Presence of SARS-CoV-2 Aerosol in Residences of Adults with COVID-19

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Running Head: SARS-CoV-2 in home air

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While vaccines are effective to prevent COVID-19, uncertainty remains about practical public health responses to vaccine-resistant variants or future novel respiratory viruses. Reducing attack rates in households, estimated as high as 54% in the U.S., is a key strategy.[1] In addition to close physical contact, emerging opinion suggests that airborne transmission is linked to SARS-CoV-2 spread, particularly in lower socioeconomic status households with greater crowding, even if isolation and PPE minimize large particle transmission.[2,3,4,5]

The size-dependent airborne behavior of particles originating from the respiratory tract has a continuous distribution from tens of nanometers to tens of microns. Recognizing this continuity, there are two primary pathways, requiring different control strategies, by which respiratory viral infections spread through air to others. First, larger respiratory droplets that rapidly settle onto surfaces, typically within 1-2 meters of the source, are amenable to hand hygiene, social distancing, and face masks. Second, albeit with more limited direct evidence, is aerosolization and spread of smaller respiratory droplets, or droplet nuclei, primarily less than 0.5 micrometers in final size, capable of staying suspended in air for hours, and requiring filtering or ventilation for interdiction.[2,3,4] We report the first naturalistic observations of household air contamination with SARS-CoV-2 RNA. We know of no prior reports of air sampling for SARS-CoV-2 RNA in homes without manipulation of the behavior/activity of participants.

Rutgers IRB approved this study, and participants provided informed consent.

Methods

Recruitment occurred in fall/winter of 2020-2021 through an email flyer at the time of notification of test positivity. Adults testing positive within the prior seven days were

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eligible to participate. Saliva screening at the first home visit verified continued positivity (Table 1).

Air samples were collected for 24 hours on PTFE filters (SKC Inc., Eighty Four, PA) in two separate rooms (if available) in each participant's home using an open-face filter holder and Leland Legacy pump (SKC, Inc.) operated at 10 L/min. Samples were eluted in RNA-grade water and analyzed by RT-PCR for the presence of three SARS-CoV-2-specific genes. There is no universal protocol for RT-PCR testing of SARS-CoV-2, let alone for its analysis in environmental samples.[6,] Our selected laboratory (Infinite BiologiX, Piscataway, NJ) used an FDA-approved procedure developed at Rutgers to target three genomic regions of SARS-CoV-2: nucleocapsid (N) gene, spike (S) gene, and open reading frame-AB (ORF1-AB) region. To maximize detection sensitivity, we assessed presence (C_T<37) or absence of each gene in our air samples.[7] The selected rooms were defined as the isolation room (the room used primarily, but not exclusively, by the subject) and the common room (a separate but adjacent room). Participants recorded hours spent in both rooms during sampling, but instructions for self-isolation were not provided. Samplers were placed one meter away from the nearest wall and away from vents, windows, traffic flow, and obstructing furniture where possible. Samplers faced downward to avoid large droplets. The study included eleven homes (Table 1) with twenty air samples (60 individual SARS-CoV-2 gene RT-PCR tests) collected from eleven isolation rooms and nine common rooms (Table 2).

Results

In addition to the primary case, one or more known or suspected recently positive individuals were reported to be present in four of eleven (36%) homes at the time of

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sampling. During sampling, participants reported spending between 10 and 24 hours in the isolation room. 73% of participants reported spending some time in the common room (range 0-14 hours) and 45% of participants reported time in other areas of the home (range 0-8 hours).

For each of the three genes, the percentage of homes with a positive air sample ranged from 36% to 45% in the isolation room and from 22% to 67% in the common room. Eight homes out of eleven (73%) had at least one gene detected, and five of eleven isolation room samples had at least two genes detected. Six of nine homes with sampling in both the isolation room and common room had at least one gene detected in the common room (Table 2), and four of these common rooms had two genes detected. Seven of these nine homes reported no other cases in the household (Table 1) including the two living alone and in five of these homes, the common room was positive for viral aerosols. An additional occupant who recently tested positive or had symptoms consistent with COVID-19 was present in only two of seven (29%) homes with multiple occupants and a valid common room test.

Discussion

Our results provide strong empirical support that aerosols of small respiratory droplets and nuclei containing airborne SARS-CoV-2 RNA are present both within and outside of home isolation rooms, presenting infection risk beyond close contact with other occupants.

Our indoor air sampling data clearly demonstrate that measurable airborne SARS-CoV-2 RNA is present in home air of most infected individuals. We found SARS-CoV-2 viral RNA, likely as both free virus and bound to other PM, in not only the isolation room but,

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importantly, elsewhere in the home (common room), consistent with high risk of home airborne transmission. Previously, detection of airborne SARS-CoV-2, likely as part of PM, has been limited to the hospital / clinic setting[8,9,10,11,12], an automobile cabin[13], and two reports identifying it in outdoor PM samples.[14,15]

Further buttressing our findings is a study of viral aerosols measured only in isolation rooms of apartments at a specified distance of two meters from the participant, using a 20-minute scripted (non-naturalistic) air sampling protocol.[6] Our novel empirical findings support the hypothesis that exposure to airborne small droplets and/or droplet nuclei is a pathway for COVID-19 transmission and a candidate explanation for high household attack rates.[1]

Despite models, laboratory experiments, and theory-based discussions, previous field data have not empirically addressed or clarified the relative importance of real-world exposure pathways that must be interdicted to prevent transmission of COVID-19. Studies are needed with adequate power and definitive assessment of infection status of all household members, their locations within the household, clear discrimination between aerosols and larger droplets by size-selective sampling, and assessment of aerosolized virus viability.[12]

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ANNALSATS Articles in Press. Published November 11, 2021 as 10.1513/AnnalsATS.202107-847RL

References

1. Lewis NM, Chu VT, Ye D, Conners EE, Gharpure R, Laws RL, Reses HE, Freeman BD, Fajans M, Rabold EM, Dawson P, Buono S, Yin S, Owusu D, Wadhwa A, Pomeroy M, Yousaf A, Pevzner E, Njuguna H, Battey KA, Tran CH, Fields VL, Salvatore P, O'Hegarty M, Vuong J, Chancey R, Gregory C, Banks M, Rispens JR, Dietrich E, Marcenac P, Matanock AM, Duca L, Binder A, Fox G, Lester S, Mills L, Gerber SI, Watson J, Schumacher A, Pawloski L, Thornburg NJ, Hall AJ, Kiphibane T, Willardson S, Christensen K, Page L, Bhattacharyya S, Dasu T, Christiansen A, Pray IW, Westergaard RP, Dunn AC, Tate JE, Nabity SA, Kirking HL. Household transmission of SARS-CoV-2 in the United States. *Clin Infect Dis.* 2020 Aug 16: Epub ahead of print.

2. Morawska L, Cao J. Airborne transmission of SARS-CoV-2: The world should face the reality. *Environ Int. 2020*, 139. Epub 2020 Apr 10.

3. Zhang R, Li Y, Zhang AL, Wang Y, Molina MJ. Identifying airborne transmission as the dominant route for the spread of COVID-19. *Proc Natl Acad Sci U S A.* 2020;117(26):14857-14863.

4. Asadi S, Bouvier N, Wexler AS, Ristenpart WD. The coronavirus pandemic and aerosols: Does COVID-19 transmit via expiratory particles? *Aerosol Sci Technol.* 2020 Apr 3;0(0):1-4.

5. Romano SD, Blackstock AJ, Taylor EV, El Burai Felix S, Adjei S, Singleton CM, Fuld J, Bruce BB, Boehmer TK. Trends in racial and ethnic disparities in COVID-19 hospitalizations, by region - United States. *Morb Mortal Wkly Rep.* 2021;70 (15):560-565.

ANNALSATS Articles in Press. Published November 11, 2021 as 10.1513/AnnalsATS.202107-847RL

6. Salvatore PP, Dawson P, Wadhwa A, Rabold EM, Buono S, Dietrich EA, Reses HE, Vuong J, Pawloski L, Dasu T, Bhattacharyya S, Pevzner E, Hall AJ, Tate JE, Kirking HL. Epidemiological correlates of PCR cycle threshold values in the detection of SARS-CoV-2. *Clin Infect Dis.* 2020; Epub ahead of print.

7. Radbel J, Jagpal S, Roy J, Brooks A, Tischfield J, Sheldon M, Bixby C, Witt D, Gennaro ML, Horton DB, Barrett ES, Carson JL, Panettieri RA Jr, Blaser MJ. Detection of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is comparable in clinical samples preserved in saline or viral transport medium. *J Mol Diagn.* 2020 l;22(7):871-875.

8. Stern RA, Koutrakis P, Martins MAG, Lemos B, Dowd SE, Sunderland EM, Garshick E. Characterization of hospital airborne SARS-CoV-2. *Respir Res.* 2021 26;22(1):73.

9. Birgand G, Peiffer-Smadja N, Fournier S, Kerneis S, Lescure FX, Lucet JC. Assessment of air contamination by SARS-CoV-2 in hospital settings [published correction appears in *JAMA Netw Open.* 2021 Jan 4;4(1):e2037904]. *JAMA Netw Open*. 2020;3(12):e2033232. Published 2020 Dec 1.

10. Kenarkoohi A, Noorimotlagh Z, Falahi S, Amarloei A, Mirzaee SA, Pakzad I, Bastani E. Hospital indoor air quality monitoring for the detection of SARS-CoV-2 (COVID-19) virus. *Sci Total Environ.* 2020 Dec 15;748:141324.

11. Lednicky JA, Shankar SN, Elbadry MA, Gibson JC, Alam MM, Stephenson CJ, Eiguren-Fernandez A, Morris JG, Mavian CN, Salemi M, Clugston JR, Wu CY. Collection of SARS-CoV-2 Virus from the air of a clinic within a university student health care center and analyses of the viral genomic sequence. *Aerosol Air Qual Res.* 2020 Jun;20(6):1167-1171.

ANNALSATS Articles in Press. Published November 11, 2021 as 10.1513/AnnalsATS.202107-847RL

12. Lednicky JA, Lauzardo M, Fan ZH, Jutla A, Tilly TB, Gangwar M, Usmani M, Shankar SN, Mohamed K, Eiguren-Fernandez A, Stephenson CJ, Alam MM, Elbadry MA, Loeb JC, Subramaniam K, Waltzek TB, Cherabuddi K, Morris JG Jr, Wu CY. Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients. *Int J Infect Dis.* 2020 Nov;100:476-482.

13. Lednicky JA, Lauzardo M, Alam MM, Elbadry MA, Stephenson CJ, Gibson JC, Morris JG Jr. Isolation of SARS-CoV-2 from the air in a car driven by a COVID patient with mild illness. *Int J Infect Dis.* 2021 Jul;108:212-216.

14. Setti L., Passarini F., De Gennaro G., Barbieri P., Perrone M.G., Borelli M. SARS-Cov-2 RNA found on particulate matter of Bergamo in northern Italy: First evidence. *Environ. Res.* 2020;188 doi: 10.1016/j.envres.2020.109754.

15. Kayalar Ö, Arı A, Babuççu G, Konyalılar N, Doğan Ö, Can F, Şahin ÜA, Gaga EO, Levent Kuzu S, Arı PE, Odabaşı M, Taşdemir Y, Sıddık Cindoruk S, Esen F, Sakın E, Çalışkan B, Tecer LH, Fıçıcı M, Altın A, Onat B, Ayvaz C, Uzun B, Saral A, Döğeroğlu T, Malkoç S, Üzmez ÖÖ, Kunt F, Aydın S, Kara M, Yaman B, Doğan G, Olgun B, Dokumacı EN, Güllü G, Uzunpınar ES, Bayram H. Existence of SARS-CoV-2 RNA on ambient particulate matter samples: A nationwide study in Turkey. *Sci Total Environ.* 2021 Oct 1;789:147976.

16. Rodríguez M, Palop ML, Seseña S, Rodríguez A. Are the Portable Air Cleaners (PAC) really effective to terminate airborne SARS-CoV-2? *Sci Total Environ.* 2021 Apr 29; Epub ahead of print.

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Table 1: Participant demographics, saliva C_T counts on day of sampling, whether the index participant had a cough, the number of individuals residing in the home, and whether any were reported to have been positive*.

*Based on participant response to the question: "Do any of the other people staying in your home during this study have a recent positive COVID test (within the past week) or current COVID symptoms?"

Home	Age	Sex	N Gene	ORF1-AB Gene	S Gene	# Household Members	Other Reported Positive*	Participant Cough
1	40	Male	24.3	23.7	23.6	2	Yes	Yes
2	46	Female	16.9	16.7	16.7	4	Yes	Yes
3	31	Male	25.0	24.7	25.0	1	N/A	No
4	47	Female	23.9	22.2	24.0	4	Yes	Yes
5	61	Female	33.7	30.9	ND	2	No	No
6	65	Female	25.5	26.3	26.8	5	No	Yes
7	30	Female	27.5	27.7	27.4	1	N/A	Yes
8	64	Male	26.3	27.9	27.4	2	No	No
9	37	Male	17.7	17.3	17.0	3	No	Yes
10	47	Male	28.1	27.5	27.7	4	Yes	No
11	62	Female	25.1	25.0	25.0	2	No	Yes

Table 2: The presence of SARS-CoV-2 RNA in air samples in 11 homes with newly positive COVID-19 subjects. ND is not detected. Bolded C_T counts represent

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positive (<37) samples for each gene in each room. Also shown is the number of hours out of 24 that participants reported being in each room*.

	Isolation Room				Common Room			
Home	**N Gene**	**ORF1-AB Gene**	**S Gene**	**Subject present (hours)***	**N Gene**	**ORF1-AB Gene**	**S Gene**	**Subject present (hours)***
1**	ND	ND	ND	16				0
2**	**34.3**	ND	**36.6**	24				0
3	ND	ND	ND	22.5	ND	ND	ND	0
4	**31.4**	**28.5**	**28.8**	10	ND	**34.5**	**36.4**	14
5	**35.8**	**32.8**	**33.1**	17	**32.0**	**30.9**	**31.6**	7
6	ND	**34.4**	ND	23.5	ND	ND	ND	0.5
7	ND	ND	ND	17	ND	**33.7**	**36.8**	7
8	ND	ND	ND	22	ND	**35.8**	ND	2
9	**32.1**	**31.3**	ND	12	**32.2**	**31.6**	**32.0**	4
10	ND	ND	ND	13	ND	ND	ND	10
11	ND	**34.7**	**36.2**	14	ND	**34.9**	ND	8
Homes detected	4	5	4		2	6	4	

*Total hours may be less than 24 due to time spent in other rooms.

** Common room air samples for homes 1 and 2 were invalid for technical reasons.

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