SARS-CoV-2 Infection during the Omicron Surge among Patients Receiving Dialysis: The Role of Circulating Receptor-Binding Domain Antibodies and Vaccine Doses

Maria E. Montez-Rath,1 Pablo Garcia,1 Jialin Han,1 LinaCel Cadden,2 Patti Hunsader,2 Curt Morgan,2 Russell Kerschmann,2 Paul Beyer,2 Mary Dittrich,3 Geoffrey A. Block,3 Julie Parsonnet,4,5 Glenn M. Chertow,1,5 and Shuchi Anand1

Due to the number of contributing authors, the affiliations are listed at the end of this article.

ABSTRACT
Background It is unclear whether circulating antibody levels conferred protection against SARS-CoV-2 infection among patients receiving dialysis during the Omicron-dominant period.

Methods We followed monthly semiquantitative SARS-CoV-2 RBD IgG index values in a randomly selected nationwide cohort of patients receiving dialysis and ascertained SARS-CoV-2 infection during the Omicron-dominant period of December 25, 2021 to January 31, 2022 using electronic health records. We estimated the relative risk for documented SARS-CoV-2 infection by vaccination status and by circulating RBD IgG using a log-binomial model accounting for age, sex, and prior COVID-19.

Results Among 3576 patients receiving dialysis, 901 (25%) received a third mRNA vaccine dose as of December 24, 2021. Early antibody responses to third doses were robust (median peak index IgG value at assay limit of 150). During the Omicron-dominant period, SARS-CoV-2 infection was documented in 340 (7%) patients. Risk for infection was higher among patients without vaccination and with one to two doses (RR, 2.1; 95% CI, 1.6 to 2.8, and RR, 1.3; 95% CI, 1.0 to 1.8 versus three doses, respectively). Irrespective of the number of vaccine doses, risk for infection was higher among patients with circulating RBD IgG <23 (506 BAU/ml) (RR range, 2.1 to 3.2, 95% CI, 1.3 to 3.4 and 95% CI, 2.2 to 4.5, respectively) compared with RBD IgG ≥23.

Conclusions Among patients receiving dialysis, a third mRNA vaccine dose enhanced protection against SARS-CoV-2 infection during the Omicron-dominant period, but a low circulating RBD antibody response was associated with risk for infection independent of the number of vaccine doses. Measuring circulating antibody levels in this high-risk group could inform optimal timing of vaccination and other measures to reduce risk of SARS-CoV-2 infection.
syndrome coronavirus 2 (SARS-CoV-2), even postvaccination, commonly results in hospitalization \(^9,10\) and carries the additional risk for in-facility transmission. \(^11\)

To date, only half of patients on dialysis have agreed to a third dose of the mRNA platform vaccines. \(^12\) Although a third dose generates an antibody response in nearly all patients receiving dialysis, \(^13,14\) the persistence of the response is unknown. Preliminary data on the clinical effectiveness of a third dose against the SARS-CoV-2 Omicron variant in this population are mixed. \(^15,16\) Moreover, because the Omicron variant receptor binding domain (RBD) differs substantially from that of the progenitor (Wuhan) virus, postvaccination or postinfection circulating antibody levels to the RBD may offer limited to no protection against infection.

In a prospective cohort of 3576 patients receiving dialysis throughout the United States in whom we have tracked monthly SARS-CoV-2 antibody response since February 1, 2021, we evaluated the longitudinal circulating RBD antibody response among patients who received one or two versus three doses of mRNA vaccines as of December 2021. We also determined the relations among the number of vaccine doses, circulating antibody response, and subsequent infection from December 25, 2021 through January 31, 2022, the period during which SARS-CoV-2 Omicron was the dominant variant in the United States.

**METHODS**

Starting in February 2021, in partnership with a central laboratory (Ascend Clinical), we tested monthly remainder plasma samples for RBD antibody from a cohort of patients receiving dialysis at US Renal Care facilities. US Renal Care is a dialysis network with >350 facilities nationwide. We have previously described sample size and sampling methods in detail. \(^3,5\) The selected cohort was representative of the full US Renal Care population, and broadly representative of the US dialysis population, with the exception of a lower proportion of patients living in the Midwest region.

We used electronic health records to ascertain patient characteristics, vaccination status, and SARS-CoV-2 diagnosis. The study received ethics approval from Stanford University. Stanford University investigators received coded data, and the Institutional Review Board waived the requirement for consent.

**Patient Population**

From our randomly sampled cohort of 4697 patients, we included patients who were active as of December 25, 2021, unvaccinated and vaccinated with one or two versus three doses of one of the two available mRNA vaccines, as reported in the electronic health record (see Supplemental Table 1 for distribution of vaccine combinations). We excluded patients who had received other vaccines due to limited numbers. We assigned type of vaccination by the first dose vaccine type.

**Documented SARS-CoV-2 Infection**

We ascertained a clinical diagnosis of COVID-19 using the US Renal Care electronic health record of a documented SARS-CoV-2 infection. \(^5\) We also extracted data on hospitalizations in the 7 days before or the 14 days after the diagnosis date. For the purposes of evaluating infection risk during the period when the Omicron variant (BA1.1, B.1.1.529, BA.2) was dominant in the United States, we evaluated SARS-CoV-2 infection diagnoses from December 25, 2021 through January 31, 2022. Centers for Disease Control and Prevention data delineate that the Omicron variant was detected in 74% of US infections by the last week of December, and increased rapidly thereafter. \(^12\)

**Laboratory Testing for RBD Antibodies**

We tested the remainder samples using the Siemens total RBD Ig assay, which measures IgG and IgM antibodies. \(^17,18\) On a monthly basis starting in February 2021, we used this assay to test remainder samples from patients we had sampled randomly, using systematic sampling with fraction intervals. \(^19\) Included in this cohort were 540 persons in whom we had observed RBD seroconversion before vaccine availability (July to December 2020). \(^5\)

After a positive total RBD Ig result, the positive sample and all subsequent monthly samples were tested using a semiquantitative Siemens RBD IgG assay (Atellica IM sCOVG assay). \(^17\) This assay is a two-step sandwich indirect chemiluminescent assay with manufacturer-reported sensitivity of 95.6% (95% confidence interval, 92.2% to 97.8%) and specificity of 99.9% (95% confidence interval, 99.6% to 99.9%) for tests performed ≥21 days after a positive RT-PCR result. An index value of 1.0 corresponds to 21.8 binding antibody units (BAU) per milliliter according to the World Health Organization international standard. \(^20\) An index value of 1.0 or greater (≥21.8 BAU/ml) is
considered reactive on this assay, and an index value of 150 (3270 BAU/ml) is the upper limit of quantification.

Statistical Analysis
The main analysis includes all patients alive and on dialysis at one of the participating US Renal Care facilities as of December 24, 2021. For determining risk of SARS-CoV-2 infection during the Omicron-dominant period by circulating antibody response, we restricted further to patients with an RBD antibody response available during December 1 to December 24, 2021 (Figure 1).

We described the cohort by vaccination status—unvaccinated, completed one to two doses, and completed three doses as of December 24, 2021—using proportions, means and SDs, or medians and 25th, 75th percentile ranges, as applicable. Next, among patients with at least one dose of the mRNA1273 or BNT162b2 and without prior documented SARS-CoV-2 infection, we described the antibody response over time by type of vaccine (defined by the vaccine type received as the first dose) and vaccination status. We estimated age- and sex-adjusted medians for RBD IgG index values using quantile regression, as implemented in the Stata qreg and margins commands. In this longitudinal data analysis, model parameters have a population-average interpretation. We used quantile regression and, in particular, the median to describe the data because it is invariant to data truncation and estimable in all of the analyses presented. Because patients receiving dialysis are tested monthly on or around the same date each month, we reported data using discrete postvaccination 30-day time windows with day 0 the day of the first dose of vaccine. To describe the full distribution of index values in each period by vaccination type and status, we produced boxplots of the RBD IgG index values.

Results
Of the 4697 patients we followed as of February 1, 2021, we included 3576 in the analytic cohort (Figure 1); 433 (12%) were on home modalities. Patients in the cohort resided in 1080 unique zip codes in 34 US states. Compared with patients who had received one to two doses of mRNA vaccination, the unvaccinated subgroup (n=852, 24%) was younger, was more likely to be non-Hispanic Black and to reside in the South, and was less likely to have diabetes (Table 1). In total, 25% of the cohort received a third dose; this subgroup was older and more likely to be Hispanic and to reside in the West compared with patients receiving one to two doses.

Among the subgroup with RBD antibody response available in December 2021, 1773 (51%) had RBD IgG index values <23 (Supplemental Table 2). The group with RBD <23 was younger, was more likely to be unvaccinated and to be non-Hispanic White, and was less likely to have diabetes.

Antibody Response to Third Vaccine Dose
Among patients without prior documented SARS-CoV-2 infection, before the third dose, median RBD IgG index values peaked between days 31 and 60 after vaccination and started to decrease by days 61–90, reaching a plateau during days 121–270 (Figure 2, A and B; Supplemental...
Patients who received the mRNA1273 vaccine had higher median values throughout the follow-up period compared with patients who received the BNT162b2 vaccine. After day 270, we observed an increase in the median index RBD values for patients with a third dose of the mRNA vaccines, concomitant with the timing of the third dose (median time to third dose, 250 [25th, 75th percentile: 231, 280] days since the first dose). Median peak RBD IgG index value response to both vaccines after third dose reached the assay limit (index value 150, 3270 BAU/ml).

Table 1. Characteristics of patients followed with monthly RBD antibody tests by vaccination status as of December 24, 2021

| Characteristic                  | Zero Doses | One to Two Doses | Three or More Doses | Overall |
|--------------------------------|------------|------------------|---------------------|---------|
|                                | n=852 (23.8) | n=1823 (51.0) | n=901 (25.2) | n=3576 (100) |
| Age (yr), mean (SD)            |            |                  |                     |         |
| 18–44                          | 58.6 (14.7) | 63.8 (13.5)     | 65 (13.7)           | 62.8 (14.0) |
| 45–64                          | 163 (19.1)  | 153 (8.4)       | 76 (8.4)            | 392 (11.0) |
| 65–79                          | 377 (44.3)  | 744 (40.8)      | 337 (37.4)          | 1458 (40.8) |
| ≥80                            | 69 (8.1)    | 714 (39.2)      | 357 (39.6)          | 1314 (36.7) |
| Women                          | 370 (43.4)  | 775 (42.5)      | 366 (40.6)          | 1511 (42.3) |
| Race and ethnicity             |            |                  |                     |         |
| Hispanic                       | 94 (11.0)   | 252 (13.8)      | 155 (17.2)          | 501 (14.0) |
| Non-Hispanic Black             | 264 (31.0)  | 422 (23.2)      | 181 (20.1)          | 867 (24.2) |
| Non-Hispanic other              | 89 (10.5)   | 261 (14.3)      | 190 (21.1)          | 540 (15.1) |
| Non-Hispanic White              | 231 (27.1)  | 558 (30.6)      | 222 (24.6)          | 1011 (28.3) |
| Missing                         | 174 (20.4)  | 330 (18.1)      | 153 (17.0)          | 657 (18.4) |
| Region                          |            |                  |                     |         |
| Northeast                       | 74 (8.7)    | 189 (10.4)      | 76 (8.4)            | 339 (9.5) |
| South                          | 530 (62.2)  | 941 (51.6)      | 292 (32.4)          | 1763 (49.3) |
| Midwest                        | 78 (9.2)    | 191 (10.5)      | 49 (5.4)            | 318 (8.9) |
| West                            | 170 (20.0)  | 502 (27.5)      | 484 (53.7)          | 1156 (32.3) |
| Prior documented SARS-CoV-2     | 148 (17.4)  | 196 (10.8)      | 85 (9.4)            | 429 (12.0) |
| Diabetes                        | 441 (51.8)  | 1082 (59.4)     | 558 (61.9)          | 2081 (58.2) |
| Vaccination type                |            |                  |                     |         |
| mRNA1273                       | —           | 846 (46.4)      | 527 (58.5)          | 1373 (38.4) |
| BNT162b2                        | —           | 977 (53.6)      | 374 (41.5)          | 1351 (37.8) |
| None                            | —           | —                | —                   | 852 (23.8) |

Data are shown as percentages unless otherwise specified.

a n=15 for patients who received four doses.

b Patients self-reporting Asian, American Indian, Alaskan, and Pacific Islander heritages are among the category defined as “other.”

Table 5 for numbers of patients included in each time window; Supplemental Figure 1, A and B for box plots depicting the entire distribution of the data. Patients who received the mRNA1273 vaccine had higher median values throughout the follow-up period compared with patients who received the BNT162b2 vaccine. After day 270, we observed an increase in the median index RBD values for patients with a third dose of the mRNA vaccines, concomitant with the timing of the third dose (median time to third dose, 250 [25th, 75th percentile: 231, 280] days since the first dose). Median peak RBD IgG index value response to both vaccines after third dose reached the assay limit (index value 150, 3270 BAU/ml).

Patients with one to two doses of mRNA1273 and BNT162b2 also had an increase in median index values after the day 270 window postvaccination, with a more pronounced

Figure 2. Age- and sex-adjusted median RBD IgG index values between February 1 and December 24, 2021 among patients who received mRNA vaccines. (A) mRNA1273. (B) BNT162b2. The figure depicts median antibody index values plotted by days since first dose of vaccine—excluding persons with documented SARS-CoV-2 (n=419)—using 30-day windows consistent with monthly laboratory draws among patients on dialysis. We assigned vaccine type by the type of first vaccine dose.
increase in median index values observed among patients receiving one to two doses of BNT162b2. We hypothesized that this increase may be related to SARS-CoV-2 breakthrough infection before December 25, 2021. A total of 28 patients had documented SARS-CoV-2 infection after day 270 and before December 25, 2021; of these 20 (71%) were in the one- to two-dose group.

**Risks for Infection during the Omicron-Dominant Period**

A total of 340 (7%) patients had documented COVID-19 between December 25, 2021 through January 31, 2022, and 115 (36%) of these were hospitalized in the 1 week before or 2 weeks after their diagnosis. The final doses of vaccines were given a median of 272 (25th, 75th percentile, 245, 303) days and 58 (25th, 75th percentile, 50, 95) days before infection for the one- to two-dose and three-dose vaccine groups, respectively. Relative risks for infection were higher among patients without vaccination, and patients with one to two doses compared with patients with three doses of the mRNA vaccines, after accounting for age, sex, and prior documented COVID-19 (Table 2). Among patients with homologous vaccination, there was evidence of benefit from receiving three doses (versus one to two doses or no doses) regardless of vaccine type (Supplemental Table 3).

Among the 3504 patients with an RBD antibody response available during December 1 through December 24, 2021, 339 (10%) patients had documented SARS-CoV-2 infection between December 25, 2021 through January 31, 2022 with a median time between index values and infection of 37 (25th, 75th percentile, 31–46) days. Relative risks for infection were higher among patients with RBD IgG index values <23 (versus RBD IgG ≥23) (Table 2). In sensitivity analyses evaluating alternative cut points, the relative risk for infection remained higher among persons with RBD index values below versus above that cut point (Supplemental Table 3), although the absolute risk for events at higher cut points was low: 71% of documented SARS-CoV-2 infections occurred at RBD index values <23 (Supplemental Table 4). Among 85 patients with a hospitalization admission or discharge diagnosis consistent with COVID-19, median RBD index values were 1.1 (25th, 75th percentile, <1, 7.9) compared with 4.5 (25th, 75th percentile, 1.0, 57.2) in the remaining 254 patients with documented SARS-CoV-2 infection. We evaluated patient deaths during December 25, 2021 to February 28, 2022, and found that among patients with RBD <23 and documented SARS-CoV-2 infection, 13% died, compared with 5% of those with RBD ≥23 and documented SARS-CoV-2 infection during December 25, 2021 to January 31, 2022.

We also evaluated the interaction between RBD IgG and vaccine doses. Median RBD index values were lower among patients with documented SARS-CoV-2 infection compared with persons without infection, irrespective of number of vaccine doses (Supplemental Figure 2). Patients with RBD IgG index values <23 had two- to three-fold higher risk for infection, irrespective of number of vaccine doses (versus patients with three doses of vaccine and RBD IgG ≥23), whereas in patients with RBD IgG index values ≥23, patients with less than three vaccine doses had a 1.1- to 1.4-fold higher risk for infection (Table 2).

### Table 2. Relative risk of infection by vaccine doses and circulating RBD IgG index values

| Risk Factor | Unadjusted | Adjusted Age and Sex | Adjusted Age, Sex, Region, and Prior SARS-CoV-2 Infectionb |
|-------------|------------|----------------------|--------------------------------------------------------|
| Vaccine doses |            |                      |                                                       |
| Zero        | 2.0 (1.5 to 2.7) | 2.0 (1.5 to 2.7) | 2.1 (1.6 to 2.8) |
| One to two  | 1.3 (1.0 to 1.8) | 1.3 (1.0 to 1.8) | 1.3 (1.0 to 1.8) |
| Three or more | Ref.     | Ref.                 | Ref.                                                   |
| RBD IgG index value |          |                      |                                                       |
| <23 versus ≥ 23 | 2.4 (1.9 to 3.0) | 2.4 (1.9 to 3.0) | 2.3 (1.9 to 2.9) |
| Vaccine doses and RBD IgGd |            |                      |                                                       |
| RBD IgG index value <23, doses |            |                      |                                                       |
| Zero        | 3.1 (2.2 to 4.5) | 3.2 (2.2 to 4.6) | 3.2 (2.2 to 4.5) |
| One to two  | 2.2 (1.6 to 3.2) | 2.3 (1.6 to 3.3) | 2.3 (1.6 to 3.3) |
| Three or more | 2.1 (1.3 to 3.4) | 2.1 (1.3 to 3.5) | 2.1 (1.3 to 3.5) |
| RBD IgG index value ≥23, doses |            |                      |                                                       |
| Zero        | 1.2 (0.7 to 2.2) | 1.3 (0.7 to 2.3) | 1.4 (0.8 to 2.5) |
| One to two  | 1.1 (0.7 to 1.6) | 1.1 (0.7 to 1.6) | 1.1 (0.7 to 1.7) |
| Three or more | Ref.     | Ref.                 | Ref.                                                   |

Ref., reference.

*a*Data in parentheses are 95% CIs.

*b*As documented in the electronic health record.

*c*Interaction *P*<0.001.

*d*n=15 for patients who received four doses.
DISCUSSION

In this nationwide cohort of patients receiving dialysis, among whom >75% had received at least one dose of the mRNA platform vaccines, 7% experienced documented SARS-CoV-2 infection during the roughly 6-week-long Omicron variant surge period in the United States. Patients who were unvaccinated, patients without a third vaccine dose, and those lacking robust circulating antibody response were at higher risk for infection. Even among patients receiving three or more doses of vaccine, RBD index values <23 (<506 BAU/ml) were associated with nearly two-fold higher risk for breakthrough infection. Although a higher number of mRNA vaccine doses was associated with reduced risks for infection with the Omicron variant, the protection was dependent on the circulating RBD antibody response, implying that antibody response assessments could inform risk stratification in this patient population.

Our data are consistent with a study including 1121 patients receiving hemodialysis in the United Kingdom who were also undergoing weekly screening by RT-PCR testing.14 In this study, 12.9% of patients receiving hemodialysis experienced Omicron SARS-CoV-2 infection (symptomatic and asymptomatic) between December 1, 2021 and January 16, 2022. Compared with patients who were unvaccinated, patients who had received three, but not two, ChAdOx1 or BNT162b2 vaccine doses experienced a reduced likelihood of Omicron infection (hazard ratio, 0.50; 95% confidence interval, 0.29 to 0.92).15 These findings are consistent with general population data from the UK Health Security Agency, in which the investigators reported suboptimal vaccine effectiveness against symptomatic Omicron variant SARS-CoV-2 among persons receiving two vaccine doses.24 Carr et al. evaluated neutralizing antibody response against Omicron, compared with Delta, SARS-CoV-2 variants, among patients receiving dialysis.16 Median neutralizing antibody titers against Omicron among patients with two doses of BNT162b2 were below assay range at day 158 after two doses, and rose significantly to detectable ranges at day 27 after three doses. Concordant with our findings, these studies suggest three doses of the current formulation of the mRNA vaccines provide enhanced protection from infection with the Omicron variant in the short term, after the third dose.

Continued illness and hospitalization of patients receiving dialysis despite vaccination, however, raises questions about durable effectiveness of the vaccines in this high-risk population, the correct vaccination dosing schedule, and the need for follow-up antibody testing. In the Carr et al. study, 25% of patients receiving dialysis did not mount neutralizing antibody titers against the Omicron variant in the immediate period after the third dose.16 Moreover, the duration of detectable neutralizing antibody titers and/or real-world protection against SARS-CoV-2 after the third dose is unknown. Compared with solid organ transplant recipients or patients receiving cytotoxic or B cell-depleting chemotherapy, in whom the Centers for Disease Control and Prevention currently recommends a fourth dose,25 patients receiving dialysis had higher rates of seroconversion after the initial (one or two doses) vaccination series, and after the third dose. Nonetheless, patients receiving dialysis experience higher rates of infection-related complications than the general population.9 Measurement of circulating anti-SARS-CoV-2 antibody levels may help identify the subgroup of patients receiving dialysis that remains at higher risk postvaccination, because the patient population on dialysis as a whole is not currently included in the moderate to severely immunocompromised group warranting prophylaxis.26 We have previously shown an association between circulating antibody levels and risk for breakthrough infection during the Delta-dominant period in the United States; in this analysis, we confirm this association during the dominance of the genetically divergent Omicron variant and among patients who had recently received three doses of mRNA platform vaccines. Even as community-level risk mitigation approaches are relaxed, it is possible that circulating antibodies could serve as a clinical indicator for high risk for infection, and allow for individualized measures of heightened protection. The subgroup with low circulating antibodies may benefit from pre-exposure prophylaxis with monoclonal antibodies, for example, or from antiviral treatment on exposure. Serial antibody monitoring may also inform the timing of additional vaccine doses among patients receiving dialysis as a whole.

Strengths of our analysis include a diverse cohort (by age, sex, self-reported race/ethnicity, geography, socioeconomic status, and dialytic modality), and use of a single, highly sensitive and specific assay over time. We are able to ascertain circulating antibody response proximal to infection and re-evaluate previously suggested RBD antibody level thresholds in the context of a new variant.

There are several limitations to our analysis as well. First, we could not evaluate risks for Omicron variant COVID-19 among patients receiving Ad26.COV2.S vaccine as the first dose due to small numbers of patients receiving this formulation at US Renal Care facilities. Second, we did not have data on type of testing performed (rapid antigen versus RT-PCR), or any genomic data identifying specific variants, which could have provided exact numbers of Omicron and non-Omicron variant infections, although the vast majority of infections over this time frame were due to Omicron variants. Third, because we measured RBD antibody levels, which respond both to infection and to vaccination, we could not identify patients with asymptomatic SARS-CoV-2 infection who may have additional immunity beyond that induced through vaccination. Asymptomatic breakthrough infection may explain the increase in median index values we observed in the day 270 or later window for the 1–2 dose group, but we are unable to test this hypothesis given our single antibody measurement of RBD.

Finally, although we demonstrate that circulating RBD index values are associated with risk for infection, there are additional other (unmeasured) domains, such as cellular
immunity, frailty, and social contacts, that are also likely risk factors for infection.

In summary, we demonstrated a meaningful but incomplete degree of protection against infection with the SARS-CoV-2 Omicron variant after a third dose of mRNA platform vaccines. The risk for infection after third vaccine dose is dependent on the antibody response. Ongoing efforts to determine the optimal schedule of SARS-CoV-2 infection surveillance and the utility and timing of antibody testing in patients receiving dialysis should yield benefits to patients receiving dialysis and the public health at large.

ACKNOWLEDGMENTS

Ascend Clinical Laboratory supported the remainder plasma testing for SARS-CoV-2 antibodies. The entire authorship team is grateful for the collaborative spirit of US Renal Care and Ascend Clinical Laboratory staff members who care directly for patients receiving dialysis and whose diligent electronic medical record keeping enabled this work.

AUTHOR CONTRIBUTIONS

S. Anand, G.M. Chertow, P. Garcia, M.E. Montez-Rath, and J. Parsonnet conceptualized the study; L. Cadden and C. Morgan were responsible for the data curation; J. Han and M.E. Montez-Rath were responsible for the formal analysis; P. Beyer and P. Hunsader were responsible for the funding acquisition; R. Kerschmann, P. Beyer, M. Dittrich, G.A. Block were responsible for the resources; S. Anand, G.M. Chertow, J. Han, P. Garcia, M.E. Montez-Rath, and J. Parsonnet were responsible for the methodology; P. Beyer, G.A. Block, L. Cadden, G.M. Chertow, and C. Morgan were responsible for the project administration; P. Beyer, G.A. Block, G.M. Chertow, M. Dittrich, P. Hunsader, R. Kerschmann, and J. Parsonnet provided supervision; P. Hunsader, C. Morgan, and R. Kerschmann were responsible for the validation; J. Han, P. Garcia, and J. Parsonnet were responsible for the visualization; S. Anand, G.M. Chertow, P. Garcia, M.E. Montez-Rath, and J. Parsonnet wrote the original draft; and G.A. Block, G.M. Chertow, M. Dittrich, P. Hunsader, and J. Parsonnet reviewed and edited the manuscript.

DATA SHARING STATEMENT

Study protocol is available from Dr. Anand (sanand2@stanford.edu). Statistical code is available from Dr. Maria Montez-Rath (mmrath@stanford.edu). The dataset is available upon investigators’ review of request, with age categories further collapsed to ensure anonymization (sanand2@stanford.edu). Analytical dataset may be subject to a data sharing agreement with US Renal Care.

SUPPLEMENTAL MATERIAL

This article contains the following supplemental material online at http://jasn.asnjournals.org/lookup/suppl/doi:10.1681/ASN.2022040504/-/DCSupplemental.

Supplemental Table 1. Observed vaccine type combinations among patients in the main analytic cohort.

Supplemental Table 2. Characteristics of patients with a RBD antibody test performed between December 1 through December 24, 2021, alive and on dialysis.

Supplemental Table 3. Sensitivity analyses for relative risk of SARS-CoV-2 during the Omicron period at varying RBD thresholds and by vaccine type.

Supplemental Table 4. Proportions of patients with documented SARS-CoV-2 infection by RBD index value categories.

Supplemental Table 5. Number of patients included in each 30-day period in Figure 2, A and B.

Supplemental Figure 1. Boxplots of antibody index values between February 1 through December 24, 2021 plotted from days since first dose, measured in 30-day periods. (A) mRNA1273. (B) BNT162b2.

Supplemental Figure 2. Boxplots of antibody index values before December 24, 2021, plotted by documented SARS-CoV-2 infection and number of vaccine doses.

REFERENCES

1. Anand S, Montez-Rath ME, Han J, Garcia P, Cadden L, Hunsader P, et al.: Antibody response to COVID-19 vaccination in patients receiving dialysis. J Am Soc Nephrol 32: 2435–2438, 2021.
2. Garcia P, Anand S, Han J, Montez-Rath ME, Sun S, Shang T, et al.: COVID-19 vaccine type and humoral immune response in patients receiving dialysis. J Am Soc Nephrol 33: 33–37, 2021
3. Grupper A, Sharon N, Finn T, Cohen R, Israel M, Agbaria A, et al.: Humoral response to the Pfizer BNT162b2 vaccine in patients undergoing maintenance hemodialysis. Clin J Am Soc Nephrol 16: 1037–1042, 2021
4. Hasmann S, Paal M, Fueßl L, Fischereder M, Schönermark U: Humoral immunity to SARS-CoV-2 vaccination in haemodialysis patients: Response to: Humoral and cellular immunity to SARS-CoV-2 vaccination in renal transplant versus dialysis patients: A prospective, multicenter observational study using mRNA-1273 or BNT162b2 mRNA vaccine. Lancet Reg Health Eur 10: 100237, 2021
5. Anand S, Montez-Rath ME, Han J, Garcia P, Cadden L, Hunsader P, et al.: SARS-CoV-2 vaccine antibody response and breakthrough infection in patients receiving dialysis. Ann Intern Med 175: 371–378, 2021
6. Berar-Yanay N, Freiman S, Shapira M, Saffoury A, Elemy A, Hamze M, et al.: Waning humoral response 3 to 6 months after vaccination with the SARS-COV-2 BNT162b2 mRNA vaccine in dialysis patients. J Clin Med 11: 64, 2021
7. Hsu CM, Weiner DE, Manley HJ, Aweh GN, Ladik V, Frament J, et al.: Seroresponse to SARS-CoV-2 vaccines among maintenance dialysis patients by 6 months. Clin J Am Soc Nephrol 17: 403–413, 2022
8. Boudabhay I, Serris A, Servais A, Planas D, Hummel A, Guery B, et al.: COVID-19 outbreak in vaccinated patients from a haemodialysis unit: Antibody titres as a marker of protection from infection. Nephrol Dial Transplant 37: 1357–1365, 2022
9. Salerno S, Messana JM, Gremel GW, Dahlers C, Hirth RA, Han P, et al.: COVID-19 risk factors and mortality outcomes among Medicare patients receiving long-term hemodialysis. JAMA Netw Open 4: e2135379, 2021
10. Centers for Medicare & Medicaid Services. Preliminary Medicare COVID-19 Data Snapshot, 2022. Available at: https://www.cms.gov/research-statistics-data-systems/preliminary-medicare-covid-19-data-snapshot/. Accessed February 12, 2022.
11. Corbett RW, Blaney S, Nitsch D, Loucaidou M, McLean A, Duncan N, et al.; West London Renal and Transplant Centre: Epidemiology of COVID-19 in an urban dialysis center. J Am Soc Nephrol 31: 1815–1823, 2020
12. Centers for Disease Control and Prevention: COVID Data Tracker. Available at: https://covid.cdc.gov/covid-data-tracker/. Accessed March 7, 2022.
13. Garcia P, Han J, Montez-Rath ME, Sun S, Shang T, Parsonnet J, et al.: SARS-cov-2 booster vaccine response among patients receiving dialysis. Clin J Am Soc Nephrol 17: 1036–1038, 2022 35383042
14. Ducloux D, Colladant M, Chabannes M, Yannaraki M, Courivaud C: Humoral response after 3 doses of the BNT162b2 mRNA COVID-19 vaccine in patients on hemodialysis. Kidney Int 100: 702–704, 2021
15. Spensley KJ, Gleeson S, Martin P, Thomson T, Clarke CL, Pickard G, et al.: Comparison of vaccine effectiveness against the omicron (B.1.1.529) Variant in hemodialysis patients. Kidney Int Rep 7: 1406–1409, 2022 35434428
16. Carr EJ, Wu M, Harvey R, Billany RE, Wall EC, Kelly G, et al.: Hemodialysis COVID-19 Consortium, Crick COVID Immunity Pipeline: Omicron neutralising antibodies after COVID-19 vaccination in haemodialysis patients. Lancet 399: 800–802, 2022
17. U.S. Food & Drug Administration. EUA Authorized Serology Test Performance, 2020. Available at: https://www.fda.gov/medical-devices/coronavirus-disease-2019-covid-19-emergency-use-authorizations-medical-devices/eua-authorized-serology-test-performance. Accessed June 28, 2021
18. Schnurrer C, Reiners N, Biemann R, Kaiser T, Trawinski H, Jassoy C: Comparison of the diagnostic sensitivity of SARS-CoV-2 nucleoprotein and glycoprotein-based antibody tests. J Clin Virol 129: 104544, 2020
19. Rossi PH, Wright JD, Anderson AB: Handbook of Survey Research, 1st Ed., edited by Rossi PH, Wright JD, Anderson AB, Cambridge, MA, Academic Press, 2013, pp 145–146
20. Kristiansen PA, Page M, Bernasconi V, Mattiuzzo G, Dull P, Makar K, et al.: WHO International Standard for anti-SARS-CoV-2 immunoglobulin. Lancet 397: 1347–1348, 2021
21. Hao L, Naiman D: Quantile Regression, London, Sage Publications, 2007
22. Marino MF, Farcomeni A. Linear quantile regression models for longitudinal experiments: An overview. METRON 73: 229–247, 2015
23. Feng S, Phillips DJ, White T, Sayal H, Aley PK, Bibi S, et al.; Oxford COVID Vaccine Trial Group: Correlates of protection against symptomatic and asymptomatic SARS-CoV-2 infection. Nat Med 27: 2032–2040, 2021
24. Andrews N, Stowe J, Kirsebom F, Toffa S, Rickeard T, Gallagher E, et al.: COVID-19 vaccine effectiveness against the Omicron (B.1.1.529) variant. N Engl J Med 386: 1532–1546, 2022
25. Centers for Disease Control and Prevention: COVID-19 Vaccines for Moderately or Severely Immunocompromised People, 2022. Available at: https://www.cdc.gov/coronavirus/2019-ncov/vaccines/recommendations/immunohtml. Accessed March 14, 2022
26. Food and Drug Administration: Frequently Asked Questions on the Emergency Use Authorization for Evusheld (Tixagevimab Co-Packaged with Cilgavimab) for Pre-Exposure Prophylaxis (PrEP) of COVID-19, 2022. Available at: https://www.fda.gov/media/154703/download. Accessed March 14, 2022

**AFFILIATIONS**

1Department of Medicine (Nephrology), Stanford University, Palo Alto, California
2Ascend Clinical Laboratory, Redwood City, California
3US Renal Care, Plano, Texas
4Department of Medicine (Infectious Diseases and Geographic Medicine), Stanford University, Palo Alto, California
5Department of Epidemiology and Population Health, Stanford University, Palo Alto, California

8 JASN JASN 33: 8–18, 2022