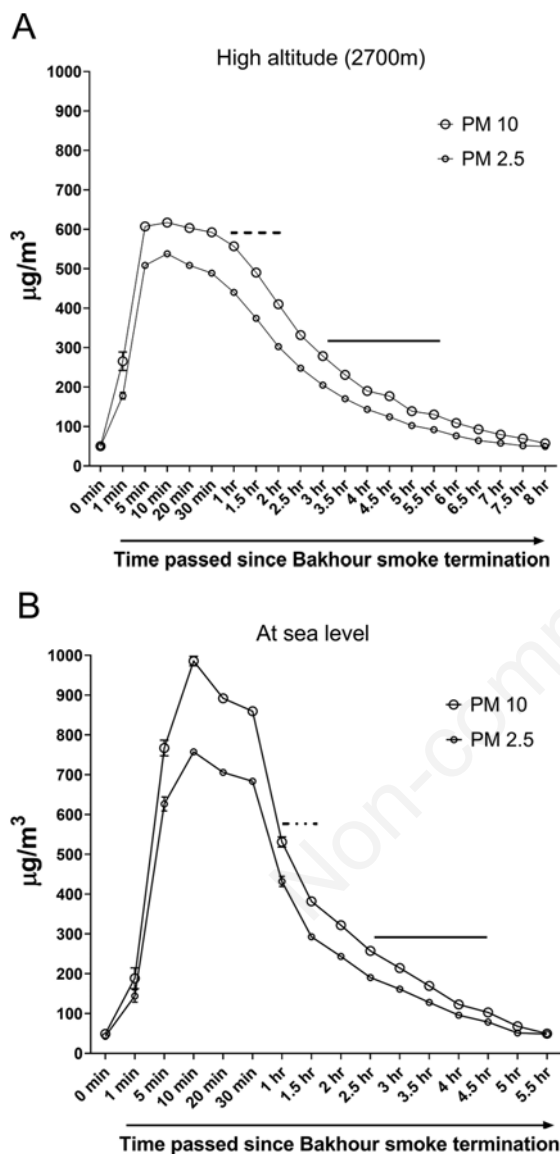


Figure 1. PM measurements of Bakhour smoke in a closed room at two different altitudes. A time-course experiment was carried out at altitudes of 2700 m (A) and sea level (B). Dashed lines indicate the period needed for $PM_{2.5}$ concentrations to reduce from $440 \mu\text{g}/\text{m}^3$ to $300 \mu\text{g}/\text{m}^3$ (1 h at 2700 m and 30 min at sea level). Solid lines indicate the period needed for $PM_{2.5}$ concentrations to reduce from $200 \mu\text{g}/\text{m}^3$ to approximately $90 \mu\text{g}/\text{m}^3$ (2.5 hr at 2700m and 2 hr at sea level). Error bars represent $\pm\text{SD}$ of the mean. Due to high reproducibility in replicates ($n=2$), error bars are smaller than the symbols used to denote PM type. Therefore, error bars are not visible for many data points.

Air quality data

Measuring outdoor pollution with an air quality detector on a large scale at many geographic locations can be extremely labour-intensive. In order to circumvent this, the annual air quality index (AQI) data were collected from Plume Labs after obtaining their kind permission to use the data for this research.¹² Their air quality data were close to the air quality measurements that were physically recorded. Historical AQI datasets were collected for cities from which I could not obtain physical PM measurements. The AQIs were collected for countries, counties, and capital cities from January 1st to August 23rd, 2020. The annual AQI in each country/county was calculated based on the mean of all annual AQIs of major cities in that county that had records of total confirmed cases of COVID-19 cases until August 23rd, 2020. Saudi Arabian cities with AQI historical records were included too. The total number of COVID-19 cases were correlated with the annual average AQI.

Total confirmed cases around the world

Counties and cities with AQI data and daily COVID-19 cases were included in the analyses. Cities and counties were excluded if there was either no AQI record or no record regarding the total number of confirmed cases. Countries with cities characterized by high variations in AQI were also excluded. Selected countries and cities were first ordered from the highest to lowest AQI. For countries, the mean annual AQIs of the major cities were calculated and correlated with the cumulative number of COVID-19 positive cases. The data regarding total confirmed cases were collected on August 23rd 2020 from the COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at John Hopkins University (<https://coronavirus.jhu.edu/map.html>). For Saudi Arabian cities, the data were collected from the COVID-19 Dashboard by the Ministry of Health (<https://covid19.moh.gov.sa>).

The reason that August was chosen as the time period to collect the total number of positive COVID-19 results for analysis is because COVID-19 cases in Saudi Arabia plummeted gradually in July after a peak period in June, in which daily cases numbered between 3,000 and 4,000. At the end of August, Saudi Arabia exhibited declines in COVID-19 cases and had their lowest numbers of cases in 4 months. In August, total cases decreased to less than 2,000 daily cases, and continued to drop in September to less than 1,000 cases on a daily basis. For statistical analyses, Pearson's correlation was used to analyse the linear correlation between AQI and total COVID-19 cases. The datasets were analysed using GraphPad Software, version 8 (San Diego, CA, USA).

Results

Dynamics of particulate matter differ at high and low altitudes

In this study, an air quality detector was used to assess indoor pollutants. The introduced particulate matters from burning Bakhour remained suspended for hours above ambient level. However, the particles remained longer at high altitude than at sea level. At high altitude, it took 1 hr for PM_{10} to decrease from $550 \mu\text{g}/\text{m}^3$ to $380 \mu\text{g}/\text{m}^3$ and 165min to decrease from $260 \mu\text{g}/\text{m}^3$ to $100 \mu\text{g}/\text{m}^3$. In contrast, the time required for these concentrations at sea-level to decrease were 2 hr and 30min respectively (Figure 1). These results indicate the importance of having datasets from different altitudes to understand the gravitational forces of PM.

Air quality may be a predictor of virus transmission

An association was found between total COVID-19 cases and air quality after analysing 77 world territories. Likewise, the selected Saudi Arabian locations exhibited quiet similar trends (Figures 2 and 3). However, the association is weak, suggesting that numerous intervening variables play rules in COVID-19 cases. After reviewing stochastic models for emerging infections,¹³ it was worth considering the overall number of infected people as a percentage of the population. Interestingly, when the proportion of the entire population was correlated with AQI, a better-fit correlation was found (Table 1). Various factors may have complicated the correlation analyses between PM levels and total COVID-19 infected cases, including the possible occurrence of second waves

of COVID-19,¹⁴ herd immunity, long term immunity against the virus, SIR (susceptible, infectious, recovered) model, and transmission dynamics.¹⁵

Compared to the high-altitude city of Abha, physical air quality measurements were higher in sea level (Gazan Region), and higher number of daily COVID-19 cases were recorded. By September 2020, the annual average AQI for Gazan was 113 while Abha registered 84 AQI. In the summer, the daily AQI in Abha was three to five times less than that of Gazan, which recorded levels deemed to extremely unhealthy (airpocalypse) for several days; at 4 pm on September 7th, 2020, air pollution reached extremely high levels in Gazan with 623 AQI. The level of PM₁₀ was 584 µg/m³ while PM_{2.5} was 623 µg/m³. Despite that, the association between particulate matter and COVID-19 cases was weak.

Table 1. Correlations between annual AQI of countries, capitals, and Saudi Arabian cities and total COVID-19 cases in each respective location.

Locations	Total cases	r	R ²
Saudi Arabia (n=22)	Total cases (cumulative)	0.1549	0.02400
	Total cases (as percentage of population)	0.2679	0.07177
Countries and capitals (n=77)	Total cases (cumulative)	-0.03773	0.001423
	Total cases (as percentage of population)	0.3866	0.1495

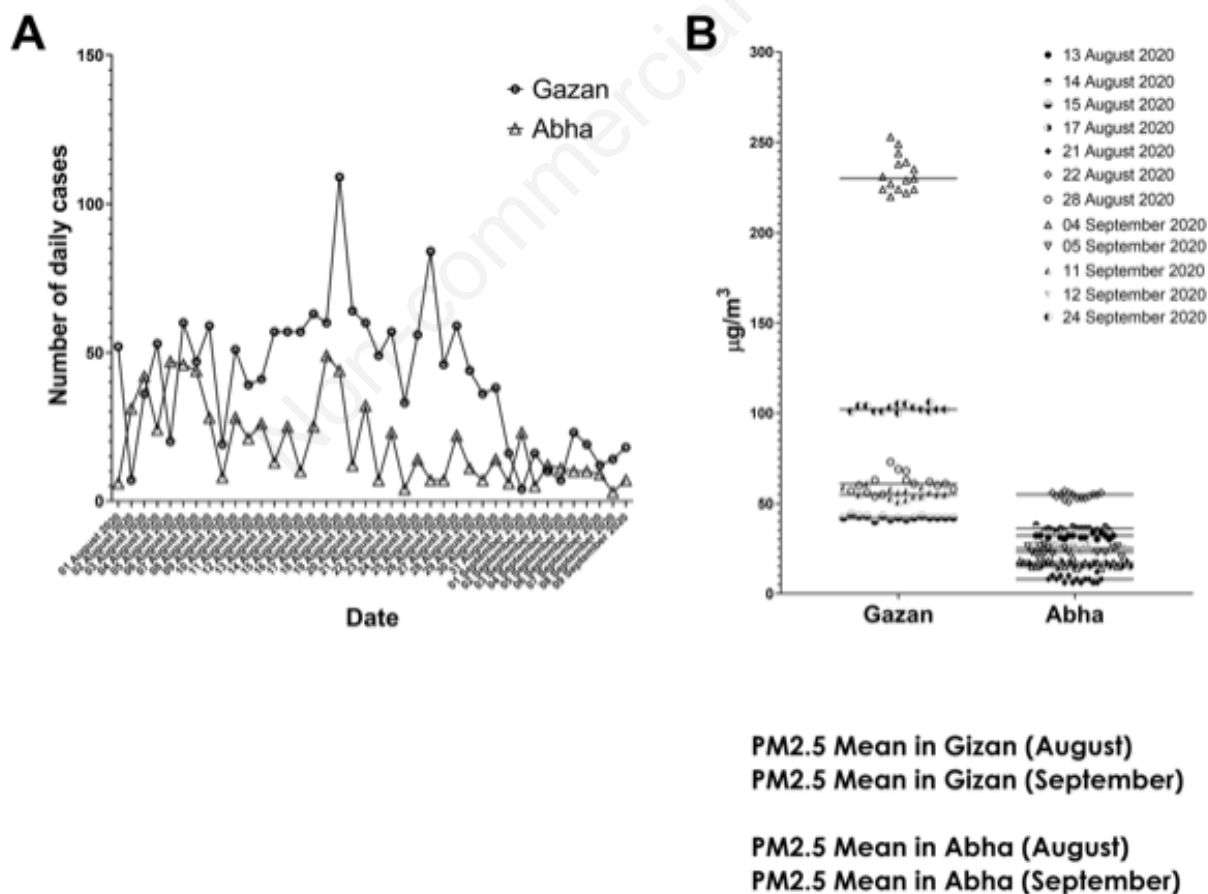


Figure 2. Number of daily COVID-19 cases versus PM_{2.5} measurements in Abha and Gazan Regions. A) Daily confirmed cases of COVID-19 recorded in Abha (the capital of Asir Region) and Gazan Region between August and September, 2020. B) PM levels in both regions between August and September 2020.

Discussion

Aerosolized droplets may transmit COVID-19. The dynamics of aerosol particles that may mediate airborne transmission of viruses were investigated. The historical records of air quality data from Plume Labs were collected and correlated with the total number of COVID-19 cases. In order to link AQI with the total confirmed cases in a biologically relevant fashion, the total number of COVID-19 cases was considered as a proportion of the overall population; not an absolute total number of cases. In Wuhan and XiaoGan, AQI was correlated with COVID-19 incidence.¹⁶ However, the study calculated the total number of cases. No statistical significance was observed in this investigation between AQI and the cumulative number of total COVID-19 cases. Here comes the importance of studying transmission dynamics.¹⁷

When a highly contagious virus emerges, it spreads in the pop-

ulation until a plateau is attained, which is followed by a decline in daily cases. If the basic reproduction rate (R_0) of SARS-CoV-2 is estimated to be 3, then cases would wane when percent of the country's population that is naturally-immunized reaches 67%.¹⁸ COVID-19 lockdowns may reduce outdoor $PM_{2.5}$ levels.¹⁹ Two separate studies conducted in Scotland and Eastern Province, Saudi Arabia found that NO_2 decreased significantly during the lockdowns.^{19,20} However, the AQI in Saudi Arabia remained high compared to many other countries. Investigating the source of pollution should be prioritized. In the Czech Republic, local heating was responsible for 70% of PM_{10} and not power plants.²¹ The substantial change from brown coal to natural gas resulted in a significant reduction of PM_{10} pollution.

$PM_{2.5}$ and PM_{10} were both measured in this study in Gizan and Abha city. While the Asir Region is characterized by a cold climate, the Gazan Region has recorded high air pollutant concentrations and high summer temperatures. The Region experienced an increase in new industrial projects such as the Gazan Economic City Project, Gazan Bulk Plant of Saudi Aramco, the Shuqaiq Water and Electricity Company, and Al Shuqaiq Water Desalination Plant. The study primarily focused on $PM_{2.5}$ levels between August and September, 2020, in two locations (Figure 2) because it is a significant pollutant with greater impact on health. It is much smaller than coarse particulates; $PM_{2.5}$ can penetrate deeper into the lung and affect alveolar macrophages.²² In a Canadian study, long exposure to $PM_{2.5}$ was positively correlated with COVID-19 incidence.²³ However, the authors recommended further investigations based on their findings. While high PM levels affect health directly and indirectly, their dynamics was studied using Bakhour-associated PM. Mesallam *et al.*²⁴ studied 72 subjects after being exposed to Bakhour in a closed 12-square meter room. Participants were exposed for 5 min to Bakhour smoke at a one-meter distance. To clear smoke between participants, the room was kept open for 10 min between every participant.²⁴ Mesallam *et al.* studied the direct effect of Bakhour incense. In this study, Bakhour incense was kept only for 1min in a 25-square meter room to start measuring PM levels to understand their dynamics and concentration over time in still air.

A physical air quality detector measures particulate matters at a specific place and time. It can be laborious to measure many places at different times. To address this, historical data of the annual averages were collected and examined for any correlations with the total number of COVID-19 cases. Another shortcoming is that concurrent measurements of PM levels in high and low altitudes could not physically be achieved, so measurements were taken on different days. To mitigate this, numerous measurements were recorded and compared to historical AQIs. The correlations were difficult to assess due to huge topographic variations throughout each location.

Transmission routes like sneezing, talking, and direct transmission of viruses from an infected patient to a healthy individual can occur even when masks are being worn, especially in a situation with very close contact. In those situations, PM is not likely to play a major role in transmitting infection. While PM can exacerbate COVID-19 by negatively impacting lung airways,²⁵ this study did not clinically investigate this, but rather focused on the association between PM levels and total COVID-19 cases. Moreover, despite the fact that total COVID-19 cases accounted for less than 2% of the populations for most of the analysed locations, the actual number of positive cases is thought to be much higher than what has been recorded.²⁶

Meteorological factors such as wind speed can impact pollutant levels. It is important to note that when PM levels were high at spe-

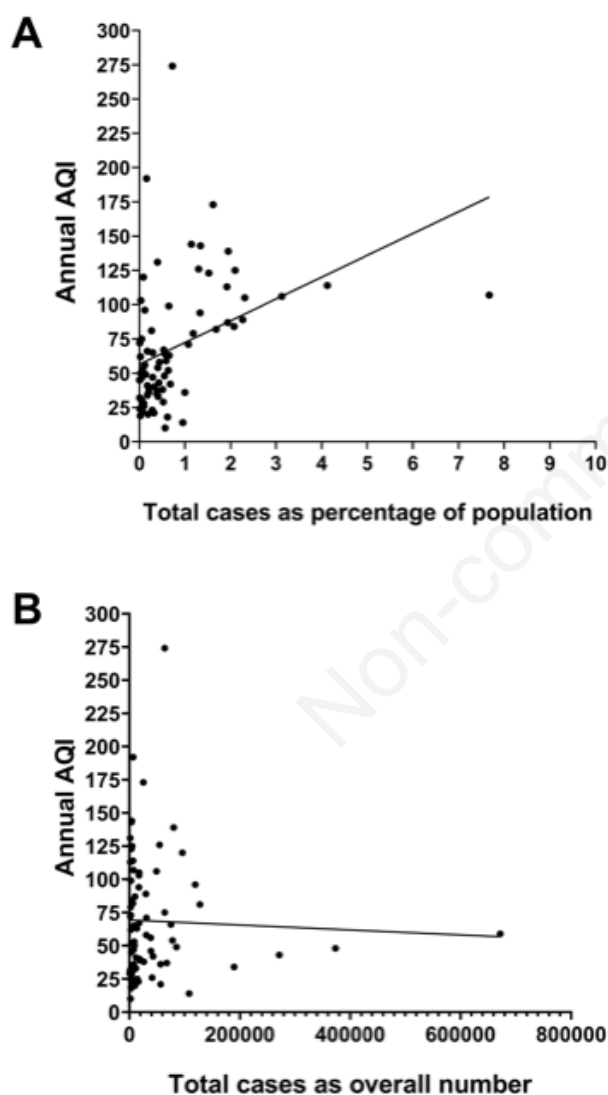


Figure 3. Annual average AQI of countries and capitals as compared to total COVID-19 cases. By using historical AQI data, the number of total confirmed cases; expressed as percentages of the population (A) and as an overall number of cases (B) as of August 23rd, 2020, were correlated with AQI averages from January to August, 2020 (n=77).

cific periods, they did not always predict a spike in COVID-19 cases, especially if the total number of positive cases had previously plummeted. The dynamics of viral infections depend on numerous variables such as herd immunity and immune system efficiency, which are mediated by humoral/antibodies and cell-mediated immunity. This study did not investigate mortality rates, but looked at the potential ability of particulate matter to transmit viruses irrespective of their virulence or disease outcomes. Furthermore, the cause of deaths can be attributed to an uncountable number of variables. However, previous studies have found that air pollution has impact on COVID-19 associated mortality.²⁷⁻²⁹ This study found a link between the AQI of 77 territories and total COVID-19 cases, but high AQI is not always a predictor for COVID-19 incidence. There are numerous variables that may contribute to SARS-CoV-2 transmission, including strictness of preventive measures, border control,³⁰ implementation of social distancing, and individual expression of the angiotensin converting enzyme 2 (ACE2) receptor, for which increased expression has been associated with increased risk of COVID-19.³¹ Last, this study was conducted in 2020 before the first COVID-19 vaccine was approved. The administration of COVID-19 vaccine in 2021 would be a significant factor to reduce the rate of infection; therefore, affecting future inter-pollation between AQI and COVID-19 cases.

Conclusions

This article studied the length of particulate matter suspension in still air and investigated its effect as a possible transmitter of viruses. We highlight the significance of air pollution on the transmission of SARS-CoV-2 and possibly other viral infections. High concentration of particulate matter can remain longer at areas of high altitude and increasing the risk of viral transmission. The total COVID-19 cases as a percentage of population seems to work as a better correlation variable than the overall number of COVID-19 cases. Based on the finding from this and previous studies, it is recommended to use respirators, masks, and air purifiers to reduce airborne particles. Further investigations on the specific mechanisms by which PM may harbour viruses are needed.

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Key words: Air quality; Bakhour incense; particulate matter; SARS-CoV-2 transmission.

Conflict of interest: The authors declare that they have no competing interests, and all authors confirm accuracy.

Ethical approval: Not applicable.

Availability of data and materials: The datasets supporting the conclusions of this study are included within the article. The total number of world cases were collected from the COVID-19 Dashboard by the Center for Systems Science and Engineering (CSSE) at John Hopkins University (<https://coronavirus.jhu.edu/map.html>) which are provided to the public strictly for educational and academic research purposes. The total number of cases in Saudi Arabian cities were collected from the publicly available COVID-19 Dashboard by the Ministry of Health (<https://covid19.moh.gov.sa>).

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Contributions: AH, funding acquisition, designed the study, collected data, performed statistical analyses, written first draft, and approved the final manuscript to be published; GD, data collection, interpretation of data, reviewing and editing, and approved the final manuscript to be published.

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