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TRANSPLANT INFECTIOUS DISEASE

ORIGINAL ARTICLE

Evaluating clinical effectiveness of SARS-CoV-2 vaccine in solid organ transplant recipients: A propensity score matched analysis

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Abstract

Background: Solid organ transplant recipients (SOTRs) are at disproportionate risk for severe Coronavirus Disease 2019 (COVID-19). Vaccination is a key preventative strategy but is associated with decreased humoral responses among SOTR. Whether dampened immune responses correlate with reduced clinical effectiveness is unclear. Our study was designed to evaluate the clinical effectiveness of SARS-CoV-2 vaccination in the early vaccine era.

Methods: We conducted a retrospective cohort study comparing SARS-CoV-2 infection rates between SOTRs who received two doses of mRNA or one dose of Ad26.Cov2.S vaccine and those not fully vaccinated (partially vaccinated and unvaccinated). To evaluate clinical effectiveness of vaccine, cause-specific Cox regression model and modified Poisson regression model were built using the propensity score-matched cohort. Additionally, the clinical outcomes of COVID-19 of fully vaccinated and not fully vaccinated SOTR were compared.

Results: Of 2705 SOTRs, 1668 were included in our final matched analysis, which showed a 73% reduction of SARS-CoV-2 infection and 76% reduction of all-cause-mortality among fully vaccinated patients. Thirty-nine SOTRs developed SARS-CoV-2 infection, including nine fully vaccinated and 30 not fully vaccinated. Among fully vaccinated patients, 22% had severe/critical COVID-19 and 0% mortality versus not fully vaccinated SOTRs, of whom 37% had severe/critical COVID-19 and 6.67% COVID-19-related mortality.

Conclusion: In SOTRs, completion of primary vaccine series in the early vaccine era was associated with a significant reduction of COVID-19 and was protective against severe/critical disease and death. Further studies are needed to evaluate the clinical

Abbreviations: COVID-19, coronavirus disease 2019; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; SOTRs, solid organ transplant recipients.

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effectiveness of current vaccine recommendations for SOTR against emerging new variants.

KEYWORDS
breakthrough infections, COVID-19, organ transplant, vaccine

1 | INTRODUCTION

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) disproportionately affects patients who are immunocompromised and leads to worse outcomes in solid organ transplant recipients (SOTRs) than the general population, as seen in several studies.[1–4] Vaccination is a key strategy to prevent SARS-CoV-2 infection and progression to severe disease. Early vaccine trials have shown high efficacy against COVID-19 in the general population, reported as 95% for BNT162b2 and 94.1% for mRNA-1273; however, patients on immunosuppressive therapy were excluded from these studies.[5,6] Meanwhile, the Ad26.COV2.S recombinant adenovirus vaccine had 66.1% efficacy in preventing moderate to severe–critical COVID-19 in the general population excluding those with immunosuppressing conditions.[7]

Due to impaired immunity in SOTRs, there is reasonable concern that available SARS-CoV-2 vaccines are less effective in this population. Brosh-Nissimov et al. found that 40% of fully vaccinated patients in Israel with breakthrough infections requiring hospitalization were immunocompromised.[8] In conjunction with decreased vaccine effectiveness, significantly reduced humoral immune response as evidenced by lower levels of anti-spike IgG antibodies has been documented in fully vaccinated liver, kidney, heart, and lung transplant recipients following mRNA vaccination compared to nonimmunocompromised vaccine recipients.[9–12]

Due to concerns about suboptimal protection with a two-dose series, the impact of additional vaccine doses on humoral immunity has been evaluated and is shown to increase likelihood of antibody response for SOTRs.[13,14] Based on these findings, the US Food and Drug Administration authorized a third primary vaccine dose 28 days after the second dose for immunocompromised patients on August 12, 2021, and the Centers for Disease Control and Prevention (CDC) subsequently updated their recommendations accordingly.[15] Furthermore, the CDC recommended an additional booster dose (4th dose), now at 3 months following completion of the primary series, although little real-world data are available to support this practice. In parallel with mounting evidence of decreased humoral immune response to SARS-CoV-2 vaccination in SOTR, studies on clinical outcomes of vaccinated SOTRs, pertaining to prevention of infection, severe disease, and death, have been emerging. A multicenter study demonstrated increased risk of breakthrough infection in fully vaccinated SOTRs compared to the general population.[16] Despite this, there were lower rates of symptomatic COVID-19 in fully vaccinated versus unvaccinated SOTRs at a time when recommendations for primary series included two mRNA vaccine doses.[17]

To determine the clinical effectiveness of SARS-CoV-2 vaccine in our SOTR cohort, we performed a propensity score-matched analysis comparing fully vaccinated SOTRs to those who were either unvaccinated or partially vaccinated.

2 | METHODOLOGY

2.1 | Data collection

This was a retrospective cohort analysis of SOTR at any time posttransplant who received transplant care at Yale New Haven Hospital (New Haven, Connecticut) from January 1, 2021 to August 6, 2021, by means of electronic medical record (EMR) review. This study was approved by the Yale University Institutional Review Board (HIC # 2000027876).

We included SOTR age ≥18 years at the time of study period who had not had SARS-CoV-2 infection prior to January 1, 2021. Vaccination status as of August 6, 2021 was determined by the data communicated to EMR from the State of Connecticut, New York, and Rhode Island vaccine registries or from documentation of the provider. Patients with mixed vaccines, >2 mRNA vaccinations, or >1 Ad26.Cov2.S vaccination were excluded since these vaccination strategies were not in accordance with CDC guidelines at the time of the study. Since data were collected prior to the change in guidelines recommending an extra primary vaccine dose for immunosuppressed patients, *fully vaccinated* patients were defined as being ≥14 days from one dose of the Ad26.COV2.S vaccine or second dose of the mRNA-1273 or BNT162b2 vaccines as of August 6, 2021. *Partially vaccinated* patients were defined as either having received a single mRNA vaccine or ≤14 days from either two doses of an mRNA vaccine or one dose of the Ad26.CoV2.S vaccine. *Unvaccinated* patients were defined as those who did not receive any SARS-CoV-2 vaccine as of August 6, 2021.

Other clinical data collected were as follows: baseline demographics, comorbidities, type of organ transplantation, follow-up time from transplantation in years, maintenance immunosuppression regimen, and type of SARS-CoV-2 vaccination. We evaluated for SARS-CoV-2 infection in this cohort until August 6, 2021. SARS-CoV-2 infection was defined as the presence of a positive SARS-CoV-2 polymerase chain reaction test. If a patient was vaccinated, the timing of SARS-CoV-2 infection from vaccination (in days) was captured. For all patients who developed SARS-CoV2 infection, regardless of vaccination status, data pertaining to COVID-19-related treatment received, hospitalization, and clinical course were collected within 30 days of

infection diagnosis. For example, SOTRs who developed infection on August 6, 2021 were evaluated until September 5, 2021. The severity of COVID-19 was classified as per National Institute of Health definition.[18]

2.2 | Statistical methods

Patients were classified as either *fully vaccinated* or *not fully vaccinated*. The latter group included unvaccinated or partially vaccinated SOTRs. Partially vaccinated and unvaccinated patients were grouped together for statistical analysis, since there were relatively fewer partially vaccinated patients, and these patients theoretically do not mount complete immunity.

Propensity scores were created using logistic regression model with vaccination status as outcome. Fully vaccinated patients were matched to not fully vaccinated patients 1:1 based on propensity score differences <1% to minimize confounders between these groups. A prior study has shown that SARS-CoV-2 vaccine acceptance correlated with age, sex, and race/ethnicity.[19] Similarly these factors are associated with severity of COVID-19[20]; hence, these were included as covariates. Comorbidities including obesity, diabetes, hypertension, stroke, chronic obstructive pulmonary disease (COPD), coronary artery disease, and congestive heart failure have also been shown to contribute to worse outcomes from COVID-19, so these were included as covariates.[21] Mycophenolate was also selected as a covariate due to its association with severe COVID-19 outcome and with vaccine effectiveness.[9–11,22] To further minimize transplant-related cofounders, our covariates also included type of transplanted organ and years after transplant. Before and after propensity matching, differences between fully vaccinated and not fully vaccinated patients were evaluated using Student's *t*-test for continuous variables and chi-square or Fisher's Exact test for categorical variables.

Kaplan-Meier curves and log rank tests were used to assess probabilities of SARS-CoV-2 infection or all-cause mortality between fully vaccinated and not fully vaccinated patients. To evaluate the protective effect of vaccination, cause-specific Cox regression model and modified Poisson regression model were built using the propensity score-matched cohort.[23,24] The follow-up time started from the index date, which was 14 days after receiving one dose of the Ad26.COV2.S vaccine or second dose of the mRNA-1273 or BNT162b2 for fully vaccinated patients (the same index date was used for not fully vaccinated patient in the matched pair), to the date of infection and censored at the last follow-up date or death. To further evaluate the protective effect of vaccination, all the above-mentioned analyses (propensity score matching, Cox regression, and Modified Poisson regression analyses) were also carried out among fully vaccinated and unvaccinated patients (excluding the partially vaccinated), as sensitivity analyses.

Descriptive statistics for patients who developed SAS CoV-2 infection were also generated by vaccination status. A two-tailed *p* value <.05 was considered statistically significant. All analyses are conducted using SAS 9.4 (SAS institute, Cary, NC).

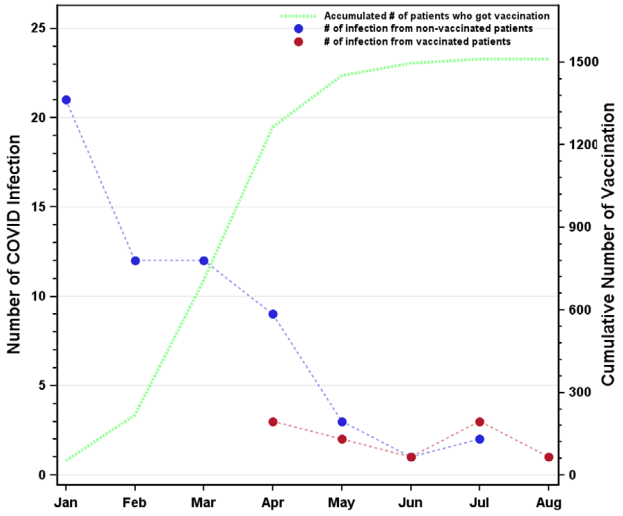

FIGURE 1 Number of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) infection cases by month among not fully vaccinated patients (blue) compared to vaccinated patients (red), with cumulative number of patients fully vaccinated shown over time (green)

3 | RESULTS

3.1 | Prepropensity score matching

There were a total of 2705 SOTRs receiving care at our center during the study period. After excluding those with mixed vaccines, >2 mRNA vaccine doses, or >1 Ad26.COV2.S vaccine doses, and those with missing covariate information, there were 2361 patients (1427 fully vaccinated and 934 not fully vaccinated) considered for propensity matching (Figure S1). During the study period, the median time to first dose of vaccine among the 1511 vaccinated SOTRs prior to excluding those with missing covariate information was 92 days (interquartile range 70–113).

Prior to propensity matching, age, race, ethnicity, and percentage of patients with diabetes, hypertension, and COPD were significantly different between the fully vaccinated and not fully vaccinated (Table 1). The fully vaccinated group had an older mean age compared to not fully vaccinated group (58.52 vs. 53.70, $p < .001$). There was higher proportion of Black race and Latinx in the not fully vaccinated group ($p < .05$). The cumulative number of vaccinated SOTRs and the number of infections per week of vaccinated and not fully vaccinated SOTR are illustrated in Figure 1.

3.2 | Propensity score matching

After propensity matching, 1668 SOTRs were included (834 fully vaccinated and 834 not fully vaccinated). Clinical characteristics of SOTRs after propensity matching were balanced between groups and are described in Table 1. A total of 39 patients developed COVID-19

TABLE 1 Baseline characteristics and outcomes before and after propensity score matching

	Before propensity score match ($N = 2631$)			After propensity score match ($N = 1668$)		
	Fully vaccinated ($n = 1427$)	Not fully vaccinated ($n = 934$)	*p*-Value	Fully vaccinated ($n = 834$)	Not fully vaccinated ($n = 834$)	*p*- Value
Age – mean (SD)	58.52 (13.64)	53.70 (15.75)	<.001	55.19 (14.46)	54.92 (15.22)	.71
Sex						
Female	561 (39.31%)	341 (36.51%)	.17	313 (37.53%)	316 (37.89%)	.88
Male	866 (60.69%)	593 (63.49%)		521 (62.47%)	518 (62.11%)	
Race						
White	949 (66.50%)	530 (56.75%)	<.001	491 (58.87%)	501 (60.07%)	.95
Black	281 (19.69%)	260 (27.84%)		214 (25.66%)	211 (25.30%)	
Asian	64 (4.48%)	35 (3.75%)		35 (4.20%)	34 (4.08%)	
Other	133 (9.32%)	109 (11.67%)		94 (11.27%)	88 (10.55%)	
Ethnicity						
Hispanic	168 (11.77%)	151 (16.17%)	.002	127 (15.23%)	119 (14.27%)	.58
Non-Hispanic	1259 (88.23%)	783 (83.83%)		707 (84.77%)	715 (85.73%)	
Comorbidity						
Obesity	494 (34.62%)	305 (32.66%)	.32	269 (32.25%)	272 (32.61)	.88
Diabetes	534 (37.42%)	303 (32.44%)	.013	293 (35.13%)	276 (33.09%)	.38
Hypertension	1070 (74.98%)	625 (66.92%)	<.001	576 (69.06%)	579 (69.42%)	.87
Stroke	68 (4.77%)	42 (4.50%)	.76	44 (5.28%)	34 (4.08%)	.25
COPD	36 (2.52%)	8 (0.86%)	.003	4 (0.48%)	6 (0.72%)	.53
Coronary artery disease	181 (12.68%)	99 (10.60%)	.13	90 (10.79%)	86 (10.31%)	.75
Congestive heart failure	166 (11.63%)	120 (12.85%)	.38	96 (11.51%)	100 (11.99%)	.76
Organ transplanted						
Heart	137 (9.60%)	99 (10.60%)	.57	83 (9.95%)	79 (9.47%)	
Kidney	1006 (70.50%)	665 (71.20%)		595 (71.34%)	602 (72.18%)	.98
Liver	254 (17.80%)	148 (15.85%)		139 (16.67%)	136 (16.31%)	
Other	30 (2.10%)	22 (2.36%)		17 (2.04%)	17 (2.04%)	
Years after transplant Mean (SD)	9.00 (7.89)	9.09 (7.57)	.77	9.00 (8.00)	9.23 (7.50)	.53
Immunosuppression						
Mycophenolate	842 (59.00%)	523 (56.00%)	.15	473 (56.71%)	472 (56.59%)	.96
Azathioprine	95 (6.66%)	60 (6.42%)	.82	64 (7.67%)	50 (6.00%)	.17
Prednisone	875 (61.32%)	566 (60.60%)	.73	525 (62.95%)	505 (60.55%)	.31
Tacrolimus	967 (67.76%)	619 (66.27%)	.45	567 (67.99%)	552 (66.19%)	.43
Cyclosporine	110 (7.71%)	56 (6.00%)	.11	50 (6.00%)	54 (6.47%)	.69
Belatacept	130 (9.11%)	71 (7.60%)	.20	72 (8.63%)	66 (7.91%)	.59
Sirolimus	67 (4.70%)	43 (4.60%)	.92	41 (4.92%)	37 (4.44%)	.64
Everolimus	16 (1.12%)	8 (0.86%)	.53	8 (0.96%)	7 (0.84%)	.80
Vaccine received						
Ad26.COV2.S	64 (4.48%)	4 (0.43%)		45 (5.40%)	4 (0.48%)	
mRNA-1273	600 (42.05%)	78 (8.35%)		362 (43.41%)	72 (8.63%)	
BNT162b2	763 (53.47%)	77 (8.24%)		427 (51.20%)	66 (7.91%)	
None	0 (0.00%)	775 (82.98%)		0 (0.00%)	692 (82.97%)	

(Continues)

TABLE 1 (Continued)

	Before propensity score match ($N = 2631$)			After propensity score match ($N = 1668$)		
	Fully vaccinated ($n = 1427$)	Not fully vaccinated ($n = 934$)	p-Value	Fully vaccinated ($n = 834$)	Not fully vaccinated ($n = 834$)	p- Value
Outcomes						
SARS-CoV-2 infection	9 (0.63%)	58 (6.21%)	<.001	9 (1.08%)	30 (3.60%)	<.001
Death from any cause	9 (0.63%)	33 (3.53%)	<.001	4 (0.48%)	15 (1.80%)	.011
Death due to COVID-19	0 (0%)	8 (0.86%)	.001	0 (0%)	2 (0.24%)	.50

Abbreviation: COPD, chronic obstructive pulmonary disease; SARS-CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2.

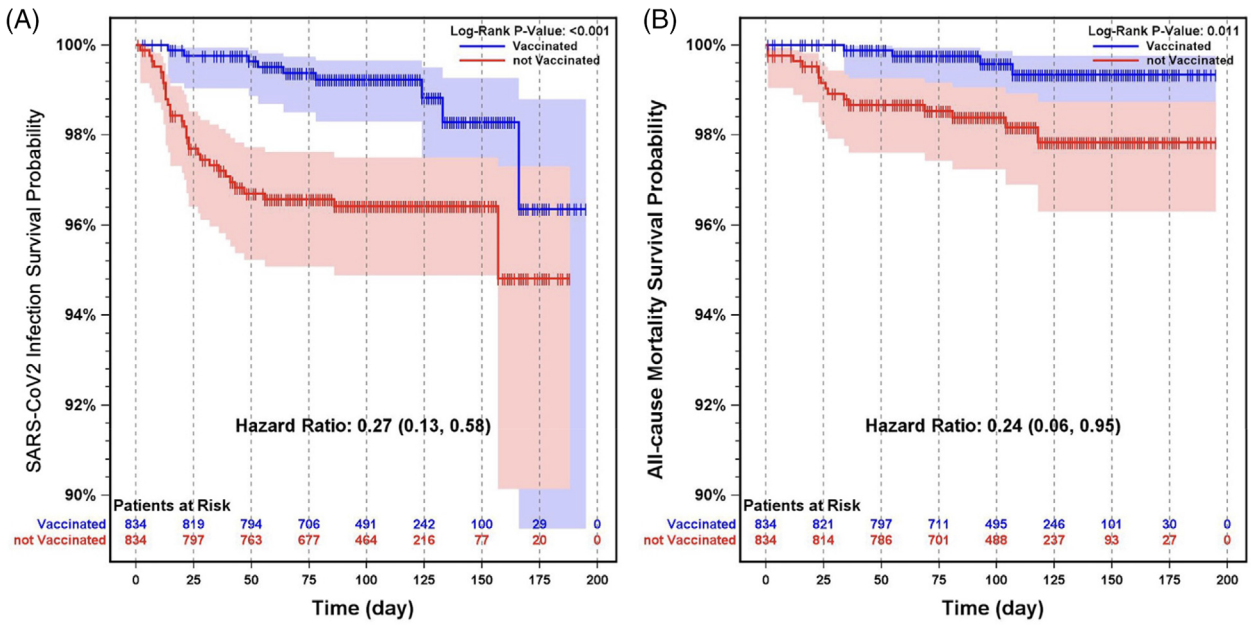

FIGURE 2 Kaplan-Meier curves of Covid infection or all-cause mortality among not fully vaccinated patients (red) compared to vaccinated patients (blue), with adjusted hazard ratios from Cox models

including nine (1.08%) in the fully vaccinated group and 30 (3.60%) in the not fully vaccinated group, including 21 unvaccinated and nine partially vaccinated SOTRs.

Using a Cox regression model, the overall SARS-CoV-2 infection rate was found to be reduced by 73% (95% confidence interval [CI] 42%-87%) in the fully vaccinated group. Kaplan-Meier curve showed that Covid infection rate was significantly lower among fully vaccinated patients, log rank test $p < .001$ (Figure 2A). This was confirmed using a modified Poisson regression model that demonstrated a 72% decrease in the rate of infection among fully vaccinated SOTR (95% CI 40%–87%). Additionally, the all-cause mortality rate was reduced by 76% (95% CI 5%–94%) among fully vaccinated SOTRs using the Cox regression model. Kaplan-Meier curve showed that all-cause mortality rate was significantly lower among fully vaccinated patients, log rank test $p = .01$ (Figure 2B). All Cox and modified Poisson model results are summarized in Table S2.

3.3 | Sensitivity analyses

To further evaluate the protective effect of vaccine, similar analyses were carried out using *unvaccinated group* as control. We found consistent findings with the prior analyses using the *not fully vaccinated* control. After propensity matching, 1658 SOTRs were included (829 fully vaccinated and 829 unvaccinated). Clinical characteristics of SOTRs after propensity matching were balanced between groups and are described in Table S1. Using a Cox regression model, the overall SARS-CoV-2 infection rate was found to be reduced by 62% (95% CI 18%–83%) in the fully vaccinated group compared to the unvaccinated patients. This was confirmed using a modified Poisson regression model that demonstrated a 60% decrease in the rate of infection among fully vaccinated SOTRs (95% CI 13%–82%). Additionally, the all-cause mortality rate was reduced by 79% (95% CI 16%–95%) among fully vaccinated SOTRs using the Cox regression model.

3.4 | Characteristics of SOTR with SARS-CoV-2 infection

Clinical characteristics of the 39 patients with SARS-CoV-2 infection included in the propensity score matching are shown in Table 2.

All nine of the fully vaccinated SOTRs with breakthrough infections had received two doses of an mRNA vaccine (seven received BNT162b2, two received mRNA-1273). The mean time from second vaccination to SARS-CoV-2 infection in this group was 92 days (range 28–180). Of these nine patients, seven (78%) had asymptomatic or mild disease, and two patients had severe disease (requiring up to 5 liters/minute oxygen via nasal cannula). Six patients were not hospitalized, and half of these received monoclonal antibody (MAb) in the outpatient setting. The remaining three patients were hospitalized. One patient with mild disease was hospitalized due to symptoms of COVID-19 with associated delirium and received MAb without progression to severe disease. A second patient who presented with mild COVID-19 was hospitalized and received MAb while inpatient; however, this patient progressed to severe COVID-19 requiring remdesivir, dexamethasone, and tocilizumab and supplemental oxygen via nasal cannula up to 5 liters/minute. The third hospitalized patient who presented with severe disease required supplemental oxygen via nasal cannula up to 5 liters/minute, dexamethasone and remdesivir. None of the fully vaccinated SOTRs with breakthrough infection developed critical disease or died.

In the not fully vaccinated group, 18 (60%) had asymptomatic/mild disease, one patient (3%) had moderate disease, six had severe disease (requiring oxygen via nasal cannula requiring 1 liter/minute to 5 liters/minute), and five had critical disease (requiring mechanical ventilation with maximum 100% fraction of inspired oxygen). Nine of the patients with mild/asymptomatic COVID-19 received MAb in the outpatient setting, and only one of these patients subsequently required hospitalization for COVID-19 symptoms without any progression beyond mild COVID-19. Eighteen SOTRs (60%) were hospitalized due to COVID-19. Of these 18, three SOTRs with mild COVID-19 were hospitalized for reasons unrelated to COVID-19, and three other SOTRs with mild COVID-19 were hospitalized due to COVID-19 symptoms including fevers, diarrhea, and upper respiratory symptoms without development of hypoxemia. Two of the six hospitalized patients with mild COVID-19 received MAb—one received treatment at outpatient setting prior to admission (noted above), and the other received treatment during their hospitalization. Neither of these patients progressed to severe disease. The remaining 12 of 18 hospitalized patients had moderate, severe, or critical COVID-19. Of the six patients with severe disease, three patients had severe disease at the time of presentation, and the other three initially presented with mild disease and received MAb, but then progressed to severe disease requiring oxygen via nasal cannula. Four patients (13%) overall died; all of whom had critical disease. Of these four deaths, two (6.67%) were attributed to COVID-19, one was due to shock of unknown etiology, and one was due to aspiration pneumonia. Both deaths that were not due to COVID-19 did occur during the same hospitalization for COVID-19.

4 | DISCUSSION

Our findings show a 73% reduction in the risk of COVID-19 among fully vaccinated SOTRs after receipt of two-dose mRNA vaccine or one-dose Ad26.Cov2.S. Additionally, vaccination was associated with 76% reduction in all-cause mortality. Our use of propensity score matching reduced the potential influence of major cofounders, which have been associated with worse COVID-19 outcomes.

Among patients with breakthrough SARS-CoV-2 infection, severe/critical disease and death were less common in fully vaccinated SOTRs than the not fully vaccinated SOTRs (severe/critical disease: 22% vs. 37%; death due to COVID-19: 0% vs. 6.67%). Prior studies have reported a high mortality rate of SOTRs with COVID-19 in the prevaccine era, ranging from 18% to 24%.[1–4] The lower death rate in our not fully vaccinated group may have been due to the inclusion of partially vaccinated patients in this group as well as improved treatments for COVID-19 including postexposure monoclonal antibodies and anti-inflammatory therapies such as tocilizumab and baricitinib.[25] Importantly, all COVID-19-related deaths in our study were in unvaccinated patients. COVID-19-related hospitalization was also lower in the vaccinated group (33%) compared to the not fully vaccinated group (60%). Some hospitalizations may have been prevented with the use of monoclonal antibody in the outpatient setting, that is, three patients in the fully vaccinated and nine patients in the not fully vaccinated groups received monoclonal antibody and were not subsequently hospitalized.

While there has been significant interest in measuring the humoral immune response as a surrogate marker for vaccine efficacy, the most important outcomes are clinical endpoints including protection from SARS-CoV-2 infection and severe/critical disease, outcomes that were evaluated in COVID-19 vaccine trials in the general population but not specifically in immunocompromised patients.[5–7] Lack of accounting for cellular immunity is one way in which antibody measurements alone may not fully predict the clinical protectiveness of SARS-CoV-2 vaccination. Studies have shown decreased cellular immunity in SOTRs compared to healthy controls in response to SARS-CoV-2 vaccination.[26,27] However in these same studies, cellular and humoral immune responses did not correlate with each other, with some patients having a robust cellular immune response without a humoral response. The T-cell role in vaccines in general remains poorly understood, due to a number of factors including the lack of approved commercially available assays to measure the T cell response.[28] Additionally, with regard to measuring the humoral immune response to COVID-19 vaccination and infection, validated calibration of cutoffs for many of the wide array of available neutralizing antibody assays is still being investigated—making it difficult to interpret the meaning of a given antibody test.[29] Our results, which show protection from infection, severe/critical disease, hospitalization, and death among fully vaccinated SOTR, suggest that measurement of antibodies should not be the sole surrogate marker for vaccine effectiveness.

Our study has several limitations. The small number of infections in our study may have been related to the relatively high vaccination

TABLE 2 Characteristics of patients with Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) infection

	Fully vaccinated ($n = 9$)	Not fully vaccinated ($n = 30$)	*p*-value
Age – mean (SD)	55.89 (18.22)	58.97 (12.20)	.56
Sex			.44
Male	4 (44.44%)	19 (63.33%)	
Female	5 (55.56%)	11 (36.67%)	
Race			.36
White	4 (44.44%)	18 (60.00%)	
Black	2 (22.22%)	7 (23.33%)	
Asian	1 (11.11%)	0 (0.00%)	
Other	2 (22.22%)	5 (16.67%)	
Ethnicity			.13
Hispanic/Latino	5 (55.56%)	8 (26.67%)	
Non-Hispanic or Latino	4 (44.44%)	22 (73.33%)	
Transplanted organ			.31
Kidney	7 (77.78%)	21 (70.00%)	
Liver	2 (22.22%)	2 (6.67%)	
Heart	0 (0%)	6 (20.00%)	
Kidney-heart	0 (0%)	1 (3.33%)	
Years from transplant – Mean (SD)	5.08 (4.39)	7.03 (6.52)	.41
Maintenance immunosuppression			
Mycophenolate	7 (77.78%)	21 (70.00%)	1.00
Azathioprine	0 (0.00%)	2 (6.67%)	1.00
Tacrolimus	5 (55.56%)	23 (76.67%)	.24
Cyclosporine	1 (11.11%)	3 (10.00%)	1.00
Belatacept	2 (22.22%)	5 (16.67%)	.65
Prednisone	5 (55.56%)	20 (66.67%)	.70
Rejection within 6 months	0	0	
COVID-19-related treatment			
Monoclonal antibody	5 (55.56%)	13 (43.33%)	.71
Remdesivir	2 (22.22%)	8 (26.67%)	1.00
Dexamethasone	2 (22.22%)	12 (40.00%)	.44
Tocilizumab	1 (11.11%)	5 (16.67%)	1.00
Severity of infection			.59
Asymptomatic/mild	7 (77.78%)	18 (60.00%)	
Moderate	0 (0.00%)	1 (3.33%)	
Severe	2 (22.22%)	6 (20.00%)	
Critical	0 (0.00%)	5 (16.67%)	
Hospitalized due to COVID-19	3 (33.33%)	18 (60.00%)	.26
Death	0	4 (13.33%)	.56
Death due to COVID-19	0	2 (6.67%)	1.00

rate in the Connecticut population at the time of this study. Thus, our results may not be generalizable to communities with low vaccination uptake. Vaccinated patients in our study were a maximum of 6 months out from vaccination, and 39% were within 4 months of vaccination, prior to anticipated waning of immunity reported in several studies after around 6 months.[30,31] Of additional importance, the SARS-CoV-2 B.1.617.2 (Delta) variant was predominant in Connecticut during our study period; hence, our findings cannot be extrapolated to infection due to B.1.1.529 (Omicron) or other variants. Our study timeframe did not evaluate for long-term risk of breakthrough infections, which may be affected by waning immunity, changes in variants, changes in public health measures (including vaccination or mask mandates and lockdowns), and ultimately COVID-19 prevalence in the community. Our center does not routinely measure antibodies postvaccination; hence, our data do not evaluate the correlation between antibody response and clinical outcomes. Our study is limited by its retrospective nature. SARS-CoV-2 infection cases may have been underestimated due to the possibility of patient's receipt of care outside of our healthcare system and missing documentation of event. Lastly, the severity of disease among those who developed SARS-CoV-2 infection was ascertained only from the EMR documentation.

Despite concerns of decreased immune response in SOTRs due to the presence of immunosuppression, SARS-CoV-2 vaccine is effective in prevention of severe COVID-19 and death within several months after full vaccination. Vaccination, in addition to other protective strategies, such as masking and early diagnosis, may reduce poor outcomes post-COVID-19 in this vulnerable population. Due to ever evolving SARS-CoV2 variants, future studies should continuously evaluate the efficacy of current vaccine strategies.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

AUTHOR CONTRIBUTIONS

M T contributed to concept/design, drafting of the article data collection, data interpretation, and critical revision of the article. M M A contributed to concept/design and critical revision of the article. E C contributed to data collection and critical revision of the article. G G contributed to statistical analysis, data interpretation, and critical revision of the article. Y G contributed to statistical analysis, data interpretation, and critical revision of the article. C F P contributed to statistical analysis and critical revision of the article. M M contributed to concept/design, data collection, data interpretation, and critical revision of the article.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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