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Original Article

ORIGINAL ARTICLE

SARS-CoV-2 antibody dynamics among kidney transplant recipients 3 months after BNT162b2 vaccination: a prospective cohort study

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ABSTRACT

Data regarding immunogenicity of mRNA severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) vaccines among kidney transplant recipients in the months following vaccination are lacking. We aimed to investigate humoral immune response at 3–4 months post-vaccination among a cohort of kidney transplant recipients, compared with a control group of dialysis patients. Anti-spike antibodies were tested at 1 and 3–4 months after vaccination. Of 259 kidney transplant recipients tested at a median time of 110 days from second vaccine dose, 99 (38%) were seropositive, compared with 83% (101/122) of control patients. Younger age, better renal function and lower immunosuppression levels were associated with seropositivity. A total of 14% (13/94) of participants seropositive at 1 month became seronegative at follow-up and 11% (18/165) became seropositive. The latter were mainly individuals with higher antibody levels at 1 month. Antibody levels at 3–4 months were significantly reduced in both study groups, although the decline was more pronounced in the control group. Kidney transplant recipients present poor antibody response to mRNA SARS-CoV-2 vaccination, with only 38% seropositive at 3–4 months. Nevertheless, the decay in antibody response over time is modest, and some patients may present delayed response, reaching adequate antibody levels at 3–4 months. Low seropositivity rates in this group call for investigating other immunization strategies.

Keywords: antibodies, COVID-19, immune response, kidney transplant, mRNA vaccine

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INTRODUCTION

Inadequate antibody response to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) mRNA vaccination has been increasingly reported among solid organ transplant (SOT) recipients. Several studies in kidney transplant recipients have shown poor humoral responses up to 1 month following the second mRNA vaccine dose, ranging from 29% to 54% seropositivity [1, 2]. Heart transplant recipients have shown similar response rates [3], while lung transplant recipients have shown even worse responses (18% seropositivity at 14–21 days following the second vaccine dose) [4].

Factors associated with reduced humoral response in these studies included increased age, lower glomerular filtration rate (GFR), and type and dose of immunosuppressive medication. Treatment with belatacept or anti-thymocyte globulin (ATG), higher doses of mycophenolic acid; or higher blood levels of calcineurin inhibitors (CNIs) were all associated with lower seropositivity rates [1, 3, 5].

Among transplant recipients following natural coronavirus disease 2019 (COVID-19) infection, a few small studies demonstrated similar immediate humoral and cellular response in comparison with healthy controls, soon after the infection [6, 7]. A study following liver transplant recipients over 6 months after natural infection showed lower seropositivity rate at 3 and 6 months when compared with healthy controls, but with a similar decline in seropositivity rates over time (77% seropositivity at 3 months to 63% at 6 months) [8].

No data are currently available regarding the durability of antibody response following vaccination in transplant recipients. Among healthy subjects, Widge *et al.* [9, 10] reported elevated antibodies persisting at 90 days and, more recently, 209 days after the second dose of mRNA-1273 (Moderna) vaccine in all 34 participants, despite a slight decrease in levels. Geometric mean titers exceeded those of convalescing non-vaccinated controls. In comparison, Naaber *et al.* [11] demonstrated a significant decrease in antibody levels among 122 healthy volunteers at 6 and 12 weeks following BNT162b2 vaccine (Pfizer).

In this second stage of a prospective cohort study following kidney transplant recipients after BNT162b2 vaccination, we assessed anti-spike (anti-S) antibody levels at 3 months after the second vaccine dose.

MATERIALS AND METHODS

Study procedures and data collection

This was a prospective, single center, cohort study, evaluating kidney transplant recipients with functioning grafts that had been vaccinated with two doses of BNT162b2 vaccine, 21 days apart. We included adult recipients (>18 years) receiving first vaccine dose at least 1 month following the transplantation surgery. Participants who had documented infection with COVID-19 at any time prior to vaccination were excluded from the study. The study was conducted according to the declarations of Helsinki and Istanbul, and was approved by the ethic committee of Rabin Medical Center (RMC). The settings, data collection, immunosuppression regimen data and laboratory methods have been previously described (Supplementary data, Supplement 1), as well as outcomes at 2–4 weeks following the second vaccine dose [1]. In this phase of the study, we further tested consenting participants for SARS-CoV-2 antibody levels at ~3 months after the second vaccine dose. The SARS-CoV-2 IgG II Quant (Abbott©) assay, testing antibodies against the receptor binding domain (RBD) of the spike protein, was used, with level >50 AU/mL considered positive [12]. A control group consisted of dialysis patients, evaluated in the same manner. The rationale for this control group was data from two studies, showing robust antibody response to mRNA vaccines among dialysis patients, similar to a healthy population [13, 14]. Dialysis patients who were treated with immunosuppressant medications were excluded from the control group.

Statistical analysis

For comparison of continuous variables between groups we used Student's *t*-test for normally distributed variables and Mann–Whitney *U* test for non-normally distributed variables. The main outcome of the study was seropositivity for SARS-CoV-2 at 3 months (defined as antibody titer >50 AU/mL) [12]. Secondary outcomes included log-transformed antibody titter (1 was added to the antibody levels and the product was transformed to decimal logarithmic scale) and the change in antibody levels between the two evaluation timepoints.

Univariate and multivariate logistic regression analyses were performed with seropositivity as outcome. Multivariate analysis was done using forward regression with a *P*-value of 0.05 for inclusion. Variables introduced into the model included: age, gender, body mass index (BMI), donor type, time from transplantation, diabetes status, time from immunization to evaluation, estimated glomerular filtration rate (eGFR), high CNI blood level, mycophenolic acid dose, treatment with ATG (within 6 month before the first vaccine dose), treatment with high-dose corticosteroids (at least 250 mg methyl prednisolone for at least 3 days, within 6 month before the first vaccine dose), treatment with inhibitors of mammalian target of rapamycin (mTOR) and treatment with cyclosporine. For evaluation of the log-transformed antibody titer, we used simple and multiple linear regression analysis. Multivariate analysis was done using forward regression with a *P*-value of 0.05 for inclusion.

To evaluate antibody dynamics between the first and the second evaluation, we used repeated measure analysis of variance (ANOVA) with the antibody levels at 1 month and 3–4 months as the repeated measures. We evaluated for interactions between the control and the study groups as well as patients' variables in the study group, and the change in antibody levels. All variables with significant interaction ($P \leq 0.05$) were introduced into multivariate model. For this analysis, age was divided into two groups (≥50 years versus <50 years) as well as mycophenolic acid dose (no treatment or ≤360 mg versus >360 mg).

We also evaluated the difference between the log-transformed antibody titer at 1 month and 3–4 months. The difference was calculated as $\log[(1+Ab_{1\ \text{month}})/(1+Ab_{3\text{-}4\ \text{months}})]$. We used simple and multiple linear regression analysis. Multivariate analysis was done using forward regression with *P*-value of 0.05 for inclusion with all variables mentioned above. All analyses were done using SPSS version 26 (IBM INC, Armonk, NY, USA).

RESULTS

Seropositivity rates

Of the original 308 consenting kidney transplant recipients, 5 had COVID-19 infection during the interval and 1 patient died. Forty-four patients were unavailable for a repeat blood sample during the study period. Two hundred fifty-nine patients (84%) had available measurements of anti-S antibodies at 3–4 months.

Table 1. Baseline characteristics of the study group

Variable	All (N = 259)	Seropositive (N = 99)	Seronegative (N = 160)	P-value
Age (years), mean ± SD	58.22 ± 13.37	54.1 ± 13.3	60.77 ± 12.8	<0.001
Female gender, N (%)	88 (34%)	34 (34.3%)	54 (33.8%)	0.922
Time from transplantation (years), mean ± SD	7.1 ± 7.51	6.17 ± 5.91	7.67 ± 8.31	0.119
First 3 months, N (%)	10 (3.9%)	3 (3%)	7 (4.4%)	0.585
Living donor, N (%)	198 (76.4%)	82 (82.8%)	116 (72.5%)	0.052
eGFR (per mL/min/1.73 m^2), mean ± SD	62.15 ± 22.3	70.54 ± 22.43	56.96 ± 20.64	<0.001
eGFR below 60 mL/min/1.73 m^2, N (%)	126 (48.6%)	29 (29.3%)	97 (60.6%)	<0.001
Diabetes mellitus, N (%)	45 (17.4%)	14 (14.1%)	31 (19.4%)	0.28
Time from second vaccine dose, mean ± SD	110.21 ± 16.65	108.47 ± 19.06	111.28 ± 14.93	0.188
BMI (kg/m^2), mean ± SD	27.12 ± 4.56	27.11 ± 4.19	27.12 ± 4.79	0.983
No mycophenolic acid, N (%)	70 (27%)	33 (33.3%)	37 (23.1%)	0.38
Low dose mycophenolic acid, N (%)	20 (7.7%)	9 (9.1%)	11 (6.9%)	
Medium dose mycophenolic acid, N (%)	99 (38.2%)	35 (35.4%)	64 (40%)	
High-dose mycophenolic acid, N (%)	70 (27%)	22 (22.2%)	48 (30%)	
Tacrolimus, N (%)	239 (92.3%)	95 (96%)	144 (90%)	0.81
Cyclosporine, N (%)	20 (7.7%)	4 (4%)	16 (10%)	
Tacrolimus level (ng/mL), mean ± SD	7.74 ± 2.14	7.1 ± 1.7	8.17 ± 2.29	<0.001
Cyclosporine level	129.8 ± 58.14	118.5 ± 42.9	132.63 ± 62.22	0.676
mTOR inhibitor, N (%)	22 (8.5%)	11 (11.1%)	11 (6.9%)	0.235
High CNI level, N (%)	150 (57.9%)	48 (48.5%)	102 (63.8%)	0.016
High dose CS[a], N (%)	22 (8.5%)	5 (5.1%)	17 (10.6%)	0.118
Treatment with rituximab, N (%)	4 (1.5%)	0 (0%)	4 (2.5%)	0.113
Treatment with ATG, N (%)	12 (4.6%)	3 (3%)	9 (5.6%)	0.334

[a]All patients were on corticosteroid treatment; this indicates percentage with high dose.
ATG—antithymocyte globulin; BMI—body mass index; CNI—calcineurin; CS—corticosteroids; eGFR—estimated glomerular filtration rate; mTOR—mechanistic target of rapamycin; SD—standard deviation.

Table 2. Antibody levels and log transformed antibody levels at 1 and 3–4 months for the study and control groups

		Control group	Study group	P-value
1 month	Antibody level (AU/mL)[a]	1533.05 (321–2903.2)	16.10 (3.8–157.2)	<0.001
	Log antibody level (log AU/mL)[b]	2.98 ± 1.48	1.48 ± 0.97	<0.001
3–4 months	Antibody level (AU/mL)[a]	364.40 (90.7–859.6)	17.70 (2.7–156)	<0.001
	Log antibody level (log AU/mL)[b]	2.46 ± 1.36	1.36 ± 0.97	<0.001

[a]Median (interquartile range).
[b]Mean ± standard deviation.

The control group included 122 dialysis patients from the RMC dialysis units [13]. For baseline characteristics of the study and control groups, see Table 1 and Supplementary data, Table S1.

For the study group, antibody levels were collected at a median time of 110 days [interquartile range (IQR) 98–122 days] from the second vaccine dose. Of the 94 patients who were seropositive at 1 month, 13 (13.8%) turned seronegative; and of the 165 patients seronegative at 1 month, 18 (10.9%) turned seropositive. (See Supplementary data, Figure S2 for visual description of antibody dynamics among these 13 seronegative and 18 seropositive patients.) Overall, of the 259 patients included, 99 (38.2%) were seropositive for anti-S antibodies at 3–4 months, compared with 112/308 (36.4%) at 1 month. Median antibody titer was 17.7 AU/mL (IQR 2.7–156) compared with 15.5 AU/mL (IQR 3.5–163.6) at 1 month. Of the 122 patients in the control group, 101 (82.8%) were seropositive ($P < 0.001$ versus study group) at 3–4 months, compared with 114/122 (93.4%) at 1 month. The values for antibody levels and log transformed antibody levels at 1 and 3–4 months for the study and control groups are presented in Table 2 and Figure 1. The distribution of log-transformed difference between anti-S antibody levels at 1 and 3–4 months was normal and is depicted in Figure 2.

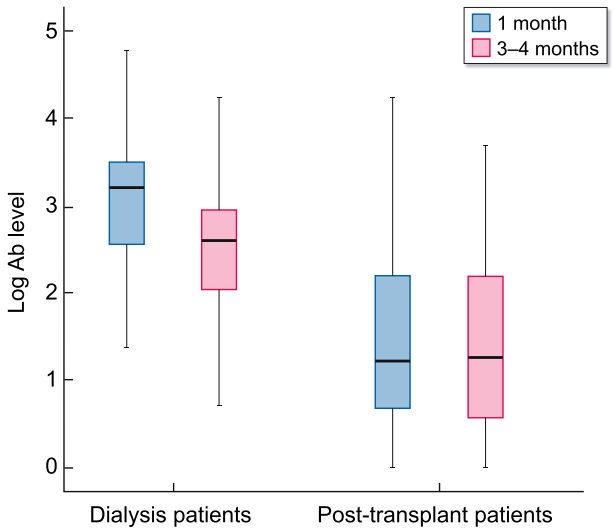

FIGURE 1: Log-transformed anti-S protein antibody levels at 1 and 3–4 months for the study and the control groups.

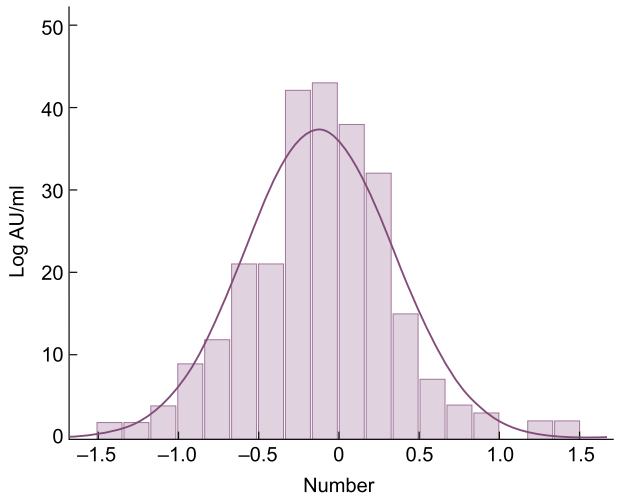

FIGURE 2: Distribution of log-transformed difference between anti-S antibody levels at 1 and 3–4 months for entire cohort.

Factors associated with seropositivity at 3–4 months

On univariate and multivariate analyses, the variables that were associated with anti-S positivity in the study group included younger age {odds ratio (OR) 1.042/year [95% confidence interval (CI) 1.02–1.065], $P < 0.001$}, eGFR above 60 mL/min/1.73 m^2 [OR 3.788 (95% CI 2.113–6.789), $P < 0.001$], lower mycophenolic acid dose [OR 1.468 per 360 mg decline (95% CI 1.135–1.898), $P = 0.003$] and low CNI blood level [OR 1.806 (95% CI 1.027–3.177), $P = 0.04$]. For the full analyses, see Table 3. This was also shown in a second analysis using the log transformed anti-S antibody levels as a continuous variable (see Supplementary data, Table S3).

Similar results were also found on additional analyses including only the 239 patients (92.3%) treated with tacrolimus, performed using tacrolimus level as a continuous variable. The results of this analysis are detailed in Supplementary data, Tables S4 and S5.

Transformation from seronegative at 1 month to seropositive at 3–4 months

Of the 165 seronegative patients at 1 month, 18 (10.9%) became seropositive. Median antibody levels at 1 month were 29 AU/mL (IQR 14–42 AU/mL) and increased to a median of 80 AU/mL (IQR 57–139 IU/mL) at 3 months. In univariate logistic regression analysis, higher antibody levels at 1 month [OR 1.107/AU/mL (95% CI 1.065–1.152), $P < 0.001$] and eGFR above 60 mL/min/1.73 m^2 [OR 4.105 (95% CI 1.389–12.13), $P = 0.011$] were associated with seroconversion at 3 months. These findings remained significant on multivariate analysis, as well as younger age, which was also significantly associated with seroconversion [OR 1.058 (95% CI 1.008–1.109), $P = 0.022$]. The results of the analysis are presented in Supplementary data, Table S6.

Transformation from seropositive at 1 month to seronegative at 3–4 months

Of the 94 seropositive patients at 1 month, 13 (13.8%) became seronegative. Median antibody levels at 1 month were 92 AU/mL (IQR 67–184 AU/mL) decreased to a median of 26 AU/mL (IQR 18–36 IU/mL) at 3 months. In univariate logistic regression analysis, these 13 patients were at longer duration from transplantation, with lower BMI, less likely to be treated with tacrolimus and had lower antibody levels at 1 month. This sample size was too small to perform multivariate analysis (13 patients) (see Supplementary data, Table S2).

Dynamics of anti-S antibody levels between 1 month and 3–4 months.

Anti-S antibody levels at 1 and 3 months for the study and control groups are presented in Table 2 and Figure 1. The anti-S antibody levels at 3–4 months were significantly reduced in the study groups ($P = 0.007$) and the control group ($P < 0.001$) compared with at 1 month. Similar findings were demonstrated in an analysis including only patients seropositive at 1 month (Supplementary data, Figure S1 and Table S7). The reduction in

Table 3. Factors associated with seropositivity at 3–4 months—univariate and multivariate analysis

	Univariate				Multivariate			
Variable	OR	95% CI for OR		P	OR	95% CI for OR		P
Younger age (per year decrease)	1.039	1.019	1.060	0.000	1.042	1.020	1.065	0.000
Female gender	1.027	0.605	1.742	0.922	–	–	–	–
Time from transplantation (per year)	0.972	0.938	1.008	0.122	0.956	0.917	0.997	0.036
Living donor	1.830	0.977	3.425	0.059	–	–	–	–
eGFR (per mL/min/1.73 m^2)	1.030	1.017	1.043	0.000	–	–	–	–
eGFR above 60 mL/min/1.73 m^2	3.716	2.173	6.356	0.000	3.788	2.113	6.789	0.000
Diabetes mellitus	0.685	0.344	1.364	0.282	–	–	–	–
Time from second vaccine dose (per day)	0.986	0.959	1.014	0.327	–	–	–	–
BMI (per kg/m^2)	0.999	0.946	1.056	0.983	–	–	–	–
Mycophenolic acid dose (per 360 mg)	1.261	1.012	1.572	0.039	1.468	1.135	1.898	0.003
Cyclosporine	0.379	0.123	1.168	0.091	–	–	–	–
mTOR inhibitor	1.693	0.705	4.067	0.239	–	–	–	–
Low CNI level	1.869	1.123	3.109	0.016	1.806	1.027	3.177	0.040
High dose CS	0.447	0.160	1.254	0.126	–	–	–	–
Treatment with ATG	0.524	0.138	1.985	0.342	–	–	–	–

ATG—antithymocyte globulin; BMI—body mass index; CI—confidence interval; CNI—calcineurin; CS—corticosteroids; eGFR—estimated glomerular filtration rate; mTOR—mechanistic target of rapamycin; OR—odds ration; SD—standard deviation.

Table 4. Factors that interact with antibody level change between 1 and 3–4 months by repeated measures ANOVA

		Univariate			Multivariate
Variable	N	Log Ab level 1 month	Log Ab level 3 months	P interaction UV	P interaction MV
All	259	1.48 ± 0.97	1.36 ± 0.97	<0.001	0.013
No antibody response at 1 month	165	0.86 ± 0.44	0.81 ± 0.64	0.001	0.006
Positive antibody response at 1 month	94	2.58 ± 0.6	2.33 ± 0.61		
Age >50 years	187	1.37 ± 0.92	1.24 ± 0.9	0.460	–
Age ≤50 years	72	1.77 ± 1.06	1.68 ± 1.06		
Male gender	171	1.53 ± 0.98	1.4 ± 0.95	0.859	–
Female gender	88	1.4 ± 0.97	1.29 ± 0.99		
eGFR ≥60 mL/min/1.73 m^2	133	1.75 ± 0.98	1.69 ± 0.98	0.032	0.028
eGFR <60 mL/min/1.73 m^2	126	1.2 ± 0.89	1.02 ± 0.82		
Living donor	61	1.34 ± 0.93	1.22 ± 0.94	0.956	–
Deceased donor	198	1.53 ± 0.98	1.41 ± 0.97		
No DM	214	1.5 ± 0.99	1.41 ± 0.97	0.026	0.065
DM	45	1.41 ± 0.92	1.15 ± 0.93		
No/low dose mycopehnolic acid	90	1.85 ± 1.06	1.51 ± 0.98	<0.001	<0.001
Medium/high dose mycophenolic acid	169	1.29 ± 0.87	1.28 ± 0.95		
BMI <30 kg/m^2	192	1.49 ± 0.94	1.38 ± 0.95	0.621	–
BMI ≥30 kg/m^2	67	1.46 ± 1.07	1.32 ± 1.02		
CNI level <7 ng/mL	109	1.68 ± 1.02	1.53 ± 1.01	0.363	–
CNI level ≥7 ng/mL	150	1.34 ± 0.92	1.24 ± 0.91		
No treatment with ATG	247	1.5 ± 0.96	1.39 ± 0.96	0.133	–
Treatment with ATG	12	1.17 ± 1.32	0.86 ± 1.06		
No mTor inhibitor	237	1.47 ± 0.99	1.35 ± 0.98	0.449	0.014
mTOR inhibitors	22	1.59 ± 0.75	1.55 ± 0.77		
No high-dose CS	237	1.53 ± 0.97	1.42 ± 0.96	0.995	–
high dose CS	22	0.91 ± 0.78	0.79 ± 0.83		

Ab—antibodies; ATG—antithymocyte globulin; BMI—body mass index; CNI—calcineurin; CS—corticosteroids; DM—diabetes mellitus; eGFR—estimated glomerular filtration rate; mTOR—mechanistic target of rapamycin; SD—standard deviation.

levels was significantly lower in the study versus control groups ($P < 0.001$).

Association between anti-S antibodies dynamics and patients' variables

Antibody level decline over time was associated with GFR <60 mL/min/1.73 m^2 ($P = 0.028$), diabetes mellitus ($P = 0.026$), no treatment or low dose of mycophenolic acid ($P < 0.001$) and positive antibody response at 1 month ($P = 0.006$) on univariate and multivariate analysis. This was shown using repeated measures ANOVA and validated on evaluation of factors associated with the log-transformed difference in antibody levels between 1 and 3–4 months (Table 4 and Supplementary data, Table S8, respectively).

Treatment with mTOR inhibitors, which had no interaction with antibody level change by univariate analysis, significantly interacted with antibody decline when introduced into the multivariate model ($P = 0.014$). The results of the repeated measure ANOVA are detailed in Table 4.

DISCUSSION

In this cohort of 259 kidney transplant recipients 3–4 months following second dose of mRNA vaccination, we demonstrated that antibody response remained low (38%) at similar rates to those observed at 1 month. Among seropositive patients at 1 month, ~14% had declining antibodies to a level of seronegativity at 3 months. At the same time, ~12% of patients seronegative at 1 month seroconverted to positive. This conversion to seropositivity was more likely in younger patients, those with increased eGFR and those who had higher antibody levels at 1 month. For the entire cohort, antibody levels declined over time, but at a slower rate in comparison with the control group of dialysis patients.

The findings of similar seropositivity rates with a modest decline at 3 months are in accordance with current knowledge on the immune response to natural SARS-CoV-2 infection. In patients after natural COVID-19 infection, studies demonstrate either sustained levels [15, 16] or progressive modest decline of IgG levels to spike protein (25% decrease by day 105 and 46% by Day 115 for anti-RBD antibodies in one study) [17]. Seropositivity rates remain high months after natural infection, reported to be 88–90% after 6–8 months [17–19]. Neutralization antibody dynamics is reported to be similar to that of anti-RBD antibodies [17, 18].

A decline in antibody titer is expected in the weeks following vaccination in general. Such decline has also been demonstrated among immunocompetent individuals after mRNA COVID-19 vaccines. Among healthcare workers, a reduction in IgG levels has been observed each month following the second BNT162b2 dose, as well as a decline in neutralizing antibody titers, decreasing by a factor of 3.9 at 3 months [20]. It has also been demonstrated that anti-RBD antibody titers decline faster than anti-spike antibody titers, which were more stable over time [9, 21, 22]. Naaber *et al.* found a decline in anti-RBD from peak mean levels of 26 928 AU/mL at 1 week after the second mRNA vaccine dose to 13 943 AU/mL at 6 weeks (45% decrease), and to 5702 AU/mL at 12 weeks after the second dose (77% decrease) among 90 healthy individuals. These levels, however, remained significantly higher compared with patients recovered from natural infection. Older age was associated with a decreased antibody titer in each time point tested in this study [11]. Similarly,

McDade *et al*. [23] reported a drop of 50% in anti-RBD IgG levels at 3 months after vaccination compared with peak levels measured after the second vaccine dose. In a group of 142 hemodialysis patients, Berar-Yanay *et al*. [24] demonstrated a response rate of 94% 1 month after second dose, declining to 78% at 3 months after the second dose of BNT162b2.

Among kidney transplant recipients, Boyarsky *et al*. [25] recently reported antibody response at 3 months after two-dose mRNA vaccination. In this study, among 75 patients with low-positive titers at 1 month, 35 (47%) became highly positive at 3 months, indicating that a delayed response may be possible, as suggested by our results. In this study, overall 43% of patients had an increase in titer from 1 to 3 months, 35% had a decrease and 21% remained stable. Four percent of seropositive patients at 1 month became seronegative at 3 months, lower than the 14% in our study [25]. An additional recent study including 312 SOT recipients demonstrated consistent results of relatively stable antibodies over time. At ∼1 month following a second dose of mRNA vaccine, 63% were seropositive; at ∼3 months, 72% were seropositive; and at 6 months, 72% as well. Seven percent of seropositive patients at 1 month became seronegative at 6 months [26].

Regarding patients who were seronegative and turned seropositive, we cannot rule out a delayed antibody response for SOT recipients, as also suggested by the two studies described above [25, 26]. Peak antibody response has been previously demonstrated at between Day 15 and 45 after natural infection [17, 22]. We were unable to explain why this was more likely in younger patients and those with higher eGFR; however, it seems reasonable that patients with some antibody response (negative according to test interpretation, but levels above zero) were more likely to mount antibody response at a later stage. Nevertheless, it is still possible that some of the patients became seropositive due to test limitations and margin of error.

To some extent, serum antibodies are a surrogate marker for vaccine effectiveness in immunocompromised patients. Annual anti-HBs (hepatitis B surface antibodies) titers monitoring is recommended for kidney transplant recipients for decisions on revaccination [27]. Monitoring antibody response to SARS-CoV-2 vaccine may also serve as a potential tool to identify the need and timing of potential revaccination. Using this surrogate, we assume that the vast majority of kidney transplant recipients seropositive at 1 month are still protected at 3 months. As the strategy of administrating a third mRNA dose is evolving [28], these findings support 1 month as a reasonable time point for serological assessment for decision-making.

This study has several limitations. The importance of waning immunity, specifically antibody levels, in protecting against disease is still uncertain. Moreover, in our study, we did not test neutralizing antibodies. However, high correlation between anti-RBD antibodies and neutralizing antibodies has been documented [22, 29], and even modest levels of neutralizing antibodies have been demonstrated to provide protection against COVID-19 [18] for the long term. In addition, detectable antibodies months after acute COVID-19 have been shown to be associated with protection against re-infection [30]. Thus, we assume that seropositivity at 1–3 months represents, at least to some extent, protection against infection. Another limitation in this regard is that no tests for T-cell response to vaccine were conducted in this study.

In summary, we document similarly low rates of antibody response at 3 months and 1 month following mRNA vaccine in kidney transplant recipients, with 14% of seropositive patients at 1 month presenting antibody decay to seronegative test levels. Additional studies are needed to determine the correlation between antibody response months after vaccination and protection against disease. The low seropositivity rates of 38% among kidney transplant recipients deserve attention and consideration of vaccination strategies aiming to improve the immune response.

SUPPLEMENTARY DATA

Supplementary data are available at *ckj* online.

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CONFLICT OF INTEREST STATEMENT

The authors of this manuscript have no conflicts of interest to disclose. The results presented in this article have not been published previously in whole or part.

DATA AVAILABILITY STATEMENT

The original data from this study may be available upon reasonable request to the corresponding author

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