



COVID-19 in children and young adults with kidney disease: risk factors, clinical features and serological response

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Abstract

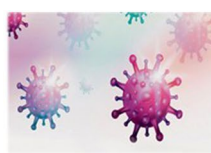
Background Chronic kidney disease (CKD) and kidney transplantation in adults are well-recognized risk factors for coronavirus disease 2019 (COVID-19) associated morbidity and mortality. Data on the toll of the pandemic on children and young adults with kidney disease is scarce. The aim of this study was to assess the incidence and severity of COVID-19, as well as the serological response, in this population.

Methods Study population included all patients with CKD stage 3–5, glomerular disease treated with immunosuppression and kidney transplant recipients followed-up at a tertiary medical center, between 1.12.2020 and 15.2.2021. Data collected included PCR testing, symptoms, exposure, and socio-demographic data. Anti-SARS-CoV-2 antibodies were tested.

Results A total of 197 children and 63 young adults were included, 57% were Jewish, 43% were Arab. PCR-confirmed COVID-19 incidence was 20.8%, 37% of cases were asymptomatic, three patients were hospitalized for observation, and the remainder had mild symptoms. Kidney function remained stable without treatment modification. Risk factors for infection included exposure at home (OR 15.4, 95% CI 6.9–34.2) and number of household members (OR 1.45, 95% CI 1.21–1.73). Anti-SARS-CoV-2 antibodies were detected in 61% of cases and were not associated with COVID-19 severity or immunosuppressive therapy. Three patients who did not develop antibodies had a mild recurrent infection.

Conclusions Unlike COVID-19 in adult patients with kidney disease, in our cohort of children and young adults, COVID-19 incidence was similar to the general population and all cases were mild. It may be unnecessary to impose severe restrictions on this patient population during the pandemic.

Graphic abstract



COVID-19 in Children and Young Adults with Kidney Disease



- 197 children and 63 young adults with kidney disease, including CKD, glomerular disease and kidney transplant recipients
- PCR-confirmed COVID-19 incidence 20.8%
- Risk factors for infection – exposure at home, number of household members
- 37% asymptomatic, 1 patient moderate disease, the remainder – mild symptoms
- No treatment modification
- Kidney function stable
- 3 cases of recurrent COVID-19 infection



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Extended author information available on the last page of the article

Keywords COVID-19 · Children · CKD · Kidney transplantation · Nephrotic syndrome

Introduction

The coronavirus disease 2019 (COVID-19) pandemic, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has affected millions of people worldwide since early 2020. Risk factors for COVID-19-related deaths in adults include increased age and comorbidities, including diabetes mellitus, obesity and malignancy [1]. Chronic kidney disease (CKD), particularly in its advanced stages, is a risk factor for COVID-19-attributable mortality in adults. Adult patients waitlisted for kidney transplantation had a 20% risk of death after testing positive for SARS-CoV-2 [2], while adult dialysis patients hospitalized with COVID-19 had a 31% mortality rate [3]. Although kidney transplantation improves life expectancy dramatically as well as quality of life, compared to dialysis, lifelong immunosuppression puts patients at risk for infections. Incidence of COVID-19 is higher in adult kidney transplant recipients (KTRs), there is an increased risk of complications, including acute kidney injury and need for mechanical ventilation, and a mortality rate of 20–32% [2, 4–7].

Over time it has become clear that pediatric cases of COVID-19 are more common than initially assumed, although many cases are asymptomatic or mild [8]. Nevertheless, some children have severe manifestations of COVID-19, leading to admission to the intensive care unit (ICU), up to 75% of complicated cases are associated with comorbidities [9]. A unique clinical entity in children and adolescents is SARS-CoV-2-related Multisystem Inflammatory Syndrome in Children (MIS-C), which is thought to be due to immune dysregulation after acute COVID-19.

There is a paucity of data regarding the incidence, clinical manifestations and outcomes of COVID-19 in children with CKD and pediatric KTRs. Our center serves the Greater Jerusalem area, with a population of over 1 million people, and is the only pediatric dialysis and kidney transplant clinic for this region. The aim of this study was to assess the incidence and severity of COVID-19 and anti-SARS-CoV-2 antibody response in our patient population, by actively evaluating all current patients with a diagnosis of stage 3–5 CKD, KTR or glomerular disease treated with immunosuppressive medication.

Methods

In this retrospective study, the electronic medical records of all patients followed at our pediatric nephrology clinic in Shaare Zedek Medical Center (SZMC), Jerusalem, Israel were reviewed. Inclusion criteria were all patients <20 years

of age followed at our pediatric nephrology clinic, with one of the following diagnoses: CKD stage 3–5 (glomerular filtration rate < 60 mL/min/1.73 m²), KTR, or immune-mediated glomerular disease treated with immunosuppression (GD). In the young adult group, inclusion criterion was age 20–35 year-old KTRs who underwent transplantation as children and continue to be followed at our center.

During the study period between December 1, 2020 and February 15, 2021, patients who fulfilled the inclusion criteria were seen at our clinic. Patients filled in a structured questionnaire which included demographic data, number of inhabitants in the home, school attendance during the pandemic, COVID-19 exposure, symptoms and nasal / oropharyngeal real-time polymerase chain reaction (PCR) COVID-19 testing (for questionnaire, see supplemental data). All PCR swabs were performed due to symptoms suggestive of COVID-19 or exposure to a confirmed case, most were done at local clinics and results were available through the Israeli computerized health care information sharing system (“Ofek”). Patients who tested positive for COVID-19 were followed by their health care organization, including daily reporting of body temperature and pulse oximetry. The pediatric nephrology team was usually consulted by the family physician after diagnosis.

The patient’s medical record was reviewed for renal function, comorbidities and medications, including immunosuppression and renin angiotensin aldosterone system (RAAS) inhibitors. Parents or patients over 18 years provided informed consent for study participation. Laboratory testing was routinely performed at the hospital as part of the clinic visit, and an additional test tube was obtained for serological testing.

Serology was performed at SZMC, using chemiluminescent microparticle immunoassay (Abbott, Ireland) for detection of IgG antibodies to the nucleocapsid protein of SARS-CoV-2 in patients’ serum. Positive results were further verified by a test to detect IgG antibodies against SARS-CoV-2 spike proteins S1/S2 (Diasorin Liason, Italy). Patients with positive serology underwent repeated antibody testing at subsequent clinic visits to assess antibody persistence. No serological tests were done after COVID-19 vaccination. COVID-19 severity was graded as asymptomatic, mild (symptoms not requiring any intervention), moderate (dyspnea or abnormal chest X-ray, oxygen saturation \geq 94% in room air), severe (oxygen saturation < 94% or any need for oxygen or other respiratory support) [10]. The study was approved by the institutional review board of SZMC.

Data are presented as mean and standard deviation or median and interquartile range. Comparisons within the patient group were performed using the Student’s t-test and

Table 1 Patients’ clinical characteristics

	Patients with COVID-19* (n = 71)	Patients without COVID-19 (n = 189)	All patients (n = 260)
Age, y (mean ± SD)	15.5 ± 7.9	13.8 ± 7.8	14.3 ± 7.8
Age			
0–9 y	16 (23)	67 (35)	83 (32)
10–19 y	35 (49)	79 (42)	114 (44)
20–35 y	20 (28)	43 (23)	63 (24)
Male	40 (56)	124 (66)	164 (63)
Patient group			
CKD	21 (30)	71 (37)	92 (36)
Glomerular disease	20 (28)	41 (22)	61 (23)
Kidney transplantation	30 (42)	77 (41)	107 (41)

Glomerular disease group included 47 patients with idiopathic nephrotic syndrome, four with atypical hemolytic uremic syndrome, three with membranoproliferative glomerulonephritis, two with IgA nephropathy, two with membranous nephropathy, and one each with focal segmental glomerulosclerosis, ANCA vasculitis and Henoch-Schonlein nephritis

y years

*Patients with COVID-19 include PCR-confirmed and serologically diagnosed cases. Values are patient number (%) unless otherwise noted

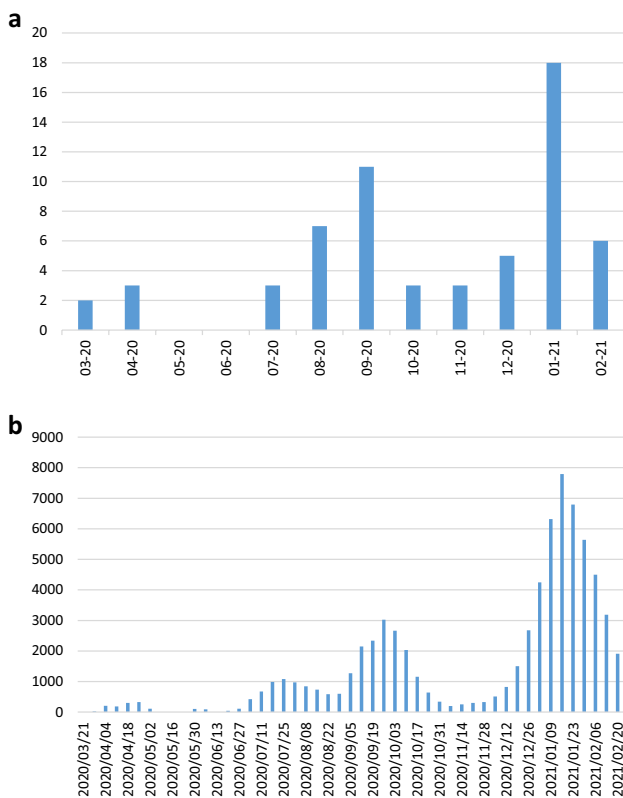


Fig. 1 Temporal trends in SARS-CoV-2 infection March 2020–February 2021. **a** In patient cohort, by month. Ten patients (14%) were diagnosed with COVID-19 by antibody testing alone and it was therefore not possible to know the date of infection. **b** In the Jerusalem area, ages 0–19 years, by week

Table 2 COVID-19 characteristics (number (%))

Diagnosis	
Viral PCR testing	54 (76)
Two antibody assays	10 (14)
Antibody assay + clinical history	7 (10)
Disease severity	
Asymptomatic	34 (48)
Mild	36 (51)
Moderate	1 (1)
Severe	0 (0)
Symptoms	
Cough	14 (20)
Fever	13 (18)
Headache	9 (13)
Dysgeusia/anosmia	8 (11)
Fatigue	6 (8)
Malaise	6 (8)
Rhinorrhea	6 (8)
GI symptoms	6 (8)
Dyspnea	4 (6)

logistic regression model. Incidence of SARS-CoV-2 infection was compared to the overall incidence in the Jerusalem area using data from the Israeli Central Bureau of Statistics [11] and ministry of health database [12], using the chi-square test. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 25.0. Statistical significance was set at $p < 0.05$.

Results

Two hundred and sixty patients fulfilled the study criteria, of whom 197 patients (76%) were under the age of 20 years, and 63 (24%) were young adult KTRs aged 20–35 years, who underwent transplantation as children. The ethnic distribution was almost identical in the under 20-year-old group and the young adult group, with a higher percentage of Arab ethnicity (43%) than in the general age-matched population (34%). Patient characteristics are summarized in Table 1.

In our cohort, 54 patients (20.7%) were infected with SARS-CoV-2, including 35/197 (17.8%) of the under 20 group, defined as a positive PCR test. The age-matched incidence in the general population in the Jerusalem area was 14.0% over the same time period ($p=0.13$) [11, 12]. The SARS-CoV-2 infection trend was closely correlated with the temporal distribution of cases in the general pediatric population (Fig. 1). The reason for testing was close exposure to a COVID-19 patient in 37% of cases, or symptoms, with or without exposure in 63% (predominantly fever, cough, headache, changes in taste and smell perception and gastrointestinal symptoms). The incidence of COVID-19 in the different patient groups was 12.0%, 23.3% and 29.5% in the CKD, KTR and GD groups, respectively ($p=0.02$). There was a higher rate of infection in the GD and KTR groups compared to CKD, odds ratio (OR)=2.53 (95% CI 1.23–5.2).

In most cases of PCR-confirmed COVID-19 (46/54–85%) the nephrology team was notified and was involved in clinical care. Most patients with COVID-19 exhibited very mild

symptoms, with 37.0% of patients being asymptomatic (Table 2). Most symptoms resolved rapidly (median 2 days, range 1–10), with supportive care alone. No modifications in immunosuppressive medications or RAAS inhibitors were made. Kidney function was unchanged from baseline in all cases. No cases of long COVID or MIS-C were reported. Three patients were hospitalized: a 7-year-old boy 1 year after a living related kidney transplantation, treated with tacrolimus and prednisone. He presented with shortness of breath, had normal blood oxygen saturation and chest X-ray, and did not require intervention. The second was a 13-year-old girl with stage 4 CKD due to Joubert syndrome who presented with fever. She had chronic pancytopenia due to her underlying liver disease and hypersplenism, which prompted admission for empiric antibiotic treatment. She had no other symptoms, chest X-ray was normal and she was discharged after 36 h. The third was a 23-year-old woman 4 years after kidney transplantation, treated with tacrolimus, mycophenolate and prednisone. She presented with diarrhea, abdominal pain and cough, chest X-ray showed bilateral ground glass opacities in the middle and lower lung fields, but blood oxygen saturation was normal. She was discharged without need of therapy, and symptoms resolved over 3–4 days.

Most patients reported being infected from a household member (56%), 17% from school or dormitory friends, and the remainder were from an unknown source. As far as we know, there were no cases of infection during hospital clinic visits or dialysis sessions.

Three patients had a second PCR-confirmed SARS-CoV-2 infection, at 191, 203 and 215 days from the first

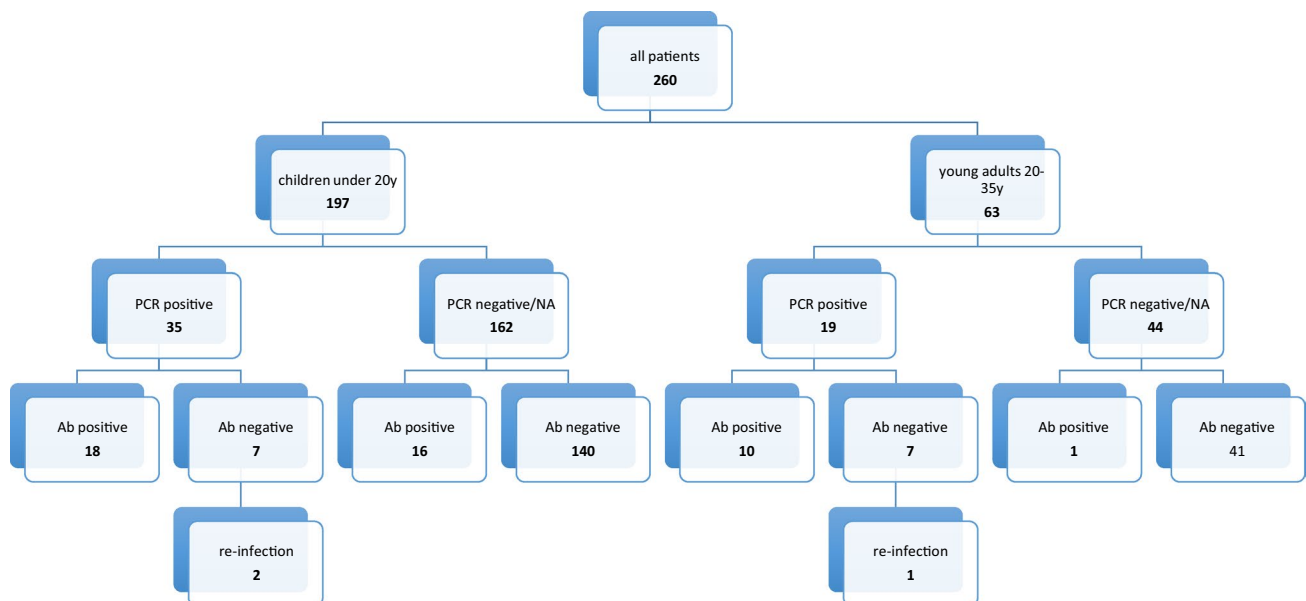


Fig. 2 Prevalence of anti-SARS-CoV-2 antibodies. Antibody test results were equivocal in nine patients and were not available in 11 patients. PCR polymerase chain reaction performed for diagnosis of COVID-19, Ab antibodies, NA not available

infection, respectively. A 10-year-old boy with stage 3 CKD, without immunosuppressive medication, developed COVID-19, which manifested as dyspnea treated with inhaled beta agonists. He was re-infected 6 months later, with 2 days of headache and weakness which resolved. The second case was an 11-year-old girl with nephrotic syndrome (NS), who developed COVID-19 for the first time about 1 month after discontinuing a 2-year course of mycophenolate. She was completely asymptomatic, but the NS relapsed 1 month later, requiring resumption of therapy. She had a second SARS-CoV-2 infection with myalgia, anosmia and dysgeusia for 3 days while on low dose prednisone (0.18 mg/kg/day) and mycophenolate (500 mg/m²/day). The third patient was a 19-year-old man with NS treated with mycophenolate

(1100 mg/m²/day). COVID-19 manifested as 1 day of fever and rhinorrhea, re-infection presented with abdominal pain and weakness, which resolved after 1 week. Of note, all three patients with recurrence were negative when tested for anti-SARS-CoV-2 antibodies 2–3 months after the first infection.

Serological data were available for 249 (96%) individuals in the entire cohort, including 46/54 (85%) patients with PCR-confirmed COVID-19, at a median time of 45 days (IQR 25.5–92.5) after their first positive swab. Antibody testing was performed for IgG antibodies to the nucleocapsid protein and positive results were verified with an assay for IgG antibodies to the spike proteins, as detailed in the “Methods” section. Patients who had a positive result on both serological assays, or a positive result on one assay

Table 3 Risk factors for COVID-19 infection in young patients with kidney disease

	Patients with COVID-19 (n = 71)	Patients without COVID-19 (n = 189)	All patients (n = 260)	OR (95% CI) Patients with vs. without COVID-19
Immunocompromised*	51 (72)	120 (63)	171 (66)	1.47 (0.81–2.66)
Triple IS	29 (41)	73 (39)	102 (39)	
Dual IS	8 (11)	15 (8)	23 (9)	
Single agent IS	13 (18)	31 (16)	44 (17)	
Corticosteroids (including in combination)	42 (59)	97 (51)	139 (53)	1.37 (0.79–2.39)
Rituximab in past year	0	3 (2)	3 (1)	
Eculizumab	0	14 (7)	14 (5)	
RAAS inhibitor therapy	18 (25)	44 (23)	62 (24)	1.12 (0.6–2.11)
Co-morbidities: total**	38 (53.5)	91 (48)	129 (50)	1.24 (0.72–2.14)
Dialysis	3 (4)	15 (8)	18 (7)	0.51 (0.14–1.82)
Hypertension	17 (24)	41 (22)	58 (22)	1.14 (0.6–2.17)
Diabetes mellitus	2 (3)	4 (2)	6 (2)	1.34 (0.24–7.49)
Obesity	9 (13)	13 (7)	22 (8)	1.97 (0.8–4.82)
Liver transplant	2 (3)	4 (2)	6 (2)	1.34 (0.24–7.48)
Demographic group				
Jewish non ultra-orthodox	13 (18)	50 (26)	63 (24)	Ref
Jewish ultra-orthodox	33 (46.5)	52 (28)	85 (33)	2.44 (1.15–5.17)
Arab	25 (35)	87 (46)	112 (43)	1.11 (0.52–2.35)
Family size***				
≤ 7 people	35 (49.3)	160 (84.7)	195 (75)	
> 7 people	32 (45.1)	24 (12.7)	56 (21.5)	6.1 (3.2–11.6)
Exposure to COVID-19 at home	50 (70)	29 (15)	79 (30)	13.14 (6.89–25.04)

Patients with COVID-19 include PCR-confirmed and serologically diagnosed cases. Values are patient number (%) unless otherwise noted

IS immunosuppression

*Triple IS = In group 1: 27 patients on Tacrolimus (Tac) + mycophenolate mofetil (MMF) + prednisone (PD) and two patients on Tac + azathioprine (AZA) + PD. In group 2: all 73 patients on Tac + MMF + PD, of whom 6 also on eculizumab. Dual IS = In group 1: four patients on MMF + PD, three on Tac + PD, one on cyclosporine (CSA) + PD. In group 2: nine patients on Tac + PD, four on MMF + PD, one each on FK + MMF, CSA + MMF. Single agent = In group 1: four patients on Tac, four on MMF (4), five on PD. In group 2: two patients on Tac, nine on MMF, ten on PD, two on CSA and eight on eculizumab alone. One patient not receiving immunosuppressive medication had severe chronic leukopenia and neutropenia due to liver involvement of Joubert syndrome

**Other comorbidities included: global developmental delay—41, asthma—8, cyanotic heart disease—2, heart transplant—1, Crohn’s disease—1

***Data on family size was missing for nine patients

with significant home exposure or compatible symptoms were considered to have recovered from COVID-19. Antibodies were detected in 28 (61%) patients, 18 children and ten young adults (Fig. 2). An additional 16 children and one young adult were found to have antibodies to COVID-19 without having had a PCR test. Follow-up serology in patients with antibodies to SARS-CoV-2 (including those with positive serology alone) after a median of 53.5 days (IQR 34.5–64.25) from the first antibody test, was available for 18 patients, of whom 9 (50%) were still positive. The longest lasting positive serology was 326 days from PCR-confirmed diagnosis.

We investigated possible predictors of COVID-19 in our cohort, (Table 3). The incidence of infection when including patients diagnosed by serology alone was 22.8%, 28% and 32.8% in patients with CKD, KTR and GD, respectively ($p=0.21$). Infection rate was higher among Ultra-Orthodox Jewish patients compared to the non Ultra-Orthodox Jewish reference group, OR 2.4 (95% CI 1.2–5.2). The incidence in Arab patients was not significantly different from the reference group (OR 1.1, 95% CI 0.5–2.4). The risk of infection was higher in patients with more than seven family members living at home, OR 6.1 (95% CI 3.2–11.6). The presence of a household member with COVID-19 was highly associated with infection (OR 14.5, 95% CI 6.6–31.8). Comorbidities, immunosuppressive therapy, age and sex were not associated with increased risk. In a multivariate model, adjusted for age and sex, demographic group was no longer found to be associated with infection, while exposure at home (OR 15.4, 95% CI 6.9–34.2) and number of people living at home (OR 1.45 for each additional person, 95% CI 1.21–1.73) remained significant.

Anti SARS-CoV-2 seropositivity after PCR-confirmed COVID-19 was not significantly associated with prednisone treatment ($p=0.15$), immunosuppressive medications ($p=0.95$), symptomatic disease ($p=0.59$), age ($p=0.76$), sex ($p=0.12$) or demographic group ($p=0.82$). The median time from COVID-19 diagnosis to antibody testing was not significantly different between seropositive and seronegative patients ($p=0.39$).

Discussion

The Jerusalem area in Israel has been severely affected by the COVID-19 pandemic. It is a relatively low income, densely populated area, composed of ethnically diverse groups. Comparison of the study population younger than 20 years with the age-matched general population, demonstrated no significant difference in the rate of infection. When including study patients who tested positive for anti-SARS-CoV-2 antibodies without PCR confirmation, the total rate of COVID-19 in our cohort was 27.3%.

A study from Italy during the early period of the pandemic (February–April 2020) which collected data from pediatric CKD, KTR and GD patients did not demonstrate a higher incidence of COVID-19, or any severe cases. However, testing for the virus was not widely performed in this cohort and only three patients had a positive PCR test [13]. Another study which included 24 patients identified from 22 centers in the USA, demonstrated an overall incidence of COVID-19 of 0.6% in pediatric KTRs [14]. Other studies were not able to estimate the incidence of COVID-19 in pediatric kidney disease, due to under-reporting of milder cases and asymptomatic patients who never presented to healthcare units [15]. We believe we were able to make a valid estimation of the incidence, by first defining the group of children and young adults with kidney disease and then actively collecting data at a clinic visit and tracking PCR tests performed at local clinics, which were available from the patient's electronic records. Serological testing identified additional asymptomatic cases, which would have otherwise been missed, however these were not used in the incidence comparison to the general population, who did not undergo serological screening.

We found that the most significant risk factor for COVID-19 was an infected household member, as was seen in previous studies, which showed that children are most likely to contract COVID-19 from an adult at home [16–18]. The risk of infection also increased proportionally to the number of household members. The disparity in rates of infection between social groups (Ultra-Orthodox Jews vs others) was not significant on multivariate analysis, and was accounted for by family size. Although most of our patients were careful to minimize exposure and avoided social interactions including school attendance, even when schools were open, family members usually continued to go out to work and school. Many patients came from large, low income families, and were therefore in close contact with more people, even during tight lock-down periods, thus increasing their exposure. Although the rate of PCR-confirmed COVID-19 was higher in KTRs and GD compared to CKD patients, when including serologically diagnosed cases, there was no difference in risk of COVID-19 between these groups.

With one exception, all positive cases in our cohort were either asymptomatic or experienced very mild symptoms. None of the COVID-19 cases were severe, although many patients had comorbidities such as dialysis treatment, diabetes mellitus, hypertension and obesity, which are significant risk factors in adults. Our cohort included six liver transplanted children (5/6 with combined liver-kidney-transplantation and one with CKD), two of whom tested positive with very mild disease. None of the patients treated with biological agents (eculizumab or rituximab) were infected with SARS-CoV-2, we cannot therefore comment on disease patterns in this population. No modifications in

immunosuppressive medications or RAAS inhibitors were made, and kidney function was unchanged from baseline in all cases.

Data regarding COVID-19 severity in pediatric KTRs or CKD patients is limited; however, most published case series report mild disease, similar to the general pediatric population. One multicenter study reported eight pediatric KTRs with COVID-19, all of whom had mild disease although two were hospitalized [19]. Another multicenter study identified 24 pediatric KTRs with COVID-19, eight were hospitalized and two were admitted to the ICU [14]. A study from 30 countries described 113 pediatric KTRs and children on immunosuppressive medication for kidney disease who were diagnosed with COVID-19 [15]. Clinical features were similar to those found in children without comorbidities. Unlike our study, these reports included only patients who underwent COVID-19 testing in their kidney transplant centers, while serological testing was not performed, possibly missing asymptomatic or mild cases. We included our data on young adult KTRs, as this group with childhood-onset kidney disease may be more similar to pediatric patients, regarding infection risk and severity. In contrast to studies which have shown a significantly increased risk of SARS-CoV-2 infection, complications, and death in predominantly older adult KTRs, we found excellent clinical outcomes in our young adult KTR cohort.

Although according to currently published data, SARS-CoV-2 re-infection is uncommon [20], three patients in our cohort (3/54, 5.6%) had two PCR-confirmed mild episodes of COVID-19, 6–7 months apart. We did not perform genetic analysis of the virus, however it is possible that re-infection was with a different strain, such as the B.1.1.7 variant which became the predominant strain in Israel in January 2021 [21]. There were no unique characteristics to these patients, other than belonging to the minority of patients who failed to seroconvert (3/14, 21%), underscoring the protective role of anti-SARS-CoV-2 antibodies in this population, similar to previous reports in the general population [22].

We performed serology testing in 96% of our patients, including 85% of the patients with PCR-confirmed COVID-19, of whom 61% developed antibodies to SARS-CoV-2. False positive serology results are unlikely, as we used two different assays to detect antibodies against SARS-CoV-2, one identifying IgG to the nucleocapsid protein (Abbott) and one identifying IgG to the spike proteins S1/S2 (Diasorin, Liaison). Both methods have a high specificity for anti-SARS-CoV-2 antibodies [23]. Surveys of plasma from COVID-19 convalescent immunocompetent patients demonstrated a higher rate of seropositivity than was found in our study, ranging from 90.2 to 100% [24–26]. Seropositivity rates in immunocompromised patients tend to be lower, both in adult KTRs [27] as well as in persons who reported any immunosuppressive therapy [28]. While patients with CKD were included in

SARS-CoV-2 antibody surveys, specific serological data in this population is lacking. Data collected from children with kidney diseases showed low prevalence of anti-SARS-CoV-2 antibodies early in the course of the pandemic [29]. However, serological studies in children with kidney disease after PCR-confirmed COVID-19 are lacking. We did not find an association between immunosuppression and seropositivity, which may be explained by the relative immunodeficiency associated with CKD [30], the only subset of our cohort not receiving immunosuppressive medications. The relatively low seropositivity rate in our cohort may also be partially explained by the findings of Weisberg et al. [31] that children produce predominantly anti-spike protein IgG and less anti-nucleocapsid protein antibodies, while in our study, the primary assay used detected nucleocapsid antibodies, whereas the anti-spike assay was used only for confirmation of positive results.

The likelihood of developing antibodies in our cohort was not associated with disease severity or demographic variables, similar to studies in adult solid organ transplant recipients [32, 33] as well as in immunocompetent patients [34]. SARS-CoV-2 seropositivity persisted in 50% of 18 patients who were re-tested after a median of 53.5 days, in accordance with previous findings that antibodies may be durable for up to 4–6 months even in immunocompromised adult patients [35].

Limitations of our study include a single center cohort, representing a specific region, a relatively small number of young adult patients and a lack of standardization in timing of serology testing after infection.

In conclusion, this study is the first comprehensive survey of COVID-19 in children and young adults with kidney disease, performed in a severely pandemic-affected area. Prevalence of infection in our cohort was similar to the general population, none of the cases were severe and all made a full recovery. A lower percentage of patients developed anti-SARS-CoV-2 antibodies after COVID-19 than has been described in the general population, with no correlation to disease severity or immunosuppression. Recurrent infection was infrequent and mild, occurring in patients who did not develop antibodies. These results suggest that children and young adults with kidney disease, including those receiving immunosuppressive medication, are less vulnerable to COVID-19 than adult KTRs and CKD patients, and may safely be advised to adhere to their regular medication regimen and to practice social distancing precautions similar to their healthy peers. Further studies are needed to determine long-term consequences of COVID-19 in children with kidney disease, as well as the longevity of protective antibodies in this population.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s40620-021-01171-2>.

Author contributions All authors contributed to the study conception, design and data collection. Conceptualization: RB-C and JW-G. Methodology and statistical analysis: RB-C, JW-G and EBS. Writing—original draft preparation: RB-C, JW-G and EBS. Review and editing, approval of final version: all authors.

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Data availability All data and materials as well as software application support our claims and comply with field standards.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical approval The study was approved by the Shaare Zedek Medical Center institutional ethics committee (Helsinki committee). The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent to participate Patients and/or parents or guardians gave informed consent to participate in the study. As initial testing was performed as part of routine clinical practice, the committee waived the need for written consent. If additional testing was performed, written informed consent was obtained from all participants or parents/guardians.

Consent for publication All authors consent to publication.


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