Population-Based Serosurvey for Severe Acute Respiratory Syndrome Coronavirus 2 Transmission, Chennai, India

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On August 15, 2020, India had the third highest number of coronavirus disease (COVID-19) cases globally (1). The Indian state of Tamil Nadu reported 332,105 cases and 5,641 deaths on August 15, and ≈35% cases were from the state capital, Chennai (2). Administratively, Greater Chennai Corporation (GCC) is divided into 15 zones that are further divided into 200 wards with populations ranging from 4,400–104,558 (3). The total population of GCC is 7.1 million and 31% of the population resides in slums.

As a part of nationwide containment strategy, Chennai was under lockdown beginning March 25, 2020; beginning May 4, the lockdown was relaxed in a phased manner. Wearing facemasks in public has been mandatory since April 13. However, the number of COVID-19 cases has been increasing in Chennai since May.

Serologic surveys can provide a comprehensive picture of community spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the causative agent of COVID-19 (4). During the first week of May, the unweighted seroprevalence in Chennai was 2% (5). We conducted a community-based serosurvey in July 2020, to estimate the seroprevalence of SARS-CoV-2 in GCC.

The Study

We conducted a household-based cross-sectional survey among usual residents ≥10 years of age in GCC. To estimate a seroprevalence of 2%, with 20% relative precision, design effect of 2.5, and 95% CI, we needed a sample size of 11,710 persons, which we rounded to 12,000. We used a multistage cluster sampling method to select the survey participants. In the first stage, we selected 51 wards by using probability proportion to population size method. In the second stage, we randomly selected 6 streets from each ward from which to recruit participants. The survey team selected a random starting point in each street and visited contiguous households to enroll ≥40 consenting persons ≥10 years of age. When no one was home or household members were unavailable, the team proceeded to the next house and completed the survey until ≥40 persons were enrolled from each street. We included all eligible persons in the household who consented.

After obtaining written consent from persons ≥18 years of age, and assent and parental or guardian approval from persons <18 years of age, we interviewed participants to collect information. We used the Open Data Kit application (https://opendatakit.org) to collect sociodemographic details, and information on exposure to laboratory-confirmed COVID-19 case, history of COVID-19 symptoms in the past 3 months, and COVID-19 testing status.
After the interview, we collected 3–5 mL of venous blood from each participant into BD Vacutainer Blood Collection Tubes (Becton Dickenson, https://www.bd.com). We later tested serum samples for IgG against SARS-CoV-2 by using SARS-CoV-2 IgG immunoassay (Abbott, https://www.corelaboratory.abbott) (Appendix, https://wwwnc.cdc.gov/EID/article/27/2/20-3938-App1.pdf) (6). The study protocol was approved by the Institutional Ethics Committee of ICMR-National Institute of Epidemiology.

We analyzed the data to estimate weighted seroprevalence of SARS-CoV-2 and 95% CI by using appropriate sampling weights. We further adjusted the seroprevalence for assay characteristics (6). We estimated the total number of SARS-CoV-2 infections among persons ≥10 years of age and infection-to-case ratio (ICR) (Appendix).

The survey teams visited 7,234 households from 321 streets across 15 zones. Of the 18,040 residents ≥10 years of age in the visited households, 14,839 (82.3%) were available at the time of survey, among whom 12,405 (83.6%) consented to participate (Appendix Table 1). The mean age of survey participants was 41.1 years (SD 17.3 years); 52.7% were female and 47.3% were male. Among 496 (4%) persons who reported prior reverse transcription-PCR (RT-PCR) testing for COVID-19, 119 (24%) reported testing positive (Table 1).

Among 12,405 serum samples tested, 2,673 were positive for IgG, a weighted prevalence of 18.7% (95% CI 15.1%–22.9%). After adjusting for the test sensitivity and specificity, seroprevalence was 18.4% (95% CI 14.8%–22.6%) (Table 2). The weighted seroprevalence was higher among female participants (20.6%, 95% CI 16.7%–25.3%) than male participants (16.6%, 95% CI 13.2%–20.6%) (p<0.001). Weighted seroprevalence was lowest among persons ≥60 years of age (13.4%, 95% CI 10.3%–17.4%) than younger persons (p = 0.001) (Table 2). We retested 100 seronegative and 40 seropositive samples and results were concordant.

From our data, we estimated a total of 1,509,701 (95% CI 1,212,711–1,856,190) SARS-CoV-2 infections in Chennai. ICR per laboratory-confirmed case was 21.4 (95% CI 17.2–26.3) until July 7 and 19.2 (95% CI 15.4–23.6) until July 14, 2020.

Conclusions

Our community-based survey indicated that ∼1/5 persons in Chennai was exposed to SARS-CoV-2 by July 2020. We noted a wide variation in the extent of infection across wards and seroprevalence ranged from 2%–50% (Appendix Table 3).

Seroprevalence was higher in northern Chennai and adjoining wards of central Chennai than in southern Chennai (Figure). Chennai witnessed a surge in COVID-19 cases in last week of April 2020 and >65% of cases were in northern Chennai (7). The number of cases showed a declining trend after the first week of July. Northern Chennai has a higher population density (55,000/km²) than Chennai (27,000/km²) and has several slum areas (7). High population density and persons living in close proximity might have contributed to the higher seroprevalence observed in northern Chennai.

Seroprevalence was lower among male participants. Laboratory surveillance data in India showed a higher proportion of laboratory-confirmed COVID-19 among male than female patients (8). Comparable seroprevalence between children and adults suggests exposure within and outside of the household settings. Lower prevalence among persons ≥60 years of age could be due to lower exposure to infected persons or stricter adherence to nonpharmaceutical interventions. Serosurveys conducted in Santa Clara County, California, USA reported lower seropositivity among persons ≥60 years of age (E. Bendavid,
Table 1. Characteristics of 12,405 participants in a SARS-CoV-2 serosurvey, Chennai, India, July 2020*

| Characteristics                          | No. (%) |
|------------------------------------------|---------|
| Age, y, n = 12,319                       |         |
| 10–19                                    | 1,473 (12.0) |
| 20–29                                    | 2,106 (17.1) |
| 30–39                                    | 2,353 (19.1) |
| 40–49                                    | 2,353 (19.1) |
| 50–59                                    | 1,927 (15.6) |
| >60                                      | 2,108 (17.1) |
| Sex, n = 12,319                          |         |
| M                                        | 5,785 (47.0) |
| F                                        | 6,493 (52.7) |
| Transgender                              | 41 (0.3) |
| History of respiratory symptoms, n = 12,248 |     |
| Symptomatic persons seeking medical care, n = 175 | 121 (69.1) |
| Hospitalization among persons seeking medical care, n = 121 | 71 (58.7) |
| Reported contact with COVID-19 case, n = 12,248 | 173 (1.4) |

*Among 12,405 persons enrolled in the survey, age and sex data were not available for 86 participants. COVID-19, coronavirus disease; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

et al. unpub. data, https://doi.org/10.1101/2020.04.14.20062463); however, in Spain, seropositivity was similar across all age groups (9) and in Greece, seroprevalence was higher among persons ≥60 years of age (10).

Most seropositive participants in our survey did not report any symptoms nor had any known contact with COVID-19 patient. IgG developed among most (107/119; 90%) recovered COVID-19 patients in our survey. Among 105 participants for whom ≥15 days had passed between RT-PCR confirmation of COVID-19 and blood sample collection for our serosurvey, 99 (94.2%) had seroconverted. Even after accounting for a 2-week delay for development of antibodies (11), ≥6% of COVID-19 patients were seronegative. Discordance between RT-PCR test results and presence of IgG might be due to poor B cell response or antibodies waning over time (12).

The ICR ranged from 19–21 and was lower than the ICR of 82–130 reported during the nationwide seroprevalence survey in India conducted in May 2020 (5). Lower ICR reflects a high level of case detection, resulting from extensive COVID-19 testing in the city. By July 15, 2020, Chennai had conducted 14,270 tests/million population.

Our study had 2 limitations. First, ≥1/3 persons from the visited households did not participate in the survey. Among them, 17.7% were not available at the time of visit and 13.5% refused to participate. Due to time constraints, we did not revisit households where persons were not available. The proportion of female participants and children 10–19 years of age was higher among persons who did not participate in the survey (Appendix Table 2), which might have influenced the seroprevalence estimates in either direction. Second, we might have underestimated the seroprevalence because antibodies to

Table 2. Characteristics of persons with IgG against SARS-CoV-2, Chennai, India, July 2020*

| Characteristics                          | No. tested | No. positive | Unadjusted seroprevalence, % (95% CI) | Weighted seroprevalence, % (95% CI) | p value | Test performance-adjusted seroprevalence, % (95% CI) |
|------------------------------------------|------------|--------------|--------------------------------------|--------------------------------------|---------|--------------------------------------------------|
| Overall                                  | 12,405     | 2,673        | 21.5 (20.8–22.3)                     | 18.7 (15.1–22.9)                     | NA      | 18.4 (14.8–22.6)                                  |
| Sex                                      |            |              |                                      |                                      |         |                                                  |
| M                                        | 5,785      | 1,115        | 19.3 (18.3–20.3)                     | 16.6 (13.2–20.6)                     | <0.001  | 16.3 (12.9–20.3)                                  |
| F                                        | 6,493      | 1,538        | 23.7 (22.7–24.7)                     | 20.6 (16.7–25.3)                     | Referent| 20.3 (16.4–25.0)                                  |
| Transgender                              | 41         | 5            | 12.2 (4.1–26.2)                      | 2.8 (0.2–27.6)                       | 0.093   | 2.4 (0.0–27.3)                                   |
| Age, y                                    |            |              |                                      |                                      |         |                                                  |
| 10–19                                    | 1,473      | 351          | 23.8 (21.7–26.1)                     | 18.9 (14.7–24.0)                     | Referent| 18.6 (14.4–23.7)                                  |
| 20–29                                    | 2,105      | 478          | 22.7 (20.9–24.6)                     | 21.1 (16.8–26.2)                     | 0.211   | 20.8 (16.5–25.9)                                  |
| 30–39                                    | 2,353      | 535          | 22.7 (21.1–24.5)                     | 18.5 (14.6–23.1)                     | 0.802   | 18.2 (14.3–22.8)                                  |
| 40–49                                    | 2,353      | 551          | 23.4 (21.7–25.2)                     | 19.6 (15.5–24.5)                     | 0.671   | 19.3 (15.2–24.2)                                  |
| 50–59                                    | 1,927      | 408          | 21.2 (19.4–23.1)                     | 20.4 (16.1–25.5)                     | 0.419   | 20.1 (15.8–25.2)                                  |
| >60                                      | 2,108      | 335          | 15.9 (14.4–17.5)                     | 13.4 (10.3–17.4)                     | 0.001   | 13.1 (9.9–17.1)                                  |
| History of respiratory symptoms          |            |              |                                      |                                      |         |                                                  |
| Yes                                      | 175        | 114          | 65.1 (57.6–72.7)                     | 59.8 (47.5–71.0)                     | <0.001  | 59.6 (47.3–70.9)                                  |
| No                                       | 12,073     | 2529         | 20.9 (20.2–21.7)                     | 18.3 (14.7–22.5)                     | Referent| 18.0 (14.4–22.2)                                  |
| Contact with COVID-19 case               |            |              |                                      |                                      |         |                                                  |
| Yes                                      | 173        | 94           | 54.3 (46.6–61.9)                     | 45.3 (34.6–56.6)                     | <0.001  | 45.1 (34.3–56.4)                                  |
| No                                       | 11,938     | 2,498        | 20.9 (20.2–21.7)                     | 18.3 (14.8–22.5)                     | Referent| 18.0 (14.5–22.2)                                  |
| Don’t know                               | 137        | 51           | 37.2 (29.1–45.9)                     | 22.1 (14.0–33.1)                     | 0.363   | 21.8 (13.7–32.8)                                  |
| Ever tested for COVID-19                 |            |              |                                      |                                      | <0.001  |                                                  |
| Yes                                      | 496        | 198          | 39.9 (35.6–44.3)                     | 34.2 (26.9–42.5)                     | <0.001  | 33.9 (26.6–42.3)                                  |
| No                                       | 11,752     | 2,445        | 20.8 (20.0–21.6)                     | 18.0 (14.6–22.1)                     | Referent| 17.7 (14.3–21.8)                                  |

*COVID-19, coronavirus disease; NA, not applicable; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.
nucleocapsid protein have been shown to decline after infection (13).

In conclusion, ≥80% of the population in Chennai is still susceptible to SARS-CoV-2 infection. Transmission is expected to continue in wards with lower seroprevalence. Maintaining high testing rates and monitoring adherence to nonpharmaceutical interventions in GCC should be continued. In addition, periodic serosurveys would help monitor the trend of infection and assess the effects of varying containment measures in the city.

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Appendix

Laboratory Procedures

We tested 12,405 serum samples for the presence of IgG against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) on the ARCHITECT i2000SR automated analyzer (Abbott, https://www.corelaboratory.abbott) by using the Abbott SARS-CoV-2 IgG immunoassay (1). The assay is a chemiluminescent microparticle immunoassay used for the qualitative detection of IgG to the nucleocapsid protein of SARS-CoV-2 in human serum and plasma. The sensitivity of the assay is 100% and specificity is 99.6% (2). The IgG in the sample binds to SARS-CoV-2 antigen-coated microparticles and undergoes a chemiluminescent reaction, producing a direct relationship between the amount of IgG and relative light units (RLU). The presence or absence of antibody in the sample is determined by comparing the RLU in the sample to the calibrator RLUs. The presence of antibody level above the cutoff index value ≥1.4 was interpreted as positive. Assay calibration was performed with positive and negative quality controls before analyses of samples. As a part of quality control, we retested 1% of the negative serum samples by using the same assay.

Statistical Analysis

The cross-sectional study considered 3 stages of sampling design. In the first stage, 51 wards were selected from among 200 wards in Chennai by using a probability proportional to size method. In the second stage, 6 streets were selected in each ward by using simple random sampling. The final stage was selecting the number of eligible persons in the household who agreed to participate in the survey.

We used a sampling fraction to compute the probability of selection at each stage of sampling. We computed design weights by the inverse of product of probabilities at all stages. The design weights were normalized and attached to the master dataset.
We used a random effects logistic regression model to address the clustering effect of estimates at all levels of hierarchical structure identified in the design. The hierarchical structure used in the analysis was ward, street, and household levels.

We modeled overall seroprevalence by using random intercept model for inclusion of each of the levels with design weights. We used the Akaike Information Criterion to select the final model. We also used this model to estimate seroprevalence for other factors, such as age and sex.

Seroprevalence estimates were obtained by exponentiating the log odds values obtained from the model and converting into probability to calculate corresponding 95% Wald confidence interval. We used the lme4 package from R software (R Foundation for Statistical Computing, https://www.r-project.org) to perform analysis.

We compared the weighted seroprevalence by selected demographic characteristics, history of respiratory symptoms, contact with laboratory-confirmed case of coronavirus disease, and coronavirus disease testing. We considered p<0.05 statistically significant.

We adjusted the weighted seroprevalence for test characteristics by using the following formula (3):

\[
\text{Adjusted prevalence} = \frac{\text{Weighted prevalence} + \text{specificity} - 1}{\text{Sensitivity} + \text{specificity} - 1}
\]

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### Appendix Table 1. Selection of wards, streets, and households and number of persons in a serosurvey for SARS-CoV-2.

**Greater Chennai Corporation, India, July 2020***

| Code | Ward | Total | No. Wards | No. streets | No. households | Eligible (%) | Available (%) | Enrolled (%) |
|------|------|-------|-----------|-------------|---------------|--------------|--------------|--------------|
| 1    | Thiruvottiyur | 14 3 | 1,290 22 | 438 | 416 (95.0) | 807 | 756 (93.4) | 654 (86.5) |
| 2    | Manali  | 7 1  | 1,446 6  | 164 | 162 (98.6) | 421 | 271 (64.4) | 245 (90.4) |
| 3    | Madhavaram | 13 2  | 1,831 12 | 295 | 271 (91.9) | 737 | 597 (81.0) | 368 (61.6) |
| 4    | Tondiarpet | 14 4  | 3,071 29 | 682 | 650 (95.3) | 1,605 | 1,181 (73.6) | 866 (73.3) |
| 5    | Royapuram | 15 4  | 1,596 24 | 598 | 493 (82.4) | 1,315 | 1,130 (85.9) | 945 (83.6) |
| 6    | Thiru-Vi-Ka | 14 5  | 2,712 31 | 849 | 709 (83.5) | 1,816 | 1,477 (81.3) | 1,085 (73.5) |

- Total 200 51 42,910 321 7,935 7,234 (91.2) 18,040 14,839 (82.3) 12,405 (83.6)

*SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

†Percentage calculated out of eligible participants.

‡Percentage calculated out of available participants.

### Appendix Table 2. Seroprevalence of IgG antibodies against SARS-CoV-2 by selected wards, Greater Chennai Corporation, India, July 2020***

| Ward Name | Seroprevalence, % (95% CI) | Test performance adjusted seroprevalence, % (95% CI) |
|-----------|-----------------------------|--------------------------------------------------|
| Test T | Positive | Unweighted seroprevalence |
|-----------|------------|--------------------------|
| Ward 47 – Korukkupet | 245 | 123 | 50.0 (43.7–56.3) |
| Ward 39 – New Washermen Pet | 230 | 113 | 49.0 (42.5–55.5) |
| Ward 14 – Kalaiadipet | 200 | 94 | 47.0 (40.1–53.9) |
| Ward 43 – Royapuram | 243 | 115 | 47.0 (40.7–53.3) |
| Ward 115 – Royapettah | 240 | 106 | 44.0 (37.7–50.3) |
| Ward 77 – Polan anthemape | 157 | 68 | 43.0 (35.0–50.7) |
| Ward 104 – Egmore | 242 | 97 | 40.0 (33.8–46.2) |
| Ward 61 – Egmore | 227 | 83 | 37.0 (30.7–43.3) |
| Ward 54 – Kondithoppu | 219 | 76 | 35.0 (28.7–41.3) |
| Ward 50 – Royapuram | 252 | 84 | 33.0 (26.2–39.8) |
| Ward 58 – Choolai | 247 | 82 | 33.0 (27.1–38.9) |
| Ward 74 – Nammalwarpet | 186 | 61 | 33.0 (27.1–38.9) |
| Ward 118 – Teynampet | 247 | 81 | 33.0 (27.2–38.8) |
| Ward 111 – Royapettah | 246 | 68 | 28.0 (22.4–33.6) |
| Ward 8 – Tiruvottiyur | 249 | 66 | 27.0 (21.4–32.6) |
| Ward 71 – Otteri | 241 | 64 | 27.0 (21.5–32.5) |
| Ward 171 – Saidapet | 246 | 66 | 27.0 (21.5–32.5) |
| Ward 122 – Raja Annamalai Puram | 249 | 64 | 26.0 (20.6–31.4) |
| Ward 173 – Raja Annamalai Puram | 259 | 64 | 25.0 (19.7–30.3) |
| Ward 21 – Manali | 245 | 59 | 24.0 (18.7–29.3) |
| Ward 1 – Kathivakkam | 205 | 47 | 23.0 (17.2–28.8) |
| Ward 97 – Ayanavaram | 241 | 56 | 23.0 (17.2–28.3) |
| Ward 140 – Saidapet | 261 | 60 | 23.0 (17.9–28.1) |
| Ward 177 – Velachery West | 274 | 62 | 23.0 (18.0–28.0) |
| Ward 36 – Vyasarpadi | 148 | 32 | 22.0 (15.3–28.7) |
| Ward 107 – Chetpet | 251 | 56 | 22.0 (16.9–27.1) |
| Ward 163 – Adambakkam | 240 | 49 | 20.0 (14.9–25.1) |
| Ward 93 – Mugappair East | 247 | 42 | 17.0 (12.3–21.7) |
| Ward 126 – Raja Annamalai Puram | 254 | 44 | 17.0 (12.4–21.6) |
| Ward 145 – Nerkundram | 269 | 47 | 17.0 (12.5–21.5) |
| Ward 170 – Ekkattuthangal | 266 | 45 | 17.0 (12.5–21.5) |
| Ward 84 – Korattur | 237 | 38 | 16.0 (11.3–20.7) |
| Ward 180 – Thiruvanniyur | 273 | 44 | 16.0 (11.7–20.3) |
| Ward 100 – Anna Nagar | 240 | 36 | 15.0 (10.5–19.5) |
| Ward 133 – West Mambalam | 244 | 37 | 15.0 (10.5–19.5) |
| Ward 89 – A.N.W. Extension | 254 | 36 | 14.0 (9.7–18.3) |
| Ward 22 – Kavanka | 203 | 22 | 11.0 (6.7–15.3) |
| Ward 137 – Nesapakkam | 236 | 26 | 11.0 (7.0–15.0) |

*†Percentage calculated out of eligible participants.*

**‡Percentage calculated out of available participants.**
### Appendix Table 3. Characteristics of persons surveyed for enrollment in severe acute respiratory syndrome coronavirus 2 serosurvey, Greater Chennai Corporation, India, July 2020

| Characteristics | Participated in the survey, no. (% of total) | Refused to participate in serosurvey, no. (% of total) |
|-----------------|---------------------------------------------|--------------------------------------------------|
| Total           | 12,319                                      | 2,434                                            |
| Age, y*         |                                             |                                                  |
| 10–19           | 1,473 (12.0)                                | 522 (21.4)                                       |
| 20–29           | 2,105 (17.1)                                | 468 (19.2)                                       |
| 30–39           | 2,353 (19.1)                                | 406 (16.7)                                       |
| 40–49           | 2,353 (19.1)                                | 364 (15.0)                                       |
| 50–59           | 1,927 (15.6)                                | 302 (12.4)                                       |
| >60             | 2,108 (17.1)                                | 372 (15.3)                                       |
| Sex**           |                                             |                                                  |
| M               | 5,785 (47.0)                                | 1,015 (41.7)                                     |
| F               | 6,493 (52.7)                                | 1,412 (58.0)                                     |
| Other           | 41 (0.3)                                    | 7 (0.3)                                          |

*SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

*χ² test comparing those participated and those who refused, 184.12 (p<0.001).

**χ² test comparing those participated and those who refused, 22.9 (p<0.001).