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RESEARCH ARTICLE

COVID Vaccine Immune Response In Hemodialysis Patients

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ABSTRACT

Background: Coronavirus disease 2019 (COVID-19) is associated with increased morbidity and mortality in chronic kidney disease patients, especially those on maintenance hemodialysis (HD). The comparison of immunogenicity of different COVID vaccines in the dialysis populations is lacking especially in the middle east region.

Methods: We conducted a retrospective observational study, that includes 164 hemodialysis patients (HD) and 54 health workers (HW), who received 2 doses of either Pfizer-BioNTech or Sinopharm vaccine. The primary endpoint was to report the rate of seroconversion and the factors affecting it.

Results: HD patients have a significantly low seroconversion rate than HW (HD vs HW: 76.54% and 100%, p=<0.05), also S1 IgG antibody level was significantly low in HD patients (HD vs HW: 183.5 and 400 BAU/ml, p=<0.05). The type of vaccine and hypo-response to the HBV vaccine were two statistically significant factors affecting the seropositivity rate in HD patients. As compared to Sinopharm, Pfizer-BioNTech vaccinated HD patients exhibit not only higher seroconversion rate (Pfizer-BioNTech vs Sinopharm: 90.80% and 60%, p=<0.05) but also express high S1 antibody titer (Pfizer-BioNTech vs Sinopharm: 425 and 162 BAU/ml (p=<0.05), however, there is no significant difference in post-vaccine COVID infection rate among the two vaccines (Pfizer-BioNTech vs Sinopharm: 39.24% and 42.22% (p= 0.176).

Conclusion: Lower Immune response to the COVID vaccine is observed in HD patients as compared to HW participants, also Pfizer-BioNTech vaccinated HD patients exhibit better seroconversion rates and higher antibody titer than Sinopharm vaccine in HD patients, so alternative vaccine strategies should be designed in dialysis patients.

Keywords: Vaccine, Pfizer-BioNTech, Sinopharm, SARS COV-2 spike S1 specific IgG Antibody, seroconversion.

Introduction

During the Coronavirus disease 2019 (COVID-19) pandemic, chronic kidney disease (CKD) patients including renal transplant recipients and those on maintenance hemodialysis (HD) were identified as high risk of patients for severe form of infection (1,2) due to compromised immune response (3), frequent contact with health workers & other patients as well as high burden of comorbid conditions (4). Incidence of COVID-19 infection and its associated mortality rate is higher in HD patients than general population, thus transmission prevention is quite important in these patients (5). Isolation, frequent hand hygiene, social distancing and use of face masks are some of the transmission control measures which are in place, however, are not proven as useful as vaccination (6). Newly introduced SARS-COV-2 vaccines generated antibodies in hemodialysis patients but lower than in the general population (7). Seroconversion is a marker of immunogenicity and achieving seroconversion for a long time is the main goal of vaccination. In patients to achieve this goal, different strategies were used previously including a doubling of dose, the use of adjuvants and additional dosage applications (8). Nonetheless, HD populations have a different immune profile (9). The basic idea of this study is to analyze the humoral immune response to SARS-COV-2 vaccines in HD patients over 3 months and the factors affecting it, and to compare the immune response with healthy controls.

Material and Methods:

STUDY DESIGN:

This retrospective observational study was carried out between 1st March 2021 to 31st Dec.2022 in the Nephrology department of Dubai Hospital. Those hemodialysis and health workers (Doctors and nursing staff) were inducted voluntarily into the study and received two doses of either Pfizer-BioNTech (30 µg of BNT162b2 developed by Pfizer-BioNTech) or Sinopharm (BBIBP-CorV developed by Sinopharm's Beijing Institute of Biological Products, China) vaccines 28 days apart. Vaccine choice was based on patients' and health workers (HW) choices. Inclusion criteria were participants aged above 15 years, while those with a history of allergy to vaccine, on immunosuppressive or corticosteroids, renal transplant recipients, chronic kidney disease stage I-IV and those who receive one dose of vaccine were excluded from the study. The primary endpoint was to observe the difference in immune response for the COVID vaccine not only between the health workers and hemodialysis patients but also between Pfizer-BioNTech and Sinopharm vaccinated hemodialysis patients and factors associated with it. Additionally, to report the incidence of seropositivity in dialysis patients and study risk factors determining low immune response. Blood samples were collected 28 days and 3 months after the second dose of vaccine to determine the immunogenicity and safety.

SARS COV-2 SPIKE S1 SPECIFIC IGG ANTIBODY:

Validated fluorescent bead-based multiplex immunoassay was used to measure SARS COV-2 spike S1 specific IgG Antibody in serum samples, having sensitivity and specificity of 99.7% and 91.6% respectively. Reference serum values were expressed as international binding antibody units (BAU/ml). These antibodies were measured at baseline for exclusion of subjects with a history of SARS-COV 2 infection, after 28 days and 3 months after the second dose of the COVID vaccine. A threshold reference value of 28 BAU/ml for SARS COV-2 spikes S1 specific IgG Antibody was used to classify participants as responders.

STATISTICAL METHODS:

Continuous variables are described as mean ± standard deviation and median with interquartile range values for normally distributed and non-normally distributed data, respectively. Categorical variables were presented as frequency and percentage. Independent *t* test and Mann-Whitney test were used for normally distributed and non-normally distributed continuous variables, respectively, and categorical data were compared with help of Pearson's $\chi 2$ test or Fischer's exact test. The correlation between risk factors and PTDM was analysed by Cox regression, where PTDM was considered a time-dependent variable because this complication started at different times following the transplant. A *p* value of <0.05 was considered statistically significant. SPSS version 20 was used for statistical analysis.

Results

The study population (Health workers or hemodialysis patients) received two doses of either the Sinopharm vaccine or Pfizer-BioNTech vaccine 28 days apart. Vaccine selection was based on patient and HW preferences.

BASELINE CHARACTERISTICS AND IMMUNE RESPONSE OF HEALTH WORKERS AND HEMODIALYSIS PATIENTS (TABLE NO: 1)

SARS COV-2 spike S1 specific IgG Antibody was compared in hemodialysis (HD) patients with health workers (HW). There were 162 HD patients and 52 HW. The median age for HD patients and HW

population was 58 (45.25-69) and 50 (38.75-55) (p=<0.05) years respectively. Male patients were more in the HD group (HD vs HW: 61.72 and 19.23 %, p= <0.05). There were predominantly Arabs (n=148,91.36%) and Asians (n=48,92.30%) in HD and HW groups respectively. Hypertension was the most common co-morbid in HD patients (HD vs HW: 79.62 and 15.38%, p=<0.05), while diabetes was predominant in HW patients (HD vs HW: 60.49 and 34.61%, p= <0.05). In HD and HW groups, 87(53.70%) and 48 (92.30%) patients were vaccinated with Pfizer-BioNTech and 75 (46.29%) and 4 (7.69%) patients received the Sinopharm vaccine respectively. The seropositivity rate among HD patients was 76.54% (n=124) and 100% (n=52) (p=<0.05) in the HW group. Median S-antibody titer in seropositive patients in both groups was 183.5 (44-993.3) and 400 (167-723) BAU/ml in HD and HW populations respectively (p= <0.05). After 3 months of vaccination, the seropositivity rate among HD pts decreases to 73.45%. Mean globulin level was 3.32±0.69 and 3±0.35 g/dl (p=0.07) and median serum albumin level was 4 (3.60-4.15) and 4.5 (4.2-4.6) g/dl (p=<0.05) in HD and HW groups respectively.

Table no: 1. Baseline characterstics of Health workers (HW) & Hemodialysis patients (HD).

	HD patients(n=162)	**Health workers(n=52)**	**p value**
Ethnicity			0.83
UAE	124(76.54)	1(1.92)	
Arab	24(14.81)	3(5.76)	
Non Arab	14(8.64)	48(92.30)	
Age in years, median (IQR)	58 (45.25-69)	50(38.75-55)	<0.05
≤ 40 years	28(17.28)	13(25)	
41-60 years	64(39.50)	39(75)	
> 60 years	70(43.20)	0(0.0)	
Gender			<0.05
Male	100(61.72)	10(19.23)	
Female	62(38.28)	42 (80.77)	
Vaccine			
Pfizer	87(53.70)	48(92.30)	
Sinopharm	75(46.29)	4(7.69)	
Immune response			<0.05
Seronegative	38(23.46)	0(0.0)	
Seropositive	124(76.54)	52(100)	
COVID Ab, median (IQR)	183.5(44-993.3)	400(167-723)	<0.05
co-morbid			
Diabetes mellitus	98(60.49)	18(34.61)	<0.05
Hypertension	129(79.62)	8(15.38)	<0.05
ADPKD	3(1.85)	0(00)	
ANCA	2(1.23)	0(00)	
FSGS	4(2.49)	0(00)	
Psoriasis	1(0.61)	0(00)	
SLE	3(1.85)	0(00)	
Memranous nephropathy	1(0.61)	0(00)	
Cystinosis	1(0.61)	0(00)	
Chronic Allograft nephropathy	21(12.96)	0(00)	
Globulin, mean (SD)	3.32±0.69	3±0.35	0.07
< 2.8	23(14.19)	10(19.23)	
≥2.8	139(85.80)	42(80.76)	
Albumin median	4(3.60-4.15)	4.5(4.2-4.6)	<0.05
<3.4	16(9.87)	0(00)	
≥ 3.4	146(90.12)	52(100)	

SEROPOSITIVE AND SERONEGATIVE HEMODIALYSIS PATIENTS (TABLE NO: 2):

The seropositivity rate among HD patients was 76.54% (n=124). The median age of seropositive and seronegative HD patients is 56.23 (±15.93) and 58.97 (±14.59) years respectively (p=0.34). Pfizer-BioNTech vaccinated HD patients exhibit significantly higher seropositivity rates than other patients, {Pfizer-BioNTech vs Sinopharm: 90.80% (n=79) and 60% (n=45), p=<0.05}. Hypertension and diabetes mellitus were the two most common comorbid in both seropositive {HTN and DM: 79.03% (n=98) and 60.48% (n=75) respectively} and seronegative {HTN and DM: 81.57% (n=31) and 60.52% (n=23) respectively} HD patients. 39.47% (n=15) seronegative HD patients had a concomitant seronegative immune response to hepatitis B vaccine (p=<0.05), while the mean globulin level for both groups was statistically insignificant: 3.10 (2.7-3.5) and 3(2.7-3.3) in seropositive and seronegative HD patients respectively (p=0.104).

Table No:2. Comparison of Characteristics of seropositive & seronegative HD patients.

	Seropositive (n=124,76.54%)	**Seronegative (n=38, 33.46%)**	
Ethniciity			0.275923
UAE	90(72.58)	34(89.47)	
Arab	20(16.12)	2(5.26)	
Non Arab	14(11.29)	2(5.26)	
Age in years, mean (SD)	56.23±15.93	58.97± 14.59	0.34606
≤ 40 years	19(15.32)	2(5.26)	
40-60 years	55(44.35)	17(44.73)	
> 60 years	50(40.32)	19(50)	
Gender			
Male	77(62.09)	23(60.52)	0.861663
Vaccine			<0.05
Pfizer	79(63.70)	8(21.05)	
Sinopharm	45(36.29)	30(78.94)	
co-morbid			
Diabetes mellitus	75(60.48)	23(60.52)	0.996264
Hypertension	98(79.03)	31(81.57)	0.733086
ADPKD	3(2.41)	0(00)	0.333128
ANCA	0(00)	2(5.26)	0.010153
FSGS	3(2.41)	1(2.63)	0.941205
Psoriasis	1(0.80)	0(00)	0.578691
SLE	3(2.41)	0(00)	0.333128
Memranous nephropathy	1(0.80)	0(00)	0.578691
Cystinosis	1(0.80)	0(00)	0.578691
Chronic Allograft nephropathy	6(4.83)	6(15.78)	<0.05
Globulin, mean (SD) (n=153)	3.10(2.7-3.5)	3(2.7-3.3)	0.104218
< 2.8	30(24.19)	14(36.84)	
≥2.8	94(75.81)	24(63.16)	
Albumin median (IQR) (n=152)	3.90(3.6-4.15)	3.95(3.7-4.10)	0.469837
<3.4	16(12.90)	3(7.89)	
≥ 3.4	108(87.09)	35(92.11)	
Hyporesponse to HBV vaccine			<0.05
Yes	24(19.35)	15(39.47)	
No	120(80.65)	23(60.53)	

SEROPOSITIVITY AND VACCINE TYPE IN HD PATIENTS (TABLE NO: 3):

The seropositivity rate for Pfizer-BioNTech and Sinopharm vaccines among HD patients was 90.80% (n=79) and 60% (n=45) respectively (p=<0.05). The median age was 59 (46-68) for Pfizer seropositive and 53 (41-65) (p=0.36) years for Sinopharm seropositive HD patients (p=0.36).

The predominant gender in both seropositive groups was male [Pfizer-BioNTech vs Sinopharm: 50 (63.29) vs 27 (60), p= 0.71]. Arabs were predominantly in both groups [Pfizer-BioNTech vs Sinopharm: 70(88.60) vs 69(91.11), p= 0.60}. There is a significant median S Ab titer between the two vaccine seropositive groups: 425(208-2080) for Pfizer-BioNTech and 162(75-548) (p=<0.05) for Sinopharm. After a 3-month follow-up period, Pfizer-BioNTech vaccinated seropositive HD patients' median S Ab titer drop to 392(164-2080), however, it was not uniform. There was a median percent increase in the Ab titer up to 38.17% (3.78-170.70) observed in 42 (52.50%) patients, and a median percent drop in Ab titer of 62.20 % (23-81) in 23 (28.75%) patients, while there was no difference in Ab titer in 15 (18.75%) patients. On the other hand, in the Sinopharm vaccinated HD patients, the median S Ab titer dropped to 122 (463). There was a median percent increase in Ab titer in 26 patients to 26.31% (38.43-149.56), while there was a drop in Ab titer in 26.31% (35.65-158.18) in 20 patients. Post-vaccine COVID infection was observed in 39.24% (n=31) and 42.22% (n=19) in HD patients vaccinated with Pfizer-BioNTech and Sinopharm respectively (p=0.176).

Table no.3: Comparison of characteristics of seropositive patients between two vaccines.

	Seropositive pfizer: 79(90.84)	Seropositive Sinopharm: 45 (60)	
Age in years, median (IQR)	59 (46-68)	53 (41-65)	0.36
Gender			
Male	50(63.29)	27(60)	0.71
COVID Ab1, median (IQR)	425(208-2080)	162(75-548)	<0.05
COVID Ab2, median (IQR)	392(164-2080)	122(66-755)	0.168043981
co-morbid			
Diabetes mellitus	45(56.96)	30(66.66)	0.287839451
Hypertension	63(79.74)	35(77.77)	0.795640024
ADPKD	3(3.79)	0(00)	0.185722278
ANCA	0(00)	0(00)	0.91
FSGS	3(3.79)	0(00)	0.185722278
Psoriasis	1(1.26)	0(00)	0.448574486
SLE	3(3.79)	0(00)	0.185722278
Memranous nephropathy	0(00)	1(2.22)	0.448574486
Cystinosis	0(00)	1(2.22)	0.448574486
Chronic Allograft nephropathy	9(10.34)	12(16)	0.73
Globulin, mean (SD)	3.11±0.68	3.30±0.70	0.164641022
< 2.8	2(27.84)	6(13.33)	
≥2.8	57(72.15)	3(86.66)	
Albumin, mean (SD)	3.79±0.64	3.77±0.51	0.861258782
<3.4	11(13.92)	5(11.11)	
≥ 3.4	68(86.07)	40(88.89)	
HbsAb median (IQR)	100(3.95-490)	176(47-999)	0.051589393
≤100	35(44.30)	12(26.67)	
>100	44(55.69)	33(73.34)	
COVID infection (post-vaccine)	31(39.24)	19(42.22)	0.744833846
Immune respone with time interval			
	Pfizer	Sinopharm	
Increase (n=18)	38.17(132)%	26.31(122.53)	n=26
Decrease (n=11)	5.55(24)%	24.69(99.82)	n=20
Same (n=2)			n=1
Globulin & COV	Pfizer	Sinopharm	<2.8
< 2.8	264 (1507)	24.8(95.75)	264 (1507)
≥ 2.8	862 (1656)	86 (380.5)	24.8(95.75)

GLOBULIN, ALBUMIN, HEPATITIS B SURFACE AB AND VACCINE TYPE (TABLE: NO:)

The mean globulin level in seropositive Pfizer-BioNTech and Sinopharm vaccinated HD patients was 3.11±0.68 and 3.30±0.70 g/dl (p=0.16) respectively. Also, the mean serum Albumin level for seropositive Pfizer-BioNTech and Sinopharm vaccinated HD patients was 3.79±0.64 and

3.77±0.51 respectively, however, this difference was not significant statistically (p=0.86). Hypo responsiveness to Hepatitis B vaccine in seropositive Pfizer-BioNTech HD patients is significantly more than their counterpart {Pfizer-BioNTech vs Sinopharm: 44.30% (n=35) and 26.67% (n=12), (p=0.0515).

Table no:4. Univariate & Multivariate regression analysis of factors affecting seropositivity among HD patients:

Table no:4. Univariate & Multivariate regression analysis of factors affecting seropositivity among HD patients:						
	Univariate			Multivariate		
	OR	CI	p-value	OR	CI	p-value
Age	5.545	0.686-36.923	0.084			
Male gender	2.452	0.667-2.189	0.503			
Type of vaccine (pfizer)	29.887	4.096-179.998	0.003	31.654	4.178-199.002	0.003
Co-morbid						
Diabetes	0.236	0.111-0.695	0.004	0.495	0.158-2.112	0.89
Hypertension	0.558	0.226-1.338	0.155			
Hyporesponse for HBV vaccine	0.115	0.040-0.362	0.001	0.23	0.090-0.852	0.05

Discussion

COVID-19 infection in HD patients is associated with high mortality and morbidity (10,11). We reported 16.67% mortality in our hemodialysis population (12). Poor vaccine immunogenicity is observed in end-stage kidney disease (ESKD) patients due to weak Immune response (3). Despite the induction of seroconversion in ESKD patients by the newly developed SARS-COV-2 vaccine, it is not well-known if that seropositivity will prevail for a longer duration. The seropositivity rate in our HD population was 76.54%, which was significantly lower than the HW group, however, it decreased to 72.83% after 3 months of follow-up. Seropositivity rates of up to 99% were reported in the dialysis population (13). In our hemodialysis population, the vaccine type predicts immune response. We observed that Sinopharm vaccinated HD patients not only exhibit statistically significant lower seropositivity rate {Pfizer-BioNTech vs Sinopharm: 90.84% (n=79) and 60% (n=45), p=<0.05}, but also it lacks stability: responder status dropped to 52% after 3 months follow up. Ahmed and Clavero et al also reported similar observations about the immune response to the inactivated vaccine (CoronaVac®) (73.6% and 51.97% respectively) in Turkish and Chile hemodialysis patients, also seropositivity rate dropped to 44.4% in Turkish patients in follow up period (14,15). We observed a significant difference in median anti-S antibody titer among HD patients receiving the inactivated vaccine and mRNA vaccine (HD patients Pfizer-BioNTech vs Sinopharm: 425 vs 162, p=<0.05). Alqassieh et al also found a difference in the antibody response between the two vaccines, though anti-S Ab titer for the Sinopharm vaccine was comparable between the two populations (16). However, the antibody response did not remain stable and overall, both vaccines demonstrated a significant drop in titer (Pfizer-BioNTech vs Sinopharm: 392, 122, p=0.116). This change in antibody titer was not uniform in both groups. In the follow-up period, Anti S antibody titer increased in 52.5% and 54.16% in Pfizer-BioNTech and Sinopharm-vaccinated HD patients respectively, while titers decreased in 28.75% and 44.44% HD patients vaccinated with Pfizer-BioNTech and Sinopharm respectively. Despite differences in the magnitude of antibody titer and seropositivity, breakthrough infection incidence was higher in both vaccinated HD populations (Pfizer-BioNTech vs Sinopharm: 39.24 and 42.22%, p=0.17). Virus variants were not identified in our study, however, Kislaya found a lower effectiveness of m-RNA vaccines in preventing infection with delta variant (17). Patients on hemodialysis have a distinctively less resilient response to vaccines such as pneumococcal, Hepatitis B, and influenza evident by lower seroconversion rate and rapid decline in antibody titer than healthy individuals (18). We observed that hypo responsiveness to the hepatitis B vaccine was significantly associated with poor immune response, 39.47% of our seronegative HD patients, there was concomitant hyporesponse to the hepatitis B vaccine (p=<0.05, table 3). Angel et al

demonstrate weak association between anti HBsAb titer & serologic response to COVID vaccine (19), whereas Danthu et al showed that non responder to hepatitis B vaccine had lowest antibody titer for COVID vaccine (20). Jens van also found serum albumin, immunosuppressive therapy, lymphocyte count, and hepatitis B non-responder status to be independent factors affecting immune response to m-RNA vaccines in the dialysis population (21).

Our study has certain limitations, Immunity decay cannot be proved in our study as it requires serial antibody level checking. Additionally, the number of participants was low, also cross-reactivity of SARS COV-2 spike S1 specific IgG Antibody with other endemic coronaviruses is reported, hence affecting test reliability (22).

Conclusion

The Pfizer-BioNTech vaccine induced a better seroconversion rate and antibody magnitude than Sinopharm. However, Hemodialysis patients showed a low seroconversion rate. In order to enhance their immunity against COVID infection, higher vaccination doses, booster doses, frequent antibody sera checking, or adjuvants should be used.

Ethics statement

The study was approved by Dubai Scientific Research Ethics Committee, DSREC-05/2022_05, Date June 15, 2022. The requirement of informed patient consent was waived by the ethical committee since the nature of the study was observational and retrospective. We took a waiver for publications from the ethics committee, and also, patient's de-identified data used in this research were carried retrospectively.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Hilbrands LB, Duivenvoorden R, Vart P, et al. COVID-19-related mortality in kidney transplant and dialysis patients: results of the ERACODA collaboration. Nephrology Dialysis Transplantation. 2020;35(11):1973-1983. doi:https://doi.org/10.1093/ndt/gfaa261
2. Chen JJ, Lee TH, Tian YC, Lee CC, Fan PC, Chang CH. Immunogenicity Rates After SARS-CoV-2 Vaccination in People With End-stage Kidney Disease. *JAMA Network Open*. 2021;4(10):e2131749. doi:https://doi.org/10.1001/jamanetworkopen.2021.31749.
3. Pitchou Kengibe, J.R. Makulo, Yannick Mayamba Nlandu, et al. Response to single dose hepatitis B vaccine in Congolese non-HIV hemodialysis patients: a prospective observational study. 2019;34. doi:https://doi.org/10.11604/pamj.2019.34.122.19603
4. Naicker S, Yang CW, Hwang SJ, Liu BC, Chen JH, Jha V. The Novel Coronavirus 2019 epidemic and kidneys. *Kidney International*. Published online March 2020. doi:https://doi.org/10.1016/j.kint.2020.03.001
5. Cancarevic I, Nassar M, Daoud A, et al. Mortality rate of COVID-19 infection in end stage kidney disease patients on maintenance hemodialysis: A systematic review and meta-analysis. *World journal of virology*. 2022;11(5):352-361. doi:https://doi.org/10.5501/wjv.v11.i5.352)
6. DaRoza G, Loewen A, Ognjenka Djurdjev, et al. Stage of chronic kidney disease predicts seroconversion after hepatitis B immunization: earlier is better. *American Journal of Kidney Diseases*. 2003;42(6):1184-1192. doi:https://doi.org/10.1053/j.ajkd.2003.08.019
7. Grupper A, Sharon N, Finn T, et al. Humoral Response to the Pfizer BNT162b2 Vaccine in Patients Undergoing Maintenance Hemodialysis. *Clinical Journal of the American Society of Nephrology*. Published online April 6, 2021:CJN.03500321. doi:https://doi.org/10.2215/cjn.03500321
8. Chiew Tong NK, Beran J, Kee SANN, et al. Immunogenicity and safety of an adjuvanted hepatitis B vaccine in pre-hemodialysis and hemodialysis patients. *Kidney International*. 2005;68(5):2298-2303. doi:https://doi.org/10.1111/j.1523-1755.2005.00689.x
9. Liu YL, Kao MT, Huang CC. A comparison of responsiveness to hepatitis B vaccination in patients on hemodialysis and peritoneal dialysis. *Vaccine*. 2005;23(30):3957-3960. doi:https://doi.org/10.1016/j.vaccine.2005.02.033
10. Taji L, Thomas D, Oliver MJ, et al. COVID-19 in patients undergoing long-term dialysis in Ontario. *CMAJ*. 2021;193(8):E278-E284. doi:https://doi.org/10.1503/cmaj.202601
11. Jager KJ, Kramer A, Chesnaye NC, et al. Results from the ERA-EDTA Registry indicate a high mortality due to COVID-19 in dialysis patients and kidney transplant recipients across Europe. *Kidney International*. 2020;98(6):1540-1548. doi:https://doi.org/10.1016/j.kint.2020.09.006
12. Ram DKN, Gulzar K, Alalawi F, Ahmed M, Manuel R, Alhadari A. COVID-19 infection in hemodialysis patients, incidence, risk factors and mortality. Single Centre Study. *New Emirates Medical Journal*. 2022;03. doi:https://doi.org/10.2174/0366622081714570 7
13. Dinits-Pensy M, Forrest GN, Cross AS, Hise MK. The Use of Vaccines in Adult Patients With Renal Disease. *American Journal of Kidney Diseases*. 2005;46(6):997-1011. doi:https://doi.org/10.1053/j.ajkd.2005.08.032
14. Murt A, Dinc HO, Altiparmak MR, et al. Waning of SARS-CoV-2 Vaccine-Induced Immune Response over 6 Months in Peritoneal Dialysis Patients and the Role of a Booster Dose in Maintaining Seropositivity. *Nephron*. 2022;146(6):559-563. doi:https://doi.org/10.1159/000524658
15. Clavero R, Parra-Lucares A, Méndez-Valdés G, et al. Humoral Immune Response of BNT162b2 and CoronaVac Vaccinations in Hemodialysis Patients: A Multicenter Prospective Cohort. 2022;10(9):1542-1542. doi:https://doi.org/10.3390/vaccines10091542
16. Alqassieh R, Suleiman A, Abu-Halaweh S, et al. Pfizer-BioNTech and Sinopharm: A Comparative Study on Post-Vaccination Antibody Titers. *Vaccines*. 2021;9(11):1223. doi:https://doi.org/10.3390/vaccines9111223
17. Kislaya I, Rodrigues EF, Borges V, et al. Comparative Effectiveness of Coronavirus Vaccine in Preventing Breakthrough Infections among Vaccinated Persons Infected with Delta and Alpha Variants. *Emerging Infectious Diseases*. 2022;28(2):331-337. doi:https://doi.org/10.3201/eid2802.211789

18. Sanders JSF, Bemelman FJ, Messchendorp AL, et al. The RECOVAC Immune-response Study: The Immunogenicity, Tolerability, and Safety of COVID-19 Vaccination in Patients With Chronic Kidney Disease, on Dialysis, or Living With a Kidney Transplant. *Transplantation*. 2021;106(4):821-834. doi:https://doi.org/10.1097/tp.0000000000003983
19. Angel-Korman A, Peres E, Bryk G, et al. Diminished and waning immunity to COVID-19 vaccination among hemodialysis patients in Israel: the case for a third vaccine dose. *Clinical Kidney Journal*. Published online October 12, 2021. doi:https://doi.org/10.1093/ckj/sfab206)
20. Danthu C, Hantz S, Dahlem A, et al. Humoral Response after SARS-CoV-2 mRNA Vaccination in a Cohort of Hemodialysis Patients and Kidney Transplant Recipients. *Journal of the American Society of Nephrology*. 2021;32(9):2153-2158. doi:https://doi.org/10.1681/asn.2021040490
21. Van Praet J, Reynders M, De Bacquer D, et al. Predictors and Dynamics of the Humoral and Cellular Immune Response to SARS-CoV-2 mRNA Vaccines in Hemodialysis Patients: A Multicenter Observational Study. *Journal of the American Society of Nephrology*. 2021;32(12):3208-3220. doi:https://doi.org/10.1681/asn.2021070908
22. Nagappa B, Marimuthu Y. Seroconversion Rate and Diagnostic Accuracy of Serological Tests for Coronavirus 2019. *Clinical Infectious Diseases*. Published online May 30, 2020. doi:https://doi.org/10.1093/cid/ciaa676