Rates of Asymptomatic COVID-19 Infection and Associated Factors in Olmsted County, Minnesota, in the Prevaccination Era

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Objective: To estimate rates and identify factors associated with asymptomatic COVID-19 in the population of Olmsted County during the prevaccination era.

Patients and Methods: We screened first responders (n=191) and Olmsted County employees (n=564) for antibodies to SARS-CoV-2 from November 1, 2020 to February 28, 2021 to estimate seroprevalence and asymptomatic infection. Second, we retrieved all polymerase chain reaction (PCR)-confirmed COVID-19 diagnoses in Olmsted County from March 2020 through January 2021, abstracted symptom information, estimated rates of asymptomatic infection and examined related factors.

Results: Twenty (10.5%; 95% CI, 6.9%-15.6%) first responders and 38 (6.7%; 95% CI, 5.0%-9.1%) county employees had positive antibodies; an additional 5 (2.6%) and 10 (1.8%) had prior positive PCR tests per self-report or medical record, but no antibodies detected. Of persons with symptom information, 4 of 20 (20%; 95% CI, 3.0%-37.0%) first responders and 10 of 39 (26%; 95% CI, 12.6%-40.0%) county employees were asymptomatic. Of 6020 positive PCR tests in Olmsted County with symptom information between March 1, 2020, and January 31, 2021, abstracted symptom information, estimated rates of asymptomatic infection and examined related factors.

Factors associated with asymptomatic disease included age (0-18 years [odds ratio {OR}, 2.3; 95% CI, 1.7-3.1] and >65 years [OR, 1.40; 95% CI, 1.0-2.0] compared with ages 19-44 years), body mass index (overweight [OR, 0.58; 95% CI, 0.44-0.77] or obese [OR, 0.48; 95% CI, 0.57-0.62] compared with normal or underweight) and tests after November 20, 2020 ([OR, 1.35; 95% CI, 1.13-1.71] compared with prior dates).

Conclusion: Asymptomatic rates in Olmsted County before COVID-19 vaccine rollout ranged from 6% to 25%, and younger age, normal weight, and later tests dates were associated with asymptomatic infection.

Globally, infection with the SARS-CoV-2 virus has caused over 383 million infections and 5.6 million deaths through February 2022. Since the beginning of the pandemic, it has been clear that there is substantial variability in severity of disease, with some SARS-CoV-2-infected persons developing severe symptoms and progressing to hospitalization and death, whereas others may be completely asymptomatic. Asymptomatic infections refer to the positive detection of nucleic acid of SARS-CoV-2 in patient samples by reverse transcriptase-polymerase chain reaction (RT-PCR) among...
persons with no clinical symptoms or signs. Detection of antibodies to SARS-CoV-2 also provides evidence of prior infection. It is important to understand asymptomatic infection because even asymptomatic infection confers a level of natural immunity, and failure to account for such infections will underestimate population-level immunity. In addition, asymptomatic persons may unknowingly transmit the virus to close contacts, although they are less infectious than symptomatic persons. Defining the characteristics of persons who are most likely to be asymptomatic can also help target public health recommendations (eg, mask wearing, social distancing) toward persons who are most likely to unknowingly transmit the virus.

Estimates of asymptomatic SARS-CoV-2 infection among positive cases has ranged from 1.6% to 56%; however, these estimates are frequently derived from studies with small sample sizes, selective inclusion criteria, and low participation rates. Many of these studies are also biased by lack of sufficient follow-up for development of symptoms and/ or ascertained only a limited number of symptoms. A recent meta-analysis of >350 studies published through March 2021 estimated 35.1% infections as truly asymptomatic, ie, cases did not develop symptoms over at least a 7-day period after a positive PCR test. The wide range in estimates of asymptomatic SARS-CoV-2 infection underscores the difficulty of obtaining accurate estimates of persons who had asymptomatic infections within a defined population. Ascertaining precise estimates of asymptomatic SARS-CoV-2 infection would require routine testing of everyone in a population and active follow-up to determine whether a given infection is truly asymptomatic or is just early in the course of the disease (presymptomatic). Such studies are challenging and to date, quite limited, particularly those of a truly population-based nature.

To address this critical evidence gap, we studied asymptomatic infection among persons residing in Olmsted County, Minnesota, between March 1, 2020, and January 31, 2021. Olmsted County is a well-characterized population with high testing rates, high access to medical care, and high interest in community-based research. Specifically, we used complementary data from 2 studies: (1) prospective antibody sampling and symptom information from county employees and first responders and (2) symptom information abstracted from medical records in a records linkage system at the time of positive PCR test for SARS-CoV-2. We also examined demographic and clinical factors associated with asymptomatic status. We focused on 3 main time periods that reflected varying mitigation efforts in the community, including 2 lockdown periods, from March to June 2020 and end of November to January 2021. Our findings reflect asymptomatic infection during circulation of the wild-type and alpha variant, which were the dominant strains circulating during the time period of this study, and may inform asymptomatic status with other COVID-19 variants in this pandemic as well as targeted groups to be tested in future pandemics.

**METHODS**

**Seroprevalence Study**

In collaboration with Olmsted County Public Health Services, we invited county employees and first responders (police, fire, sheriff) to participate in a seroprevalence study in November 2020. First responders worked in person throughout the pandemic and were expected to be at higher risk of contracting COVID-19. Olmsted County employees were expected to represent the general Olmsted County population because these employees had a mix of occupational and community interactions. For example, some worked from home during the study period and others continued to work in community settings as essential workers, with masking and distancing restrictions. A small group of employees from Zumbro Valley Health Center were also invited and contributed to the county group. All employees were emailed an invitation letter through either the county police/fire department.

Interested participants registered for an appointment at one of multiple testing events that took place between November 1, 2020 and February 28, 2021. Participants provided informed consent and a finger-stick blood sample for the antibody test. They also completed an online questionnaire about
COVID-19 symptoms and prior COVID-19 testing in addition to giving consent to access medical records. Testing for anti-SARS-CoV-2 antibodies was performed using dried blood spot extracts on the Luminex xMAP SARS-CoV-2 multi-antigen assay, as described previously, which measures IgG against 3 SARS-CoV-2 antigens—the nucleocapsid, the receptor-binding domain, and the spike glycoprotein S1 subunit. Compared with the Roche serology assay, the positive and negative percent agreement for the Luminex assay was 96.1% and 97.2%, respectively. Remuneration for participation was provided. The Mayo Clinic Institutional Review Board approved the study protocol and informed consent process.

**Asymptomatic Status at Positive PCR Test**

To define asymptomatic status at the time of positive COVID-19 test and factors associated with asymptomatic COVID-19, we used the Rochester Epidemiology Project (REP) medical records linkage system, which links medical records from local health care providers for 1.7 million persons who have lived in a 27-county Midwest region after January 1, 2010. For this study, we focused on persons living in Olmsted County, where the REP captures most (94.2%) of the population and their electronic medical record information. Health care data from all visits to each health care provider are coded and indexed electronically. Therefore, the REP includes demographic data and comprehensive information about medical diagnoses, hospital admissions, surgical procedures, drug prescriptions, laboratory test results, body mass index (BMI; calculated as the weight in kilograms divided by the height in meters squared), and smoking status, etc.

We searched the REP electronic indexes to identify all persons who resided in Olmsted County and who had a positive nasopharyngeal PCR test for COVID-19 between March 1, 2020, and January 31, 2021 (11 months). Persons who did not provide authorization to use their medical records for research were excluded (n=868, 9.9%). For multiple tests, the first positive test was considered. The complete medical records of these persons were reviewed, and symptoms recorded at the time of the positive test (presenting symptoms) were abstracted by experienced nurse abstractors and study coordinators. Symptoms included dyspnea, chest pain or tightness, dizziness/lightheadedness, cough, fever, chills, myalgia, sore throat, headache, loss of taste or smell, runny or stuffy nose, congestion, rhinorrhea, nausea, vomiting, abdominal pain, diarrhea, skin changes or rash, or fatigue. If the records indicated that the person had no symptoms at the time of the positive PCR test, records were reviewed to determine if new symptoms developed over an additional 14 days after the test, given the reported incubation period.

Body mass index was extracted from the medical records closest to the date of the positive test result and categorized into 3 categories: underweight or normal weight (<25 kg/m²), overweight (25 to <30 kg/m²), and obese (≥30 kg/m²) for adults. For persons aged ≤18 years, growth charts were used, and categories were defined as underweight or normal weight (85th percentile and under), overweight (between 86th and 95th percentile), and obese (>95th percentile). International Classification of Diseases diagnosis codes (ICD-9 and ICD-10) for the 5 years before the positive test result were used to capture patient comorbidities and to define the Charlson comorbidity index.

Socioeconomic status (SES) was determined using HOUsing-based SocioEconomic Status (HOUSES) index, which is a validated individual-level measure of SES derived from real property data. HOUsing-based SocioEconomic Status is an aggregated z-score of housing value, number of bedrooms, area of living space, number of bathrooms, and number of bedrooms, with higher scores indicative of higher SES. HOUsing-based SocioEconomic Status was seen to be associated with lower test and higher positive rate of COVID-19 infection in Olmsted County, Minnesota, from March to October 2020. Addresses at the time of the PCR test were derived from the REP.

We also examined differences because of lockdown periods in Olmsted County. As described by Lopes et al (2022), there were 3 major COVID-19–related state orders among residents of Olmsted County (Figure 1). First, a peacetime state of emergency was declared on March 12 with...
corresponding lockdown strategies, including closure of schools and pause in elective operations. Lockdown strategies began to lift on June 1, with re-opening of businesses, including restaurants, which could resume outdoor dining, and elective medical procedures. Then, starting November 21, greater restrictions were again imposed on businesses as well as social gatherings outside of one’s household. However, hospitals did not reduce or stop elective operations. Given that community testing was also limited in Olmsted County before June, we defined the 3 periods as follows: first lockdown (March 12 to May 31), between lockdowns (June 1 to November 20), and second lockdown and after (November 21 to January 31) (Figure 1).

**Statistical Analyses**

For the prospective seroprevalence study, we calculated the prevalence of antibodies in each risk group. This analysis included stratification by prior positive PCR COVID-19 test and further included estimated rates of SARS-CoV-2 seropositivity, rates of any evidence of infection from either antibody or PCR tests, and the proportion of those who reported no prior COVID-19 symptoms (asymptomatic). To estimate the precision of the estimates, 95% CIs using the Wilson (score) binomial CIs when a simple random sample was assumed or the hypergeometric CIs with normal distribution when a finite population correction was needed. The small number of cases limited the examination of associations of asymptomatic status with other factors.

We next examined the prevalence of asymptomatic vs. symptomatic COVID-19 among all positive PCR tests in Olmsted County over the entire time period and by time intervals that reflected 3 lockdown periods in Minnesota, as described above. We examined the association of demographic and clinical characteristics, HOUSES index, and comorbidities with asymptomatic status using logistic regression (odds ratios [ORs]; 95% CIs). Our models were adjusted for age and BMI as appropriate. The HOUSES index was analyzed both continuously (z-score) and in quartiles reflecting SES status.

**RESULTS**

**Seroprevalence Study**

Overall, 564 (44%) of 1284 county employees and 191 (63%) of 302 first responders who were invited to participate provided a blood sample. The median age for both risk groups was 44 years, but...
there was a higher percentage of men (77%) in the first responders compared with county employees (42%). Thirty-eight (6.7%; 95% CI, 5.0%-9.1%) of the county employees and 20 (10.5%; 95% CI, 6.9%-15.6%) of the first responders had positive antibodies (Supplemental Table 1, available online at http://www.mcpiqojournal.org).

After combining information from antibody testing and known prior infections reported in the electronic medical record or questionnaire, there were a total of 48 (9%;
95% CI, 6.5%-11.1%) county employees and 25 (13%; 95% CI, 9.0%-18.6%) first responders with evidence of prior COVID-19. Among persons with questionnaire information, 10 of 39 (25.6%; 95% CI, 12.6%-40.0%) county employees and 4 of 20 (20%; 95% CI, 3.0%-37.0%) first responders reported no prior COVID-19 symptoms at any time over the previous year (Supplemental Table 1).

Asymptomatic COVID-19 Among PCR-Positive Tests

We identified 8730 persons in Olmsted County with a positive COVID-19 PCR test result between March 1, 2020, and January 31, 2021; 7862 (90%) had provided authorization to use their medical records for research and were included in the study. We abstracted symptoms noted up to 14 days after the PCR test date for most of the study population (n=6020; 69% of total). Persons with symptom information had similar demographic and clinical characteristics as the overall sample (Supplemental Table 2, available online at http://www.mcpiqojournal.org). The 23% of persons without any symptom information in their medical records were more likely to be male, of younger age, of White race, with no comorbidities, and tested during the November-January time frame compared with persons with symptom information (Supplemental Table 2).

Among persons with symptom information, 131 (2.2%) were asymptomatic at the time of the PCR test but developed symptoms over the 14-day period. These persons were considered presymptomatic at the time of the test and were subsequently classified as symptomatic. Persons not reporting any symptoms (n=385) (6%; 95% CI, 5.8%-7.1%) over the 14 days formed the asymptomatic population. Figure 2 shows the rates of symptomatic and asymptomatic COVID-19 across time (Figure 2A), highlighting relevant lockdown time periods in Olmsted County, overall and by age group (Figure 2B). The prevalence of asymptomatic infection was lowest in March-May (3%), which parallels the lowest rates of tests per day (151) and lowest rates of symptomatic COVID-19 in Olmsted County (Figure 2A) as well as the first lockdown for the state. Higher rates were seen between lockdowns (June-November 2020; 6%) and during the time period encompassing the second lockdown (November 2020-January 2021; 7.5%) (Figure 2A and B); the rates of COVID-19 testing during these periods were higher, at 328 and 324, respectively. The older age group (>65 years) had higher asymptomatic rates during the early period, when testing was more frequent in this population in particular nursing homes. Children aged 0-18 years had the highest asymptomatic rates across the June 2020-January 2021 time period (Figure 2B).

The Table shows the distribution of clinical and demographic factors by symptom status at the time of the positive PCR test. Compared with that in ages 45-64 years (reference group), there were over 2-fold greater odds of an asymptomatic positive test in children aged 0-18 years (OR, 2.3; 95% CI, 1.7-3.1) and suggestive increase of asymptomatic infection in the >65 age group (OR, 1.4; 95% CI, 1.0-2.0) (Table). There were no significant differences for those aged 19-44 years (OR, 0.97; 95% CI, 0.73-1.3). Positive COVID-19 patients who were overweight (OR, 0.58; 95% CI, 0.44-0.77) or obese (OR, 0.48; 95% CI, 0.57-0.62) were less likely to be asymptomatic than those who were normal or underweight. Adjustment for age slightly attenuated the findings (Table). Having a positive test after November 20, 2020, was associated with greater odds of asymptomatic COVID-19 (OR, 1.39; 95% CI, 1.1-1.7) than a test before this date, likely reflecting the increased testing during this period. There were no statistically significant associations (all P>.05) of asymptomatic infection with sex (P=.25), race or ethnicity (all P>.05), number or type of comorbidities, education, or SES, even after adjustment for age and BMI (Table). In exploratory analyses, in which we examined individual conditions that form the Charlson comorbidity index (Supplemental Table 3, available online at http://www.mcpiqojournal.org), we found higher rates of dementia and lower rates of mild liver disease among persons with asymptomatic infection but no differences for diabetes.
Symptoms by Age, Ethnicity, and Race

We also described symptoms at presentation at the time of the COVID-19 test overall and by age, sex, race, and ethnicity for the 6020 positive tests with symptom information in the medical records (Supplemental Table 4, available online at http://www.mcpiqojournal.org).

The most common symptoms were headache (45%) and cough (53%). Younger ages (≤18 years) were less likely to present with coughing, chills, or myalgia than middle or older age groups. The youngest cases (0-5 years) were most likely to present with fever. Older cases (>65 years) had a lower percentage of...
sore throat and headaches but a higher percentage of fatigue (Supplemental Table 4). Fever was reported in 38% of Black persons, in 27% of White, and in 30% of other races, whereas runny nose/congestion was 18% in Black and 28% in White persons. The prevalence of each of the symptoms was similar by ethnicity and sex.

**DISCUSSION**

Two complementary sampling strategies were used to add to the understanding of asymptomatic COVID-19 in Olmsted County before widespread introduction of live attenuated vaccines. First, our prospective study of first responders and county employees found rates of prior infection from either SARS-CoV-2 antibody testing or prior positive COVID-19 tests to range from 9% to 13%. Of these prior infections, 20% to 26% were asymptomatic. Second, our review of the medical records of all positive COVID-19 tests in the Olmsted County population over an 11-month period found 6% to be asymptomatic within the 14-day period after the positive test. Younger age (<18 years), normal BMI, and testing after November 1, 2020 were associated with asymptomatic COVID-19 in this population.

Rates of asymptomatic COVID-19 varied substantially between our 2 studies, from 6% to 26%. Asymptomatic rates reported by Olmsted County Public Health during this same period were approximately 14.5% of positive PCR tests, but they lacked symptom data on up to 40% of positive cases (Personal communication, Olmsted County Public Health Department). The lower proportion of asymptomatic COVID-19 in our REP study may reflect a few factors. First, in the REP study, we were able to review symptom information over a 14-day period instead of just at the time of a positive test, which identified additional individuals with symptoms that arose after initial testing (presymptomatic). Next, we lacked symptom information for >30% of positive cases in Olmsted County over this time period. These persons were more likely to be younger and to have a test after November 2020; both characteristics are associated with increased asymptomatic rates. Our higher rates of asymptomatic COVID-19 in the first responders and county employees (20%-26%) compared with that in the general population were not surprising given the difference in study designs and testing. Screening for antibodies is more likely to identify evidence of asymptomatic virus infection, whereas PCR testing is more likely to be performed due to symptomatic illness. Also, the prospective study is at risk for selection bias as those who had greater concern about having a prior COVID-19 infection may have been more likely to participate, thereby over-estimating seroprevalence. Recall bias is also a problem for defining asymptomatic status in the prospective study, given the long time period for recalling symptoms and potential for differential recall by concern over having had a prior infection. Finally, our prospective screening studies are relatively small. However, these higher asymptomatic rates are consistent with several reports in the literature, as noted below.

Access to COVID-19 testing likely impacted our findings for the REP study, given the increased trend in asymptomatic rates across the time period, with the greatest rates after November 20, during which testing was widespread. In fact, 20% of Olmsted County residents had at least 1 COVID-19 test by October 2020, illustrating the high testing rates in this community. Before June, testing was limited to symptomatic patients, nursing home surveillance, and nonelective procedures, and the high asymptomatic rates among those aged 65 years and older reflect the targeted testing.

Several reviews have been conducted to summarize prevalence of asymptomatic COVID-19 across multiple populations. In a systematic review and meta-analysis of 79 studies through June 2020, Buitrago-Garcia et al. noted that an estimated 20% (95% CI, 17%-25%) of people infected with SARS-CoV-2 remain asymptomatic. In a subset of 7 studies in defined populations who were screened and followed to account for presymptomatic cases, this estimate increased to 31% (26%-37%). The largest review to date, of over 350 studies between January 2020 and April 2021, which corresponds with the timeframe of our study, estimated rates of asymptomatic disease at the time of PCR testing after removing index cases that were thought to inflate estimates of
symptomatic disease. They found overall rates of 35.1% in persons with at least 7 days of follow-up and who were noted as truly asymptomatic. Importantly, the review included >45 studies of at least 50 cases or more in a community setting, involving population surveillance and cohort studies. The average prevalence of silent infection in these communities was 29.8%, and for the few that were able to correctly classify preymptomatic COVID-19, the average of asymptomatic prevalence was similar, at 32.3%.

Even with the many studies of asymptomatic infection, few studies have specifically examined clinical factors associated with this milder presentation. Most previous studies found an inverse trend of asymptomatic rates with age, with the highest rates in children. Our findings support a higher prevalence of asymptomatic illness in children and are also suggestive of increases among the elderly, which has not been seen in most studies to date. However, one of the largest studies of asymptomatic COVID-19, a nationwide cohort in South Korea, also reported a U-shape distribution with age. Our findings in older age groups may reflect widespread testing that occurred in long-term care facilities in Olmsted County, resulting in greater detection of asymptomatic illness. In fact, a previous review reported higher rates of asymptomatic COVID-19 in aged care (20%) than in non-aged care (16%). Further, preprocedural COVID-19 testing was likely prevalent in Olmsted County, in particular at older ages. Of our 327 asymptomatic cases identified at Mayo Clinic, only 16 (5%) had tests before procedures, so this did not appear to be driving our findings.

Comorbidities are one of the most consistent factors associated with lower asymptomatic rates. Although our data did not show statistical significance, the odds of asymptomatic COVID-19 were less than 1 in those with 1 (OR, 0.90) or 2 or more comorbidities (OR, 0.89) compared with that in those with no comorbidities. Interestingly, adjustment for BMI resulted in attenuating the comorbidity association (OR, 0.99 for 1 and OR, 1.01 for >2 comorbidities), underscoring the relative importance of BMI in asymptomatic COVID-19 and the suggestion that BMI may be on the same pathway or a confounder of these previously reported associations of comorbidities and symptomaticity. In fact, the few studies that examined the association of BMI with asymptomatic COVID-19 found stronger associations of overweight and obesity with symptomatic COVID-19, which mirrors the positive associations of BMI or obesity with increased risk of severe COVID-19. Regarding the exploratory findings of higher rates of dementia among persons with asymptomatic infection, we hypothesize that higher asymptomaticity may be due to inaccurate recall or underreporting of symptoms. The suggestive association with mild liver disease is provocative in light of at least 2 prior studies that found differences in liver function between asymptomatic and symptomatic patients. We found no evidence for differences in asymptomatic COVID-19 by race or ethnicity in Olmsted County, and access to testing was widespread, with approximately 47% of the Olmsted County population having at least 1 COVID test by June 18, 2021, which may partially explain our findings compared with that in other populations.

Some of the heterogeneity in findings across studies is likely due to the accuracy of the tests administered, which has improved over the course of the pandemic. Our nasopharyngeal PCR test used to define positive COVID-19 in Olmsted County over most of this period is considered a gold standard, with generally good accuracy. Further, our screening study used dried blood spots for ease of off-site serology testing, which has shown high concordance (96.9%) with serum assays using the Roche Diagnostics Elecsys anti-SARS-CoV-2 ECLIA or the Euroimmun anti-SARS-CoV-2 IgG ELISA. However, IgG testing alone may miss some previous infections, and including antibodies to IgA as part of serologic surveys may improve retrospective identification of asymptomatic infection. Similar to ours, most of the early first-responder surveys were based on testing exclusively for IgG, and they may have significantly underestimated the rate of SARS-CoV-2 exposure and infection. Dried blood spot testing is a feasible method for informing community seroprevalence rates as it can be done at a low cost, is easy to collect and store, and can be readily transported and distributed.
Methods such as these will be important in making testing more available, to help increase the identification of past infection, in particular, asymptomatic COVID-19, and to increase our understanding of factors that contribute to the development of asymptomatic infection.

There are several strengths of our study, including the population-based investigation of asymptomatic COVID-19 in the REP, the partnership with Olmsted County Public Health, and the use of PCR and serology tests, which had both high sensitivity and specificity. Furthermore, we were able to examine rates among both persons at high risk because of their occupation and in the general population. However, we acknowledge the small sample sizes for the seroprevalence study. In addition, the observed prevalence of antibodies depends on the durability of the antibody response after infection and the time elapsed since infection, resulting in a possibility of underestimating seroprevalence. We also recognize that our findings are specific to Olmsted County during the period of observation and reflect mitigation strategies during this time period. The wild-type SARS-CoV-2 was predominant through most of the study, with potential for some involvement of the alpha variant in the final month; we know that later strains, in particular omicron, has been associated with less severe symptomatic disease and higher rates of asymptomatic infection.44 Our study was also conducted before COVID-19 vaccines were available. Vaccination is known to reduce disease severity and, consequently, rates of asymptomatic disease in vaccinated populations are likely to be higher.43 However, we expect that age and BMI will continue to be important factors for severity of infection across all variants and could inform targeted vaccination and prevention strategies.

POTENTIAL COMPETING INTERESTS
Ms Vierling receives funding from the Mayo Clinic Robert D. And Patricia E. Kern Center for the Science of Health Care Delivery. Dr Kennedy has a patent pending for SARS-CoV-2 peptide vaccine development and has received grant funding from ICW Ventures for preclinical studies on a peptide-based COVID-19 vaccine. He also receives grant funding from NIH and CDC, paid to Mayo Clinic. Dr Theel served on the advisory board or as a consultant to Roche Diagnostics, Serimmune Inc, and Euroimmun US. Dr Juhn receives funding from NIH and GSK grants, paid to his institution, which are not related to this manuscript. He has 1 pending and 1 issued patent not related to this manuscript. William Morice serves as Chair, Board of Directors, for the American Clinic Laboratory Association outside the work of this manuscript. Dr Cerhan receives research funding from Genetech, Genmab, BMS, and NanoString outside of this work. He also participates on a Safety Monitoring Committee for Protagonist and a scientific advisory board for BMS, both outside of this work. Dr Jacobson is funded by Mayo Clinic for his work. In addition, he received honoraria from Oklahoma University Health Sciences Center for grand rounds, from the Minnesota Board of Medical Licensure for expert opinion, and from Merck & Co. for service on an external data and safety monitoring board for a series of clinical vaccine trials. Dr Sauver receives funding from the National Institutes of Health, Exact Sciences, APP Australian Grant, Mayo Clinic Kern for the Science of Health Care Delivery, and Mayo Clinic President’s Fund, all paid to her institution. Dr Vachon received funding from Mayo Clinic President’s Fund for this work but holds grants from GRAIL and NIH, unrelated to this manuscript.

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SUPPLEMENTAL ONLINE MATERIAL
Supplemental material can be found online at http://www.mcpiqojournal.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: BMI, body mass index; HOUSES, HOUsing-based Socioeconomic Status; OR, odds ratio; PCR, polymerase chain reaction; REP, Rochester Epidemiology Project; RT-PCR, reverse transcriptase-polymerase chain reaction; SES, socioeconomic status

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