ABSTRACT

BACKGROUND: School closures were initially believed to mitigate SARS-CoV-2, but instead may have had a limited role in reducing community SARS-CoV-2 transmission. We describe a single school’s experience with in-person education during the COVID-19 pandemic.

METHODS: From August 17, 2020 through January 23, 2021, we conducted a prospective study at a private pre-kindergarten through 12th grade (PreK-12) school in North Carolina. The school employed numerous SARS-CoV-2 mitigation measures, including mandatory masking and physical distancing without mandated laboratory screening tests. We analyzed de-identified contact tracing data collected by the school.

RESULTS: Seventy-five primary cases were reported among the 2110 students, faculty, and staff during the study period. Twenty-one (28%) of the primary cases were on-campus during their infectious periods; however, no classroom close-contacts subsequently reported a positive SARS-CoV-2 test result. Two secondary cases likely resulted from unmasked exposure at a school athletic event. There was no correlation between community incidence and secondary transmission in the school.

CONCLUSIONS: Despite high rates of SARS-CoV-2 community incidence during the study period, routine mitigation practices including daily health screenings, mandatory face coverings, and efficient contact tracing contributed to minimal secondary SARS-CoV-2 transmission within an urban PreK-12 school. The limited school-associated transmission occurred when masks were not used during athletic events.

Keywords: COVID-19; secondary transmission; sports; athletics.

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Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus that causes coronavirus disease 2019 (COVID-19), has infected >7 million children in the United States, including >200,000 children in North Carolina (NC). To prevent SARS-CoV-2 transmission, many schools implemented a prolonged shutdown of all in-person education in 2020; however, school closures detrimentally affect students’ learning and mental health. In low community transmission settings, numerous studies demonstrated minimal transmission of SARS-CoV-2 in schools. Nevertheless, when community transmission soared, efforts to resume in-person education stalled in various states, especially for public schools. On the other hand, private schools remained open for in-person education despite varying COVID-19 community case rates. While SARS-CoV-2 vaccines have had a significant impact on COVID-19 cases among adults, in some cases, vaccination rates among children and adolescents have lagged behind adults, and rising community incidence due to SARS-CoV-2 variants has led renewed calls for school closures. Therefore, questions remain regarding the safety of school reopening and the implementation of mitigation measures. In this manuscript, we characterize school-associated secondary transmission and COVID-19 incidence among the population of a single PreK-12 school during a period of high-community SARS-CoV-2 incidence.

METHODS

Participants

We conducted a prospective study among all students, faculty, and staff at a private school located in urban Mecklenburg County, NC, from August 17, 2020 through January 23, 2021 (23 weeks). During this time, weekly SARS-CoV-2 incidence in the county ranged from 58.5 to 775.2 new cases per 100,000 persons.

The school employed 317 faculty and staff members and enrolled 1793 students. Sixty-one percent of students were non-Hispanic white, 7.1% were non-Hispanic black, 2.8% were Hispanic/Latino, 20.1% were other races/ethnicities (eg, Asian or multiracial), and 8.9% did not have race/ethnicity data available. Forty-nine percent of students were female. Approximately 73% of faculty and staff members were non-Hispanic white and 11.1% were non-Hispanic black; no further demographic data were available for this group.

Students were divided into 3 cohorts by grade level; 681 (37.9%) students were in lower school (PreK-5th grade), 469 (26.1%) students were in middle school (6th-8th grade), and 643 (36.8%) students were in upper school (9th-12th grade). During the semester, students could choose to switch between in-person and remote learning every 3 weeks; throughout the 23-week study, an average of 201 (9.5%) students were fully remote (standard deviation = 50.6).

Mitigation Measures

The school implemented numerous interventions to mitigate SARS-CoV-2 transmission. Lower school students attended in-person classes 5 days per week in reduced (50%) capacity classrooms until October 2020, when PreK-3rd grade classes returned to full (100%) capacity. Middle and upper school students were divided into 2 cohorts by alphabetical order, with each cohort attending in-person classes on alternating days. Six-foot physical distancing was enforced in middle and upper school classrooms, while 3-ft physical distancing was implemented in lower school classrooms.

All persons on-campus were required to wear masks at all times, except for meals and “mask breaks,” both of which were held outdoors with >6-ft distancing. Masks were not required during athletic events until a statewide mandate was issued on November 15, 2020, after which masks were required for all athletes within indoor spaces. Air-conditioning systems at the school were upgraded with minimum efficiency reporting value 11 filters, and teachers were encouraged to open windows to improve ventilation. Specialized interventions were implemented for activities that posed high risk of transmission (eg, coverings for wind instruments and conducting choral performances outdoors). Additional measures included disinfection of surfaces, plexiglass barriers on all student desks, 1-way stairwells, and visitor restrictions at sporting events. School nurses and administrators periodically reminded students of the importance of adherence to mitigation measures at whole-school assemblies, as well as via emails sent to students and their parents/guardians. Prior to holiday breaks, school administrators sent email and video messages to students and parents/guardians encouraging the masking and distancing outside of school. If school administrators were informed of large gatherings of students, targeted messaging was conducted to encourage the use of mitigation measures or the cancelation of the event.

Daily Health Screening

Students, faculty, and staff were required to complete daily online health screening forms (http://www.basecamp-health.com) to identify and exclude individuals with SARS-CoV-2 symptoms or exposures from attending classes or school events. The screening asked individuals to self-report symptoms, community SARS-CoV-2 exposures, and any results of recent SARS-CoV-2 testing. Persons who reported symptoms were required to undergo SARS-CoV-2 testing and...
not permitted to return to school until symptoms resolved. Each morning, school administrators and nurses reviewed compliance with the daily screening and required a caregiver follow-up phone call prior to school attendance for noncompliant students. Per local guidance for schools,9 individuals who reported community SARS-CoV-2 exposures were quarantined for 14 days and encouraged, but not required, to seek testing. Students who became symptomatic at school were immediately isolated in the nurse’s office and sent home.

Definitions
We defined SARS-CoV-2 case-patients as persons with a positive SARS-CoV-2 reverse transcription-polymerase chain reaction (RT-PCR) or antigen test result. We further categorized cases as either primary or secondary. Primary cases included persons with a positive SARS-CoV-2 test result and either: (1) known community exposure to a SARS-CoV-2-infected individual during non-school-affiliated activities (eg, family gatherings or travel); or (2) symptoms, but no reported exposure to a SARS-CoV-2 case. Secondary school-related cases were defined as persons with a positive test result after known contact with a primary case while participating in classes or school-affiliated activities.

Using Centers for Disease Control (CDC) and NC Department of Health and Human Services (NCDHHS) guidance, close contact was defined as being within 6 ft of a case for ≥15 minutes over a 24-hour period.9,10

School Case Investigation and Contact Tracing
Per NCDHHS and school protocol,9 when an individual reported a positive SARS-CoV-2 test result via the daily screening, a trained school nurse would conduct a case investigation interview with the case, the case’s parent/guardian, and/or the case’s classroom teacher. Interview lengths varied from 10 minutes to a few hours and depended on the number of contacts. If the case was determined to be at school while infectious (2 days prior until 10 days following symptom onset or specimen collection), then contact tracing was initiated by the school nurses to identify any close contacts using standardized forms verified by local public health departments. School nurses used seating charts to assist with the determination of close contacts.

All school-associated close contacts were immediately quarantined for 14 days and encouraged to seek SARS-CoV-2 RT-PCR testing ≥5 days following exposure and if new symptoms developed during quarantine. Persons who were in the same classroom as a case, but did not meet the close contact definition, were not required to quarantine; however, these individuals were monitored for symptoms. In accordance with CDC guidance, persons who had recovered from SARS-CoV-2 <90 days before exposure did not have to quarantine.

Data Analysis
School nurses and administrators collected data from case investigations, contact tracing, and health screening in a line-list spreadsheet form. These data were de-identified prior to research use. School administrators also provided information regarding compliance with mitigation measures and demographic information for the school population. Mecklenburg County SARS-CoV-2 case rates were calculated using data from the USAFacts COVID-19 Dashboard.8 The county population was obtained from the US Census Bureau.

We performed descriptive statistics using OpenEpi (www.openepi.com) to analyze secondary transmission and incidence. Case adjudication and data analyses were reviewed by physicians in the ABC Science Collaborative under a data use agreement.

RESULTS
During the study, 75 primary cases were reported, of which 59 (78.7%) resulted from community-associated exposure and 16 (21.3%) had an unknown association (Table 1).

School Exposures
Case investigation determined 54 (72%) primary cases never attended classes or school activities while infectious. Twenty-one (28%) of primary cases were on-campus while infectious, resulting in the identification and quarantine of 76 school-associated close contacts (70 students, 6 staff) (Figure 1). Among the 70 students quarantined, 503 days of in-person school were lost.

The average number of school-associated close contacts generated by each on-campus primary case was 3.6 (range = 0-26). Of the 76 total school-associated contacts, 2 (2.6%) had positive SARS-CoV-2 RT-PCR test results; 3 (3.9%) developed symptoms, but had negative RT-PCR test results; 41 (53.9%) had negative RT-PCR test results and no symptoms; and 30 (39.5%) had no symptoms and did not undergo testing. Among school-associated contacts who underwent testing, 34 (73.9%) were tested ≥5 days following exposure; median time from exposure until specimen collection was 6 days (range = 0-9). Date of test was missing for 8 (10.5%) contacts, all of whom were negative.

Secondary Transmission
During the study period, no individual with a COVID-19 classroom exposure subsequently reported
Table 1. Characteristics of SARS-CoV-2 Cases

| Characteristic       | No. (%) of Primary Cases (n = 75) | No. (%) of Secondary Cases (n = 2) |
|----------------------|----------------------------------|-----------------------------------|
| Grade level          |                                  |                                   |
| Lower school         | 14 (18.7)                        | 0                                 |
| Middle school        | 14 (18.7)                        | 0                                 |
| Upper school         | 26 (34.7)                        | 2 (100)                           |
| Faculty and staff    | 21 (28)                          | 0                                 |
| Learning plan†       |                                  |                                   |
| Fully remote         | 3 (3.9)                          | N/A                               |
| In-person/hybrid     | 72 (96.1)                        | 2 (100)                           |
| Symptom status       |                                  |                                   |
| Any symptoms‡        | 45 (60)                          | 1 (50)                            |
| Asymptomatic         | 30 (40)                          | 1 (50)                            |

*Table includes only laboratory-confirmed (RT-PCR or antigen-positive) cases. Primary cases include cases with community or unknown association. Secondary cases include cases with school association.
† Students could switch between learning plans approximately every 3 weeks; learning plan for cases was determined by what learning plan they were in at the time of infection.
‡ https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html

Prior to the mask mandate during athletics, a school-associated sports event resulted in secondary SARS-CoV-2 transmission. At this event, the index case was a faculty member who reported compliance with mask use; however, student-athletes were not always wearing masks. Ten persons met the close-contact definition following this event, and all underwent post-exposure testing. Two contacts (1 symptomatic, 1 asymptomatic) subsequently had positive SARS-CoV-2 tests. An additional 2 contacts became symptomatic >3 days following exposure, but tested RT-PCR negative >2 days after symptom onset.

COVID-19 Incidence

During the study period, 21 (6.4%) faculty, 28 (4.5%) upper school students, 14 (3.0%) middle school students, and 14 (2.1%) lower school students tested positive for SARS-CoV-2. A moderate positive correlation between weekly Mecklenburg County incidence and the school primary case incidence was observed (correlation coefficient [R] = .72; P = .0001). No correlation was observed between weekly community incidence and school secondary case incidence (R = −.03; P = .89) (Figure 2). Weekly SARS-CoV-2 incidence is shown in Figure 3.

DISCUSSION

Limited secondary SARS-CoV-2 transmission was observed during 23 weeks of in-person education at 1
Figure 2. Correlation Between Community SARS-CoV-2 Incidence per 1000 Persons and Primary Case Incidence (A); and Secondary Case Incidence (B)

Figure 3. Weekly SARS-CoV-2 Incidence

- Secondary Cases
- Primary Cases
- Mecklenburg County

Winter Break
Long Weekend
Fall Break
Thanksgiving Break
mission risk during rigorous exercise.\textsuperscript{14} Notably, once athletes are often in close proximity while breathing, secondary transmission likely occurred in the absence of less than 6 ft of physical distancing.\textsuperscript{14-16} CoV-2 transmission in lower school classrooms with found few occurrences of school-associated SARS-CoV-2 transmission, such as in Israel\textsuperscript{12} and in a Georgia school, there were also reports of poor adherence to mitigation strategies.\textsuperscript{13}

At the Mecklenburg County, NC school, high (>90\%) masking compliance was reported, and no individuals with classroom-based close contact with a primary case tested positive for SARS-CoV-2. A multipronged mitigation plan that included daily symptom screening completed online, mask use, and distancing, may have contributed to this low rate of classroom SARS-CoV-2 transmission. School nurses also played an instrumental role in providing COVID-19 prevention tips, monitoring mask compliance, identifying ill students or staff, and performing detailed contact tracing to facilitate isolation and quarantine. By preventing individuals from attending school while symptomatic or exposed, opportunities for SARS-CoV-2 exposure and secondary transmission in the school were limited. Less than one fourth of primary cases were on-campus while infectious, which may be attributable to the daily screening, but also may be due to infections occurring during school breaks and reduced student density due to the hybrid schedule. Additionally, similar to other studies, we found few occurrences of school-associated SARS-CoV-2 transmission in lower school classrooms with less than 6 ft of physical distancing.\textsuperscript{14-16}

Both confirmed cases of school-associated secondary transmission likely occurred in the absence of face mask use during indoor athletics. Student-athletes are often in close proximity while breathing heavily, thereby posing increased COVID-19 transmission risk during rigorous exercise.\textsuperscript{14} Notably, once a mask mandate during athletics was issued, there were no additional occurrences of SARS-CoV-2 transmission during athletics until the end of the study period. This finding is consistent with research indicating high secondary attack rates during indoor sports\textsuperscript{17} and underscores the importance of adherence to face mask use in preventing SARS-CoV-2 transmission during close-contact athletic events.

This single-school study included several prolonged school breaks, including a 2-week holiday in December 2020. SARS-CoV-2 incidence among the school population increased during and following these school breaks, which may be attributable to increasing community incidence, but could also suggest that students may be participating in higher-risk activities when outside of the structured school setting, which typically promotes strict adherence to mitigation measures in the classroom. Further emphasis and education regarding the importance of mitigation strategies when outside of school may reduce the number of primary cases. While primary cases in the school were correlated with community incidence, school-associated secondary transmission remained low throughout the study period, suggesting that schools implementing mitigation measures can remain open safely even when community incidence is high. This finding is of importance, due to the rapidly increasing SARS-CoV-2 incidence in some states. SARS-CoV-2 vaccines are currently authorized for persons older than age 5, and the CDC has recommended school faculty and staff be prioritized for vaccination\textsuperscript{18} Both of these factors may result in decreased incidence among faculty, staff, and students, but, due to SARS-CoV-2 variants and low vaccine uptake in some areas, may not negate the need for additional mitigation measures such as universal masking.

Limitations

Our study has some limitations. First, we relied upon contact tracing to determine the extent of secondary transmission and the school did not mandate post-exposure testing for contacts, which could potentially miss some asymptomatic secondary cases. Nevertheless, this limitation is ameliorated by 3 factors: (1) 46 (60.5\%) of 76 school-associated contacts (which is a high proportion) underwent post-exposure SARS-CoV-2 testing; (2) research in which widespread testing and whole-genome sequencing were used have validated contact tracing as an accurate estimate of school-associated SARS-CoV-2 transmission\textsuperscript{19,20}; and (3) even if we did not detect most asymptomatic secondary cases, secondary transmission in this school would still be extremely low. Approximately 30-50\% of SARS-CoV-2 cases are asymptomatic\textsuperscript{21} and 2 secondary cases were identified in this school; therefore, even doubling the number of secondary cases still results in a low attack rate (<6\%) among school-associated contacts. The second limitation involves our reliance upon self-reporting of symptoms, community exposures, and test results, which may have resulted in an underestimation of infections. Another limitation is that the staffing, resources, and independence in decision-making regarding COVID-19 mitigation, contact tracing, and screening in this private school may not be available or cost-effective.
for other school settings. The final limitation is that this study was conducted prior to the first reported cases of the Delta and Omicron SARS-CoV-2 variants in NC. Although these variants may be more transmissible, full implementation of a series of mitigation measures, including masking and the recent addition of vaccinations, will likely maintain their effectiveness against limiting transmission of SARS-CoV-2 variants. Additionally, screening and evaluation, as undertaken in this school, can allow for assessment of within-school transmission of these variants to inform mitigation strategies.

Conclusions
In conclusion, in school settings with COVID-19 mitigation measures, in-person education presents minimal risk of SARS-CoV-2 transmission across all age groups, even with rising community incidence. Importantly, SARS-CoV-2 transmission can occur when mitigation strategies are not followed, especially during athletic events. Multimodal mitigation strategies, including masking and daily screening, are important for minimizing exposure to, and transmission of, SARS-CoV-2 in schools.

IMPLICATIONS FOR SCHOOL HEALTH
Our study of SARS-CoV-2 infections at a PreK-12 school during peak community incidence suggests that schools can safely provide in-person education with minimal secondary transmission among students, faculty, and staff if appropriate mitigation strategies are followed.

As community SARS-CoV-2 incidence increases prior to the start of the 2021-2022 school year, there remains ongoing debate on required mitigation measures for schools. Our study findings add to the growing evidence that mitigation measures (eg, masking) are highly effective in preventing SARS-CoV-2 transmission in schools until more students become eligible for vaccination or COVID-19 community transmission is negligible. Additionally, schools should consider daily screening of students, faculty, and staff for SARS-CoV-2 symptoms or exposure to prevent potentially infectious students from attending classes.

By implementing these simple and inexpensive mitigation measures until COVID-19 vaccination rates substantially increase, schools can remain open and minimize disruption to students’ learning. Notably, the school described in this report was able to achieve minimal secondary transmission without the use of costly and complicated strategies such as universal testing of all students or contact tracing devices.

The COVID-19 pandemic has also demonstrated the value provided by school nurses to the school environment. At this school, school nurses also played an instrumental role in the mitigation of SARS-CoV-2 transmission. After completing a free online training course, the school nurses managed the daily symptom screening and conducted contact tracing. This allowed for contact tracing to begin immediately after the report of a positive test via the daily screening. Additionally, school nurses had access to detailed information, such as classroom layout maps and seating charts, to inform contact tracing decisions, therefore preventing unnecessary quarantines while also minimizing secondary transmission. Schools should consider utilizing the expertise of school nurses to assist with contact tracing, which may also reduce the burden on state and local health departments, but also require ongoing support and investment in school nursing. This 1793-student private school employed 2 full-time nurses to conduct contact tracing in addition to caring for ill students. In larger school districts, additional funding may be needed to provide the necessary staffing and resources for school nurses to take on these additional responsibilities.

Human Subjects Approval Statement
This study is not human subject research, due to the use of de-identified data. This study was determined to be exempt by the Duke University Institutional Review Board (Pro00108025).

Conflict of Interest
The authors declare no conflict of interest.

REFERENCES
1. American Academy of Pediatrics. Children and COVID-19: state-level data report. Available at: https://services.aap.org/en/pages/2019-novel-coronavirus-covid-19-infections/children-and-covid-19-state-level-data-report/. Accessed 17 December 2021.
2. North Carolina Department of Health and Human Services. North Carolina COVID-19 dashboard - demographics. Available at: https://covid19.ncdhhs.gov/dashboard/cases-demographics. Accessed 17 December 2021.
3. Verlenden JV, Pampati S, Rasberry CN, et al. Association of children’s mode of school instruction with child and parent experiences and well-being during the COVID-19 pandemic—COVID Experiences Survey. United States, October 8-November 13, 2020. MMWR Morb Mortal Wkly Rep. 2021;70:369-376.
4. Kuhfeld M, Soland J, Tarasawa B, Johnson A, Ruzek E, Liu J. Projecting the potential impact of COVID-19 school closures on academic achievement. Educ Res. 2020;49(8):549-565.
5. Falk A, Benda A, Falk P, Steffen S, Wallace Z, Hoeg TB. COVID-19 cases and transmission in 17 K-12 schools—Wood County, Wisconsin, August 31-November 29, 2020. MMWR Morb Mortal Wkly Rep. 2021;70:136-140.
6. Zimmerman KO, Akinboyo IC, Brookhart MA, et al. Incidence and secondary transmission of SARS-CoV-2 infections in schools. Pediatrics. 2021;147:e2020048090.
7. Institute of Education Sciences. Monthly school survey dashboard. Available at: https://ies.ed.gov/schoolsurvey/about.aspx. Accessed 20 May 2021.
8. USAFacts. US COVID-19 cases and deaths by state. Available at: https://usafacts.org/visualizations/coronavirus-covid-19-spread-map/. Accessed 20 May 2021.

9. North Carolina Department of Health and Human Services. StrongSchoolsNC: COVID-19 contact tracing procedures for K-12 schools. Available at: https://covid19.ncdhhs.gov/media/1404/open. Accessed 20 May 2021.

10. Centers for Disease Control and Prevention. Operational considerations for adapting a contact tracing program to respond to the COVID-19 pandemic in non-US settings. Available at: https://www.cdc.gov/coronavirus/2019-ncov/global-covid-19/operational-considerations-contact-tracing.html. Accessed 20 May 2021.

11. Centers for Disease Control and Prevention. Symptoms of COVID-19. https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html. Accessed 25 May 2021.

12. Stein-Zamir C, Abramson N, Shoo H, et al. A large COVID-19 outbreak in a high school 10 days after schools’ reopening, Israel, May 2020. Euro Surveill. 2020;25:2001352.

13. Gold JAW, Getting JR, Kimball A, et al. Clusters of SARS-CoV-2 infection among elementary school educators and students in one school district—Georgia, December 2020-January 2021. MMWR Morb Mortal Wkly Rep. 2021;70:289-292.

14. Atherstone C, Siegel M, Schmitt-Matzen E, et al. SARS-CoV-2 transmission associated with high school wrestling tournaments—Florida, December 2020-January 2021. MMWR Morb Mortal Wkly Rep. 2021;70:141-143.

15. van den Berg P, Schechter-Perkins EM, Jack RS, et al. Effectiveness of three versus six feet of physical distancing for controlling spread of COVID-19 among primary and secondary students and staff: a retrospective, state-wide cohort study. Clin Infect Dis. 2021;73(10):1871-1878.

16. Centers for Disease Control and Prevention. Operational strategy for K-12 schools through phased prevention. Available at: https://www.cdc.gov/coronavirus/2019-ncov/community/schools-childcare/operation-strategy.html. Accessed 20 May 2021.

17. Getting JR, Gold JAW, Kimball A, et al. SARS-CoV-2 transmission in a Georgia school district—United States, December 2020-January 2021. Clin Infect Dis. 2022;74(2):319-326.

18. Centers for Disease Control and Prevention. COVID-19 vaccines for teachers, school staff, and childcare workers. Available at: https://www.cdc.gov/coronavirus/2019-ncov/vaccines/recommendations/specific-groups/teachers-childcare.html. Accessed 20 May 2021.

19. Hershov RB, Wu K, Lewis NM, et al. Low SARS-CoV-2 transmission in elementary schools—Salt Lake County, Utah, December 3, 2020-January 31, 2021. MMWR Morb Mortal Wkly Rep. 2021;70:442-448.

20. Dawson P, Worrell MC, Malone S, et al. Pilot investigation of SARS-CoV-2 secondary transmission in kindergarten through grade 12 schools implementing mitigation strategies—St. Louis County and City of Springfield, Missouri, December 2020. MMWR Morb Mortal Wkly Rep. 2021;70:449-455.

21. Oran DP, Topol EJ. The proportion of SARS-CoV-2 infections that are asymptomatic: a systematic review. Ann Intern Med. 2021;174:655-662.

22. Centers for Disease Control and Prevention. Delta variant: what we know about the science. Available at: https://www.cdc.gov/coronavirus/2019-ncov/variants/delta-variant.html. Accessed 20 December 2021.

23. Gurley E. COVID-19 contact tracing. Coursera https://www.coursera.org/learn/covid-19-contact-tracing. Accessed July 26, 2021.