phrp
OSONG PUBLIC HEALTH AND RESEARCH PERSPECTIVES

pISSN 2210-9099 eISSN 2233-6052
https://doi.org/10.24171/j.phrp.2023.0125
Osong Public Health Res Perspect 2023;14(4):252-262

Original Article

Risk factors for transmission in a COVID-19 cluster infection in a high school in the Republic of Korea

Jin-Hwan Jeon[1], Su Jin Kang[2], Se-Jin Jeong[3], Hyeon-Cheol Jang[4], Young-Joon Park[5], Sang-Eun Lee[5]

[1]Jeju Branch Office-Honam Regional Center for Disease Control and Prevention, Korea Disease Control and Prevention Agency, Jeju, Republic of Korea
[2]The Institute for Social Development and Policy Research, Seoul National University, Seoul, Republic of Korea
[3]Data Analysis Team, Korea Disease Control and Prevention Agency, Cheongju, Republic of Korea
[4]Intelligent Crime Investigation Team-Ansan Sangnok Police Station, Gyeonggi Nambu Provincial Police Agency, Korean National Police Agency, Ansan, Republic of Korea
[5]Division of Epidemiological Investigation Analysis, Korea Disease Control and Prevention Agency, Cheongju, Republic of Korea

ABSTRACT

Objectives: This study aimed to examine the scale, characteristics, risk factors, and modes of transmission in a coronavirus disease 2019 (COVID-19) outbreak at a high school in Seoul, Republic of Korea.

Methods: An epidemiological survey was conducted of 1,118 confirmed cases and close contacts from a COVID-19 outbreak at an educational facility starting on May 31, 2021. In-depth interviews, online questionnaires, flow evaluations, and CCTV analyses were used to devise infection prevention measures. Behavioral and spatial risk factors were identified, and statistical significance was tested.

Results: Among 3rd-year students, there were 33 confirmed COVID-19 cases (9.6%). Students who used a study room in the annex building showed a statistically significant 4.3-fold elevation in their relative risk for infection compared to those who did not use the study room. Moreover, CCTV facial recognition analysis confirmed that 17.8% of 3rd-year students did not wear masks and had the lowest percentage of mask-wearers by grade. The air epidemiological survey conducted in the study room in the annex, which met the 3 criteria for a closed space, confirmed that there was only 10% natural ventilation due to the poor ventilation system.

Conclusion: To prevent and manage the spread of COVID-19 in educational facilities, advance measures that consider the size, operation, and resources of each school are crucial. In addition, various survey methodologies should be used in future studies to quickly analyze a wider range of data that can inform an evidence-based quarantine response.

Keywords: COVID-19; Epidemiology; Risk factors; Surveys and questionnaires; Video analysis

Received: May 9, 2023
Revised: May 21, 2023
Accepted: May 23, 2023

Corresponding author:
Sang-Eun Lee
Division of Epidemiological Investigation Analysis, Korea Disease Control and Prevention Agency, 187 Osongsaengmyeong 2-ro, Osong-eup, Heungdeok-gu, Cheongju 28159, Republic of Korea
E-mail: ondalgl@korea.kr

Introduction

Coronavirus disease 2019 (COVID-19) is spread primarily by droplets expelled from the respiratory tract of infected individuals in closed, crowded, and close-contact environments, and transmission can occur by touching a surface contaminated with the virus and then touching the mouth, eyes, or nasal mucosa without washing one's hands [1,2]. Among the various living environments encountered in daily life, educational facilities pose a high risk of infection (3 risk factors: enclosed, crowded, and close contact) because many students are in close contact for extended periods of time, such as during classes, meals, and sports activities [1].

At the beginning of the COVID-19 pandemic, many schools worldwide closed or were only partially operated to prevent the further transmission of the disease [3–5]. Educational facilities have suggested infection control measures such as wearing masks in schools, checking body temperature and respiratory symptoms, practicing hand sanitization, and not allowing students with symptoms to attend classes to reduce the risk of infection [6]. In May 2021, educational facilities in the Republic of Korea provided in-person or online classes according to the social distancing stages by region during the COVID-19 pandemic [7].

Following a cluster of 33 COVID-19 cases at a high school in Seoul, a large-scale epidemiological investigation was conducted from May 21 to May 31, covering a total of 1,118 people, which included both cases and contacts. All of the cases belonged to the same grade (3rd-year students), enabling an online survey, CCTV video analysis, and aerodynamic experiments to be conducted with 3rd-year students only (n=343) to investigate the outbreak pattern and key risk factors.

The existing literature on risk factor survey methods for COVID-19 prevention is diverse. This study was the first to use multiple survey methods to identify risk factors for rapid prevention in educational settings where there is a high risk of infection.

HIGHLIGHTS

- The study utilized various research techniques to examine the scale, characteristics, risk factors, and modes of transmission in a COVID-19 outbreak in a high school in the Republic of Korea.
- In-depth interviews, online surveys, on-site aerodynamic testing, and CCTV analysis were used to identify risk factors for the spread of COVID-19.
- The identified risk factors included not wearing masks and using the annex study room, which was an enclosed space. This information can be used to devise effective infection prevention measures at schools.
- Utilizing various survey techniques facilitated the identification of risk factors and enabled the development of comprehensive, evidence-based guidelines for preventing the future spread of infectious diseases.

Materials and Methods

Participants

This was a cross-sectional study. The sample included 1,118 high school students and staff from the high school. All infections were in 3rd-year students. Therefore, to analyze the behavioral characteristics of 3rd-year high school students related to COVID-19 infection, we conducted an online survey of 343 3rd-year students and analyzed the mask-wearing rate by grade among the entire school population of 1,118 participants. Given the COVID-19 incubation period, we defined cases as individuals who tested positive for severe acute respiratory syndrome coronavirus 2 genetic material in an upper respiratory tract specimen using reverse transcription-polymerase chain reaction testing according to the test criteria in the diagnostic assay between May 30, 2021, which was the date the first case was confirmed, and June 13, 2021.

Epidemiological Investigation

Based on the date of onset of symptoms of the index patient (May 23, 2021), the incidence rate was determined by calculating the proportion of confirmed COVID-19 cases among 3rd-year students within the incubation period. For symptomatic patients, the incidence rate was determined based on the date of symptom occurrence according to an individual basic epidemiological survey and an in-depth epidemiological survey conducted by the public health center in the jurisdiction of the confirmed patient's area of residence related to the cluster infection. In cooperation with the school principal, we collected a list of students who attended classes and users of the annex self-study room.

Risk Factor Analysis

Online questionnaire

The survey was designed to identify significant differences in the behavioral characteristics of students with and without confirmed COVID-19 infections at the study school in order to devise strategies to prevent future infections.

The survey was conducted online using Google Forms with the condition that no personal information would be included. Participants were informed about the purpose of the survey, the conditions of participant consent for information collection, the legal basis for the study, and the planned destruction of participant data after analysis. The survey totaled 25 questions across 6 categories, focusing on behaviors that could cause vulnerability to infection, such as whether individuals were previously infected with COVID-19, whether they switched classes, their food intake history, and whether they wore masks, performed hand sanitization, and talked with classmates (online survey: https://forms.gle/ZF2HqMrc5DTVaKE99) (Supplementary Material 1). With the permission of the person in charge of the school and parents, the study was conducted only with the 343 third-year students, regardless of their COVID-19 infection status. We asked students to respond about their in-school behaviors between May 21 and May 31, 2021, and conducted an online survey on June 1. Among the 343 students, 266 responded. The collected survey data were extracted and organized in Excel ver. 2016 (Microsoft Corp.). Basic statistics, the t-test, and the Pearson chi-square test were conducted using STATA ver. 17.0 (StataCorp LLC). Based on a reference study that conducted a survey about COVID-19, statistical significance was set at $p < 0.05$ [8].

Investigation of the environment

The floor plans of the main and annex buildings of the high school were obtained to confirm the routes of transmission of the cluster infection. We verified that the school administration complied with the school quarantine management regulations. Interviews and on-site surveys were conducted with the school's facilities manager to determine whether features to improve ventilation, such as windows and air conditioners, were installed in the annex self-study room.

Video analysis

In order to prevent school violence and ensure a safe learning environment in schools, as covered by Article 2 of the Elementary and Secondary Education Act, the school principal must follow the Standard Guidelines for Installation and Operation of Video Information Processing Devices in Schools created by the Ministry of Education by installing a CCTV system. Therefore, we analyzed the students' movements and mask-wearing rates by grade during the exposure period (May 20 to May 31) using CCTVs installed in the schools.

The CCTV footage was collected in accordance with the Ministry of Education's Personal Information Processing Policy and Article 18, Paragraph 3, of the Constitution of the Republic of Korea (Act on the Prevention and Control of Infectious Diseases) on the legal grounds that information disclosure requests and submission of documents necessary for epidemiological investigations, respectively, can be requested. For CCTV analysis, we used BriefCAM Investigator software ver. 5.4 (BriefCAM Investigator), which is currently used by the Korean National Police Agency for investigations requiring extensive information analysis. The program filters out all faces identified in the footage. Filtering was performed using artificial intelligence (AI) for face detection, during which the face resolution, face image quality, and face pose were identified. The filtered faces were then removed via alarm triggers for objects with low quality or when no face was detected. The faces, extracted using AI, were automatically mosaicked and categorized according to whether the subject was wearing a mask, not wearing a mask, or wearing a mask across the chin only. The program was run on a laptop registered as the property of the Gyeonggi Southern Police Agency. The laptop was protected by physical and digital security systems and could not be connected to the Internet. Therefore, information leakage was impossible. Furthermore, the analysis was performed by an investigator affiliated with the police department. At the end of the analysis, all data were permanently deleted.

Field experiment on aerodynamics

The epidemiological investigation confirmed that the index case and additional cases all occurred among students who had used the annex study room, which is a closed, densely packed, and close-contact environment. Therefore, we investigated the movement of infectious disease droplets in the annex room. First, we divided the area into 10 zones. The concentration distribution for ventilation and airflow and the change in droplet particle concentration in the selected areas were measured with the windows both closed and opened. The concentration of contaminants in each area was measured with a smoke generator, oil vapor generator, indoor air quality sensor, and particle imaging velocimeter system to evaluate the possible horizontal spread of droplet-type particles in the target building space.

Ethics Approval

This study was approved by the Institutional Review Board of the Korea Disease Control and Prevention Agency (2022-10-01-PE-A) and performed in accordance with the principles of the Declaration of Helsinki.

https://doi.org/10.24171/j.phrp.2023.0125

Results

General Characteristics of the Confirmed Cases

Outbreak pattern of all confirmed cases in the school: The school was an all-boys school, and the infected students and contacts were all male. A total of 33 confirmed cases of COVID-19 were identified among the students, with no confirmed cases among faculty members. The incidence rate was the highest in class 11, with 9 infected students (30%), while there were no confirmed cases in class 2 (Table 1). Twenty-eight patients (84.8%) responded that they had clinical symptoms of COVID-19, while 5 students (15.2%) were asymptomatic. Among the students with symptoms, 16 (23.2%) had a sore throat, 12 (17.4%) had a headache, and 11 (15.9%) had a fever (Figure 1).

Outbreak pattern of confirmed cases according to the use of the self-study room in the annex: A total of 21 out of the 33 confirmed cases (63.6%) involved those who used the study room. Among the students who tested negative, 144 (46.5%) used the study room. Therefore, the relative risk of patients who used the study room compared to those who did not was 2.2 (95% confidence interval, 1.12–4.37) (Table 2).

Trends of the Epidemic

Of the 33 high school students with confirmed COVID-19 infections, 14 used the annex self-study room, which is

Table 1. Prevalence of symptoms and incidence of COVID-19 infection by high school class

Class	No. of students	Infected			Non-infected	Infection rate (%)
		Total	Symptomatic	Asymptomatic		
Total	343 (100.0)	33 (100.0)	28 (100.0)	5 (100.0)	310 (100.0)	9.6
3rd-year students						
Class 1	33 (9.6)	1 (3.0)	1 (3.6)	0 (0)	32 (10.3)	3.0
Class 2	34 (9.9)	0 (0)	0 (0)	0 (0)	34 (11.0)	0.0
Class 3	32 (9.3)	1 (3.0)	1 (3.6)	0 (0)	31 (10.0)	3.1
Class 4	31 (9.0)	6 (18.2)	6 (21.4)	0 (0)	25 (8.1)	19.4
Class 5	30 (8.7)	1 (3.0)	1 (3.6)	0 (0)	29 (9.4)	3.3
Class 6	30 (8.7)	2 (6.1)	2 (7.1)	0 (0)	28 (9.0)	6.7
Class 7	32 (9.3)	5 (15.2)	3 (10.7)	2 (40.0)	27 (8.7)	15.6
Class 8	31 (9.0)	3 (9.1)	3 (10.7)	0 (0)	28 (9.0)	9.7
Class 9	30 (8.7)	3 (9.1)	3 (10.7)	0 (0)	27 (8.7)	10.0
Class 10	30 (8.7)	2 (6.1)	2 (7.1)	0 (0)	28 (9.0)	6.7
Class 11	30 (8.7)	9 (27.3)	6 (21.4)	3 (60.0)	21 (6.8)	30.0

Data are presented as *n* (%).

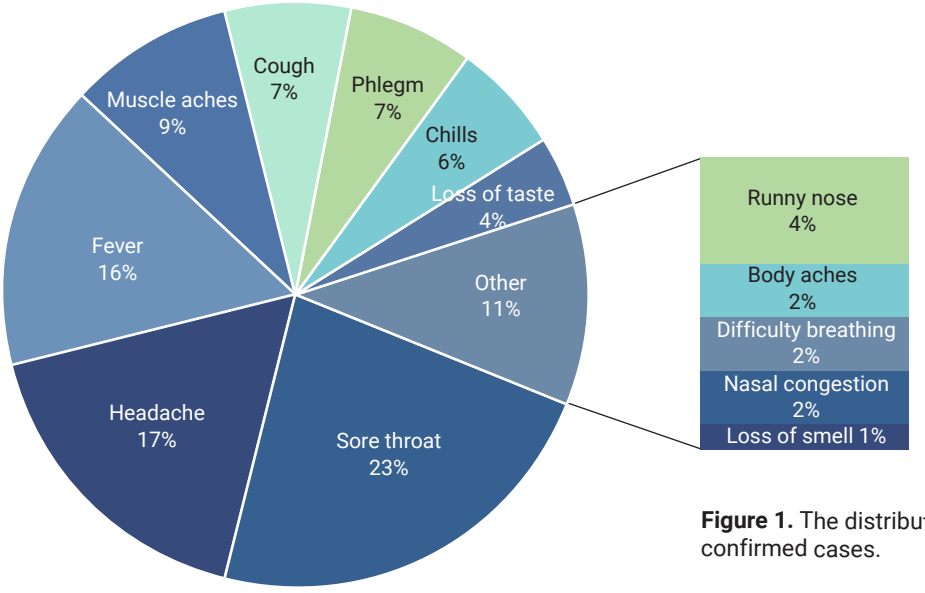

Figure 1. The distribution of clinical symptoms in COVID-19 confirmed cases.

Table 2. The relative risk of COVID-19 infection among 3rd-year high school students according to whether they used the self-study room

School annex self-study room	Positive (*n* = 33)	Negative (*n* = 310)	Total (*n* = 343)	RR (95% CI)	*p*
Used	21 (63.6)	144 (46.5)	135 (39.4)	2.2 (1.12–4.37)	0.018
Not used	12 (36.4)	197 (63.5)	208 (60.6)	Ref.	

Data are presented as *n* (%) or RR (95% CI).
RR, relative risk; CI, confidence interval; ref., reference.

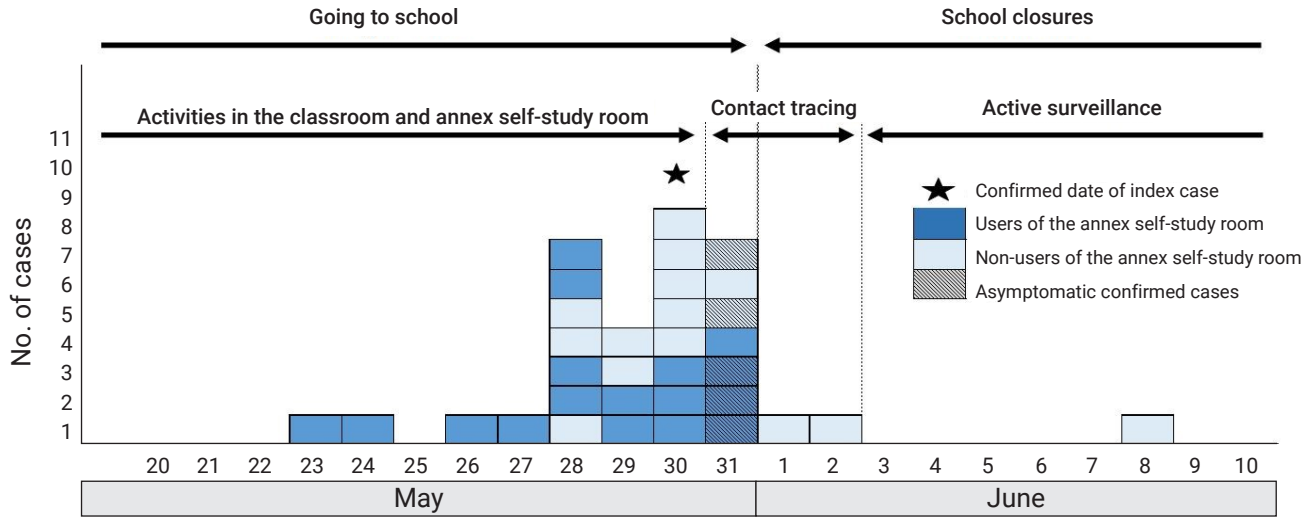

Figure 2. Epidemic curve for the characteristics of the COVID-19 outbreak in schools from May 20 to June 20, 2021, and the presence of symptoms.

exclusively for 3rd-year students. It is speculated that secondary transmission occurred in each class after the initial transmission in the annex self-study room, considering that users of the room spent more time at school than non-users and the room was not well-ventilated (Figure 2).

Personal Preventive Behavior

Using the results of the survey to identify behavioral risk factors, 266 of the 3rd-year students who participated in the survey were asked about their preventive behaviors in the classroom. Of the 28 students with confirmed infections, 17 (60.7%) always wore masks in the classroom and 10 (35.7%) often wore them. Of the 238 non-cases, 141 (59.2%) always wore a mask and 91 (38.2%) often wore a mask. In addition, 220 students (82.7%) took off their masks while drinking water, and 19 (7.1%) and 3 (1.1%) students took off their masks while talking to friends and giving presentations, respectively.

Personal precautions when using the study room: Of the 33 students with confirmed infections, 21 (63.6%) used the study room and 12 (36.4%) did not. Of the total participants, 135 (50.4%) answered that they had used the study room. Among them, most used it 4 times a week (40.7%), followed by 5 or more times (34.1%). The average duration of use was more than 3 hours (87.4%). Overall, 37.8% of the students answered that they often wore a mask, while 3.7% (5 students) reported that they never wore a mask (Table 3).

Relationship between mask-wearing and confirmed COVID-19 infections when using the annex self-study room: There was a significant difference in the frequency of mask-wearing in the self-study room between students who tested positive for COVID-19 and those who did not, confirming that wearing a mask was effective ($p = 0.003$) (Table 3).

Mask-Wearing Rate Based on CCTV Analysis

An in-depth analysis of footage from the CCTV system installed in the main building of the high school was conducted to assess the routes of transmission and quarantine compliance. The school had 12 CCTVs, with 3 to 4 installed on each floor. The rate at which students did not wear masks by grade was analyzed using video data for 12 days from May 20 to May 31, 2021, which was considered the transmission period. Individuals for whom it could not be determined whether they wore a mask through facial recognition during the time period were excluded (Figure 3). After collecting 17,693 data

https://doi.org/10.24171/j.phrp.2023.0125

Table 3. Survey results on the frequency of the use of the annex self-study room and personal preventive behaviors

Characteristic	Total	Positive	Negative	*p*
Total	135 (100.0)	21 (100.0)	114 (100.0)	
No. of times students used the annex self-study room in a week (time)				0.439
1	9 (6.7)	1 (4.8)	8 (7.0)	
2	7 (5.2)	1 (4.8)	6 (5.3)	
3	18 (13.3)	2 (9.5)	16 (14.0)	
4	55 (40.7)	6 (28.6)	49 (43.0)	
≥5	46 (34.1)	11 (52.4)	35 (30.7)	
Average hours of use of the annex self-study room (h)				0.498
<1	3 (2.2)	0 (0)	3 (2.6)	
1–2	2 (1.5)	1 (4.8)	1 (0.9)	
2–3	12 (8.9)	2 (9.5)	10 (8.8)	
>3	118 (87.4)	18 (85.7)	100 (87.7)	
Frequency of mask-wearing in the annex self-study room				0.009
Always	47 (34.8)	3 (14.3)	44 (38.6)	
Often	51 (37.8)	8 (38.1)	43 (37.7)	
Sometimes	32 (23.7)	7 (33.3)	25 (21.9)	
Never	5 (3.7)	3 (14.3)	2 (1.8)	
Frequency of hand sanitization in the annex self-study room				0.369
Always	5 (3.7)	1 (4.8)	4 (3.5)	
Often	20 (14.8)	2 (9.5)	18 (15.8)	
Sometimes	49 (36.3)	5 (23.8)	44 (38.6)	
Never	61 (45.2)	13 (61.9)	48 (42.1)	
Activities performed in the annex self-study room				0.726
Discussion	43 (31.9)	6 (28.6)	37 (32.5)	
Self-guided learning	92 (68.1)	15 (71.4)	77 (67.5)	
Whether the student wore a mask in the annex self-study room				0.003
Yes	100 (74.1)	10 (47.6)	90 (79.0)	
No	35 (25.9)	11 (52.4)	24 (21.0)	
Whether the student used mobile learning in the annex self-study room				0.028
Yes	121 (89.6)	16 (76.2)	105 (92.1)	
No	14 (10.4)	5 (23.8)	9 (7.9)	
Whether the student ate in the annex self-study room				0.103
Yes	97 (71.9)	12 (57.1)	85 (74.6)	
No	38 (28.1)	9 (42.9)	29 (25.4)	

Data are presented as *n* (%).

points on 1st-year students, 16,883 data points on 2nd-year students, and 27,603 data points on 3rd-year students, we were able to determine whether individuals wore a mask (Table 4). Among the identifiable individuals, 3rd-year students were most likely to not wear a mask, at a rate of 17.8%, followed by 2nd-year students at 11.0% and 1st-year students at 9.6%. Based on this, the rate at which students on the 2nd floor, where the 3rd-year classroom was located, did not wear masks was found to be approximately 2% to 3% higher than that of students on other floors. In addition, frequent contact occurred between students in the hallway and bathroom, which were infection control blind spots where the infection control supervisor was absent.

Aerodynamic Investigation in the Annex Self-study Room

When the air conditioner was operated with the windows closed, the air diffused faster to the 16th and 17th positions with high ceilings, and the highest droplet concentration (30%) was maintained even after 1 hour of diffusion in the room because of the airflow from the inlet and outlet of the air conditioner. In addition, when natural ventilation was not used, the use of the air conditioner greatly increased the diffusion in the room. However, when the air conditioner was used with the window partially (one-third) open, the horizontal movement increased with the direction of the external airflow. In addition, due to the effect of natural ventilation using a window, the concentration after 1 hour was approximately 10% of the highest

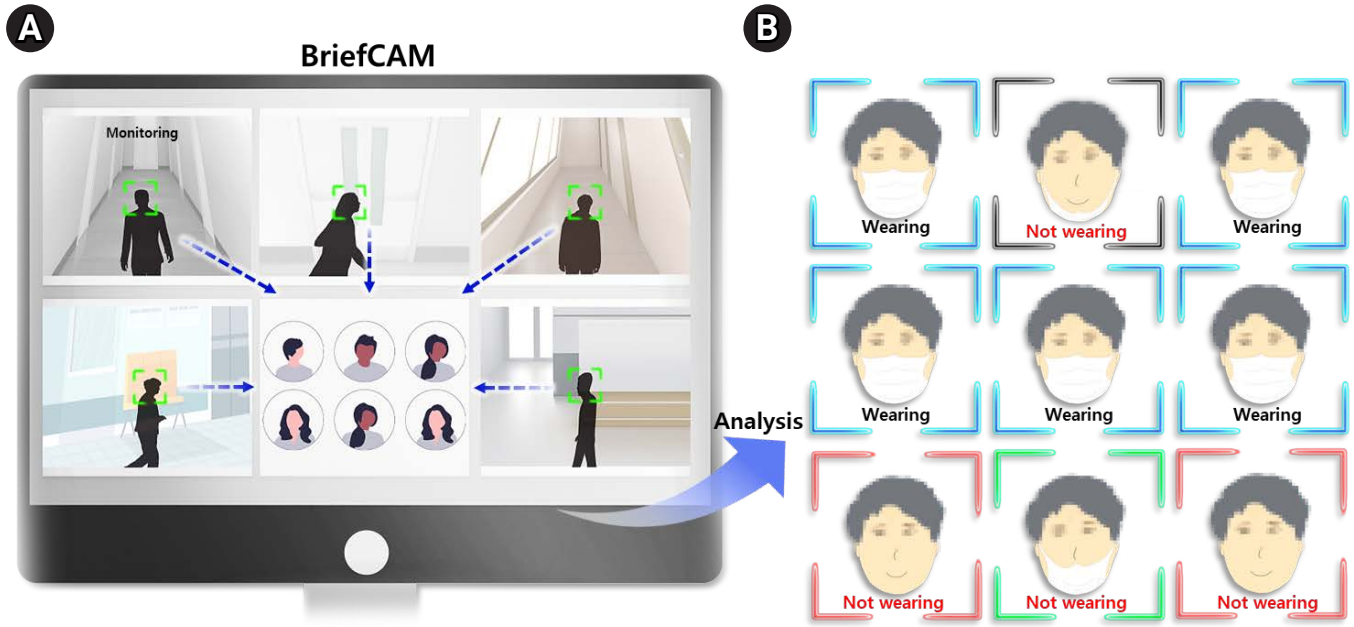

Figure 3. CCTV face recognition analysis using BriefCAM Investigator.
(A) Recognition of people in the video. (B) Extraction of the face of the recognized person, and then mosaic processing of the extracted person.

Table 4. Percentage of students who wore masks in the hallways of each floor by grade

Grade	Total	Unidentifiable faces[a)]	No. of identifiable students	No. of students not wearing masks	Students who did not wear masks (%)
1st-year	59,857 (100.0)	40,468 (67.6)	17,693 (29.6)	1,696 (2.8)	9.6
2nd-year	53,485 (100.0)	34,741 (65.0)	16,883 (31.6)	1,861 (3.5)	11.0
3rd-year	84,023 (100.0)	51,505 (61.3)	27,603 (32.9)	4,915 (5.8)	17.8
Total	197,365 (100.0)	126,714 (64.2)	62,179 (31.5)	8,472 (4.3)	13.6

Data are presented as *n* (%) unless otherwise specified.
[a)]Objects with low quality or no detectable faces were removed.

concentration. Regarding natural ventilation using a window at the target facility, projection windows were installed at the bottom of the room; therefore, the effect of natural ventilation was relatively insignificant compared to other facilities (Figure 4).

Discussion

In the present study, the epidemiological investigation and risk factor analysis revealed that quarantine management protocols, such as checking students' temperatures before entering classrooms, thorough classroom education on infection prevention, hand sanitization, mask-wearing, and ventilation, were fully implemented by teachers. Classroom teachers and school nurses were appointed as infection control managers according to the Korean government's Guidelines for Prevention and Management of COVID-19 in elementary, middle, high, and special schools (5th edition, July 19, 2021). However, our results showed that the spread of infectious diseases occurred due to multiple risk factors, such as not wearing a mask during recess or operating air conditioners in closed rooms with no open windows, such as in the annex self-study room, where natural ventilation is unlikely.

Video analysis of CCTV footage using the BriefCAM Investigator program, which is commonly used in police investigations, allowed us to track objects and detect abnormal behavior and events using CCTV images [9]. The results confirmed a low mask-wearing rate among the students, despite education on personal hygiene and social distancing measures in the school, indicating that compliance with COVID-19 rules was insufficient.

One strength of this study is that, while most previous case-control and cohort studies of infectious diseases

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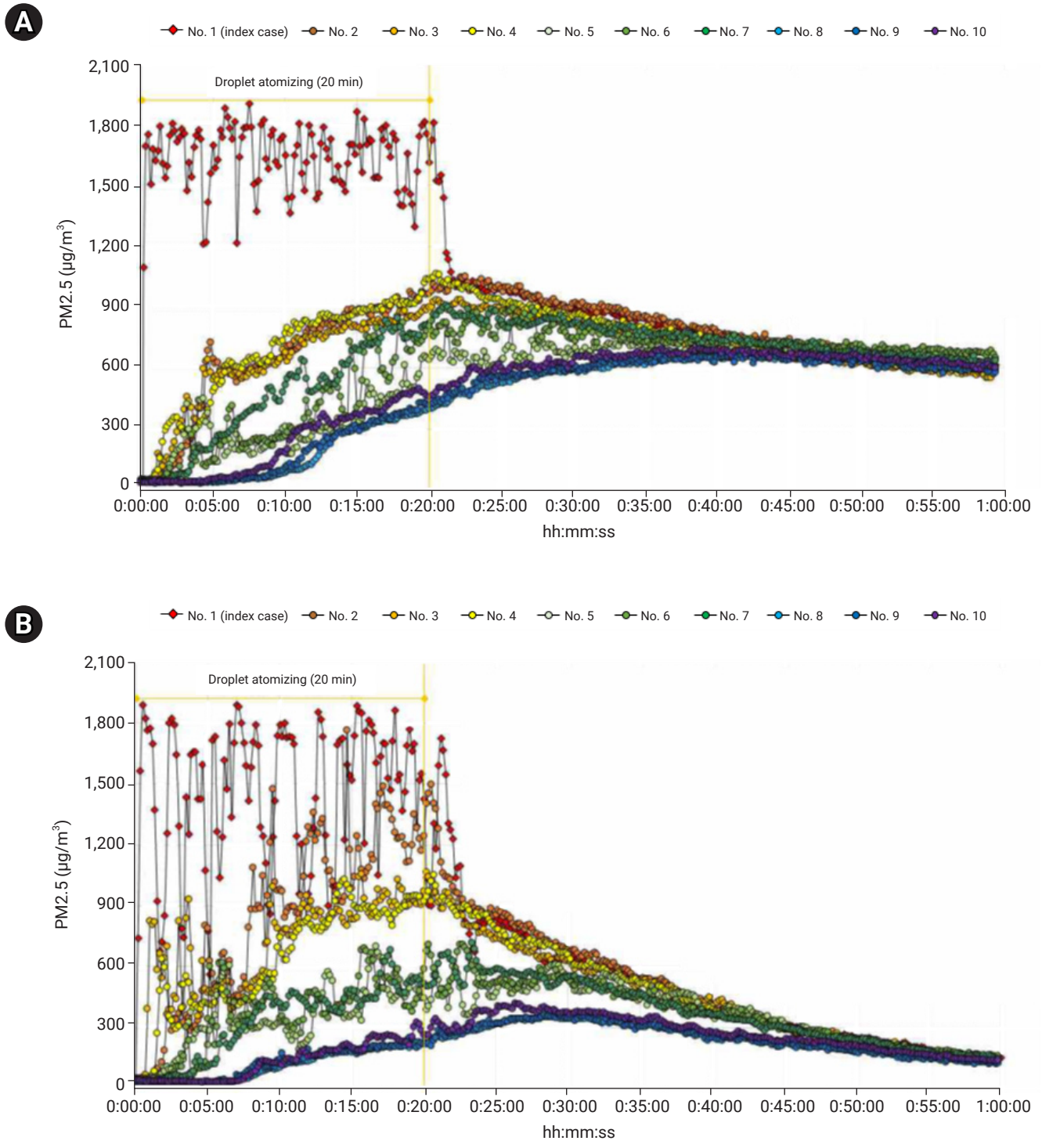

Figure 4. Droplet concentrations in the annex self-study room with and without natural ventilation at 10 locations.
(A) Air conditioning on and windows not open. (B) Air conditioning on and windows open.

have conducted 1 or 2 epidemiological investigations, we attempted to use multiple techniques that allowed us to identify and assess risk factors comprehensively [10–15]. Considering the size of the sample and the rapid epidemiological investigation, our results are consistent with those of previous studies that emphasized the importance of convenience and speed in infectious disease investigations [16,17].

As the importance of social distancing has been highlighted by the COVID-19 pandemic, software that uses AI and algorithms has been developed to monitor the spread of infectious diseases, eliminating constraints in terms of manpower and time and enabling rapid and efficient monitoring [8,18]. However, the use of personal or biometric information remains a controversial legal issue. Therefore, it was necessary to inform participants about the purpose of the study before it was used and to take specific measures for the collection, storage, use, and deletion of data [19,20]. By addressing the above issues, this tool can be effective in preventing the further spread of infectious diseases.

Ventilation is another preventive measure against COVID-19 infection [21,22]. In addition, the main areas where students spend their time at school are classrooms and self-study labs. The windows in the self-study room in the annex were closed while the air conditioner and air purifier were running, which inhibited effective ventilation. The artificial droplet experiment showed that the effect of ventilation in the study room was insignificant. This was because of the high ceiling in the building and the types of windows installed at the bottom of the room. In other words, since the room was not sufficiently ventilated, the viral droplets expelled from the student with the first confirmed infection remained in the air for hours. This result is similar to that of a previous simulation study that examined the effect of ventilation according to window opening area [23]. Finally, overcrowding was another risk factor identified in this study, since the annex self-study room was designed for 164 students with 80 seats and could have been overcrowded.

This study has several limitations. First, the study identified several infection control blind spots in the school, such as rooms with poor ventilation, and the results may have been biased since aerodynamic tests were not conducted in all areas. Therefore, if there are blind spots for infection control in each school, preventive measures should be designed and implemented that are tailored to the operation and structure of each school. Second, this study was conducted only at a school and did not investigate risk factors outside of schools; therefore, the study may not have identified all possible risk factors that outside of a school setting.

Our findings suggest a need to manage and supervise mask-wearing during classes and breaks and to maintain an appropriate distance between students when using the restroom. Intensive quarantine management in enclosed spaces, such as study rooms outside of classrooms, is also needed. Frequent and proper ventilation should be encouraged, and guidelines for creating proper ventilation conditions are critical.

Conclusion

This was the first study in the Republic of Korea to perform risk factor analysis for a school outbreak using multiple epidemiological techniques. Our findings suggest effective strategies to minimize further transmission in the event of an outbreak of novel respiratory infections, such as COVID-19, in schools.

In our study, the patient with the earliest onset of symptoms (May 23) was thought to be the source of the initial transmission in the annex study room, leading to the secondary transmission to other students at the school. Immediate countermeasures were needed to prevent further infection and to reduce anxiety among teachers, students, and parents. Detailed countermeasures for encouraging preventive behaviors, such as mask-wearing, should be recommended in schools.

To prevent and stop future outbreaks in schools, it is necessary to identify the relevant variables, such as the size, operation, and resources of each school, to establish COVID-19 prevention and control measures and facility management plans. Adequate ventilation and exhaust systems for building structures and natural ventilation measures, such as opening windows, should also be emphasized. In addition, prevention efforts should focus on how to implement various investigative techniques to quickly analyze a wide range of information and rapidly implement an active, evidence-based prevention response. These techniques can be used to investigate infection control blind spots not monitored by on-site surveillance systems or quarantine personnel in high-risk facilities, including schools and community living facilities.

Supplementary Material

Supplementary Material 1. Survey on the outbreak at a high school in Gangbuk-gu Seoul. Supplementary data are available at https://doi.org/10.24171/j.phrp.2023.0125.

https://doi.org/10.24171/j.phrp.2023.0125

Notes

Ethics Approval
This study was approved by the Institutional Review Board of the Korea Disease Control and Prevention Agency (2022-10-01-PE-A) and performed in accordance with the principles of the Declaration of Helsinki.

Conflicts of Interest
The authors have no conflicts of interest to declare.

Funding
This work was supported by funding from the Korea Disease Control and Prevention Agency (2023, 6231-335-210-01).

Availability of Data
The datasets are not publicly available but are available from the corresponding author upon reasonable request.

Authors' Contributions
Conceptualization: JHJ, SEL, YJP; Data curation: JHJ, SJK, SJJ; Formal analysis: JHJ, SJK, SJJ, HCJ; Funding acquisition: SEL; Investigation: JHJ, SJK, HCJ; Methodology: JHJ, SJK, SJJ, HCJ; Project administration: JHJ; Resources: JHJ; Software: JHJ; Supervision: SEL; Validation: SEL; Visualization: JHJ, HCJ; Writing–original draft: JHJ; Writing–review & editing: all authors. All authors read and approved the final manuscript.

Additional Contributions
We thank all of the local government (Gangbuk Health Center, Seoul Metropolitan) infectious disease managers.

References

1. Ministry of Education. Press release: COVID-19 status in the education field [Internet]. Ministry of Education; 2022 [cited 2023 May 31]. Available from: https://www.moe.go.kr/boardCnts/viewRenew.do?boardID=294&boardSeq=91497&lev=0&searchType=null&statusYN=W&page=43&s=moe&m=020402&opType=N. Korean.
2. Chan JF, Yuan S, Kok KH, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. Lancet 2020;395:514–23.
3. Klimek-Tulwin M, Tulwin T. Early school closures can reduce the first-wave of the COVID-19 pandemic development. Z Gesundh Wiss 2022;30:1155–61.
4. Baron EJ, Goldstein EG, Wallace CT. Suffering in silence: how COVID-19 school closures inhibit the reporting of child maltreatment. J Public Econ 2020;190:104258.
5. Auger KA, Shah SS, Richardson T, et al. Association between statewide school closure and COVID-19 incidence and mortality in the US. JAMA 2020;324:859–70.
6. Ministry of Education, Central Disaster Management Headquarters, Central Disease Control Headquarters, Ministry of Food and Drug Safety. Guidelines for preventing and managing COVID-19 in kindergarten, elementary, middle, high, and special schools. 4th ed. Ministry of Education; 2021. Korean.
7. World Health Organization (WHO). COVID-19 vaccines [Internet]. WHO; 2021 [cited 2021 Mar 15]. Available from: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/covid-19-vaccines.
8. Shukla P, Kundu R, Arivarasi A, et al. A social distance monitoring system to ensure social distancing in public areas. In: 2021 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE); 2021 Mar 17-18; Dubai: IEEE; 2021.p. 96–101.
9. Assini JM, Deyo M, Galarneau E, et al. Investigation & litigation: how agencies' use of surveillance technologies, including wire-tapping, impact current criminal investigation and how the use of DNA has propelled the criminal justice system into the 21st century. Albany Law J Sci Technol 2019;29:123.
10. Liang W, Zhu Z, Guo J, et al. Severe acute respiratory syndrome, Beijing, 2003. Emerg Infect Dis 2004;10:25–31.
11. Wu JT, Cowling BJ, Lau EH, et al. School closure and mitigation of pandemic (H1N1) 2009, Hong Kong. Emerg Infect Dis 2010;16:538–41.
12. Zhang C, Gu J, Chen Q, et al. Clinical and epidemiological characteristics of pediatric SARS-CoV-2 infections in China: a multicenter case series. PLoS Med 2020;17:e1003130.
13. Lee N, Chan PK, Hui DS, et al. Viral loads and duration of viral shedding in adult patients hospitalized with influenza. J Infect Dis 2009;200:492–500.
14. Glass LM, Glass RJ. Social contact networks for the spread of pandemic influenza in children and teenagers. BMC Public Health 2008;8:61.
15. Bohmer MM, Buchholz U, Corman VM, et al. Investigation of a COVID-19 outbreak in Germany resulting from a single travel-associated primary case: a case series. Lancet Infect Dis 2020;20:920–28.
16. Wright KB. Researching Internet-based populations: advantages and disadvantages of online survey research, online questionnaire authoring software packages, and web survey services. J Comput Mediat Comm 2005;10:JCMC1034.
17. Gesser-Edelsburg A, Cohen R, Hijazi R, et al. Analysis of public perception of the Israeligovernment's early emergency instructions regarding COVID-19: online survey study. J Med Internet Res 2020;22:e19370.
18. Shao Z, Cheng G, Ma J, et al. Real-time and accurate UAV pedestrian detection for social distancing monitoring in COVID-19 pandemic. IEEE Trans Multimedia 2022;24:2069–83.
19. Ramos LF. Evaluating privacy during the COVID-19 public health emergency: the case of facial recognition technologies. In: Proceedings of the 13th International Conference on Theory and Practice of Electronic Governance (ICEGOV '20); 2020 Sep 23-25; Athens: Association for Computing Machinery; 2020. p. 176–9.
20. Sella-Villa D. An early evaluation of the privacy impacts of the COVID-19 pandemic. Bus Lawyer 2020–2021;76:259–64.
21. Morawska L, Tang JW, Bahnfleth W, et al. How can airborne transmission of COVID-19 indoors be minimised? Environ Int 2020;142:105832.

22. Buonanno G, Ricolfi L, Morawska L, et al. Increasing ventilation reduces SARS-CoV-2 airborne transmission in schools: a retrospective cohort study in Italy's Marche region. Front Public Health 2022;10:1087087.
23. Hendrawati D. Natural ventilation performance for schools during a pandemic and the post-pandemic COVID 19. J Archit Res Des Stud 2021;5:55–62.

https://doi.org/10.24171/j.phrp.2023.0125