



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



SARS-CoV-2 in Solid Organ Transplant Recipients: A Structured Review of 2020

Markus Quante^a, Linda Brake^a, Alexander Tolios^{b,c,d}, Andrea Della Penna^a, Christoph Steidle^a, Magdalena Gruendl^e, Anna Grishina^f, Helene Haeberle^g, Martina Guthoff^{h,i,j}, Stefan G. Tullius^k, Alfred Königsrainer^{a,l}, Silvio Nadalin^a, and Markus W. Löffler^{a,l,m,n*}

^aDepartment of General, Visceral, and Transplant Surgery, University Hospital Tübingen, Tübingen, Germany; ^bDepartment of Blood Group Serology and Transfusion Medicine, Medical University of Vienna, Vienna, Austria; ^cCenter for Physiology and Pharmacology, Institute of Vascular Biology and Thrombosis Research, Medical University of Vienna, Vienna, Austria; ^dCenter for Medical Statistics, Informatics, and Intelligent Systems, Institute of Artificial Intelligence, Medical University of Vienna, Vienna, Austria; ^eDepartment of Epidemiology, Technical University Munich, Munich, Germany; ^fDepartment of Pediatrics I, University Medicine Essen, Essen, Germany; ^gDepartment of Anesthesiology and Intensive Care Medicine, University Hospital Tübingen, Tübingen, Germany; ^hDepartment of Diabetology, Endocrinology, Nephrology, Section of Nephrology and Hypertension, University Hospital Tübingen, Tübingen, Germany; ⁱInstitute for Diabetes Research and Metabolic Diseases of the Helmholtz Center Munich, University of Tübingen, Tübingen, Germany; ^jGerman Center for Diabetes Research (DZD e.V.), Neuherberg, Germany; ^kDivision of Transplant Surgery and Transplant Surgery Research Laboratory, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts; ^lCluster of Excellence iFIT (EXC 2180) "Image-Guided and Functionally Instructed Tumor Therapies," University of Tübingen, Tübingen, Germany; ^mDepartment of Immunology, Interfaculty Institute for Cell Biology, University of Tübingen, Tübingen, Germany; and ⁿDepartment of Clinical Pharmacology, University Hospital Tübingen, Tübingen, Germany

ABSTRACT

Background. The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic is challenging health systems all over the world. Particularly high-risk groups show considerable mortality rates after infection. In 2020, a huge number of case reports, case series, and consecutively various systematic reviews have been published reporting on morbidity and mortality risk connected with SARS-CoV-2 in solid organ transplant (SOT) recipients. However, this vast array of publications resulted in an increasing complexity of the field, overwhelming even for the expert reader.

Methods. We performed a structured literature review comprising electronic databases, transplant journals, and literature from previous systematic reviews covering the entire year 2020. From 164 included articles, we identified 3451 cases of SARS-CoV-2–infected SOT recipients.

Results. Infections resulted in a hospitalization rate of 84% and 24% intensive care unit admissions in the included patients. Whereas 53.6% of patients were reported to have recovered, cross-sectional overall mortality reported after coronavirus disease 2019 (COVID-19) was at 21.1%. Synoptic data concerning immunosuppressive medication attested to the reduction or withdrawal of antimetabolites (81.9%) and calcineurin inhibitors (48.9%) as a frequent adjustment. In contrast, steroids were reported to be increased in 46.8% of SOT recipients.

Conclusions. COVID-19 in SOT recipients is associated with high morbidity and mortality worldwide. Conforming with current guidelines, modifications of immunosuppressive therapies mostly comprised a reduction or withdrawal of antimetabolites and calcineurin inhibitors, while frequently maintaining or even increasing steroids. Here, we provide an accessible overview to the topic and synoptic estimates of expectable outcomes regarding in-hospital mortality of SOT recipients with COVID-19.

SINCE the World Health Organization declared the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) outbreak starting in 2019 a pandemic, many countries have been

*Address correspondence to Dr Markus W. Löffler, Department of General, Visceral, and Transplant Surgery, University Hospital Tübingen, Hoppe-Seyler-Str 3, Tübingen 72076, Germany. Tel: +49 7071 29 80992; Fax: +49 7071 29 5653. E-mail: Markus.Loeffler@med.uni-tuebingen.de

severely affected by continuously rising infection rates. This unprecedented situation has challenged health systems on a global scale, straining patient treatment *inter alia* because of an altered risk assessment for a variety of patient cohorts. Based on rapidly emerging data, factors such as age, diabetes mellitus, chronic lung disease, and hypertension have been identified to increase disease-related mortality [1]. This is why close attention has been paid to vulnerable patient populations. For instance, in patients undergoing surgery, an international cohort study has established an excessive mortality risk when patients became infected with SARS-CoV-2 directly before or during the first month after surgery [2]. Although this risk profile is most probably modulated by a variety of factors, the scale of these effects is unparalleled and calls for cautionary and preventative measures in regions affected by SARS-CoV-2 propagation.

Against this background, patients who received a solid organ transplant (SOT) have been identified as another high-risk group. An analysis of more than 17 million electronic health care records from the United Kingdom, including >10,000 deaths related to coronavirus disease 2019 (COVID-19), suggests a 6-fold increased sex- and age-adjusted risk of death (95% confidence interval, 4.73-7.61) in SOT recipients [3]. This relates both to patients who recently underwent transplantation and long-term SOT recipients. In addition to immunosuppression, transplant recipients frequently have additional risk factors that may favor detrimental outcomes. Meanwhile, an array of case reports, case series as well as case-control studies has been published, predominantly confirming an increased mortality risk for SOT recipients when infected with SARS-CoV-2 and developing COVID-19.

Multiple systematic reviews on the topic have become available throughout 2020, with steadily increasing case numbers. However, the massive increment of publications on SARS-CoV-2 has resulted in an unprecedented complexity of the field, which is overwhelming even for the expert reader [4]. This situation has also fostered a surge of non-peer-reviewed research published as preprints [5]. Although the rapid distribution of latest research findings represents a valuable tool to combat the pandemic, it is also linked to inherent limitations. Furthermore, pandemic pressure and the urge to catch up with the flood of information and findings already supplied by news and social media as well as in preprints has resulted in more rapid review by many scientific journals and the publication of preliminary reports. Taken together, revisiting available empirical data systematically seems highly relevant. Here, comprehensive synoptic analyses are a gateway to access the available literature, for example, allowing a broad-ranging overview and risk assessment for SARS-CoV-2-infected SOT recipients, which may help with addressing the many urgent unanswered key questions arising in this context [6]. Thus, we performed a structured literature review, providing an overview that compiles all relevant scientific literature from January 1, 2020 until December 31, 2020, to produce a current synoptic assessment of mortality and clinical outcomes subsequent to infection and COVID-19 in SOT recipients, as well as a comprehensive summary of the relevant scientific literature that even a multitude of preceding systematic reviews falls short to provide so far [7-19].

MATERIALS AND METHODS

We performed a structured review searching for publications reporting on patients after SOT with confirmed SARS-CoV-2 infections and/or COVID-19. The search strategy conformed to applicable guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist [20] is available from the authors of this article on request). A total of 626 articles were identified by searching the electronic database MEDLINE through PubMed (<https://pubmed.ncbi.nlm.nih.gov/>) and the Cochrane library (<https://www.cochranelibrary.com/>). Respective search terms and search strings used to query electronic databases is available from the authors of this article on request. This search was complemented by screening reference lists as well as dedicated journals including the *American Journal of Transplantation* (Online ISSN: 1600-6143), *Transplantation* (Online ISSN: 1534-6080), and *Liver Transplantation* (Online ISSN: 1527-6473), identifying 160 additional articles through predefined search terms (including SARS-CoV-2, COVID-19, and transplantation). We searched for all articles published within the period from January 1, 2020, until December 31, 2020.

In addition, because of the high current interest in the topic, we also systematically searched PubMed for previously published systematic reviews relevant to the topic and identified 99 references from 13 systematic reviews (Table 1), totaling 728 references after duplicate removal to be screened.

In a first screening step, 519 of these publications were excluded and the 209 remaining articles were individually assessed and screened in detail for the relevant minimum required information defined by us. Characteristics searched for were SOT recipients 10 years or older with confirmed SARS-CoV-2 infection and/or COVID-19. Additional essential information required before article inclusion were the number of SARS-CoV-2/COVID-19-positive SOT recipients, transplanted organs, and clinical outcomes. Review articles, unassignable registry data, surveys and non-English-language articles were excluded. After excluding 40 full-text-publications with reasons, 169 suitable articles were identified and 164 were included in the review (Fig 1). Five articles were removed because they are potentially reporting on the same set of patients.

Data were compiled and tabulated using Microsoft Excel (Microsoft Corporation, Redmond, Washington, United States); data analysis and visualization were performed by using the free and open-source programming language GNU R [21] with the additional packages easy-PubMed [22] as well as ggplot2 [23]. Figures were drawn using Inkscape (<https://inkscape.org>) and Biorender (<https://biorender.com/>).

Data were processed to depict the relative number of cases up to each time point, both overall as well as separated by group (type of study as well as geographic area). Data are presented in total numbers and percentages. References to all included articles and extracted data used for evaluations with transparent and reproducible methodology are available from the authors on request.

RESULTS

Included Literature

This structured literature review identified 164 publications overall within our defined scope, which report on 3451 patients in total. The literature search strategy for the selection of scientific articles is illustrated in Fig 1. Most included studies were case reports (n = 89) [24-112], followed by cohort studies (n = 38) [113-150], case series (n = 26) [151-176], multicenter cohort studies or case series (n = 8) [177-184], and 3 case-control studies [185-187]. An overview on the largest patient cohorts is provided in Table 2.

Table 1. Characteristics of Previously Published Systematic Reviews

No.	Author	Period Until	Transplanted Organ(s)	Date Published	Included Articles, No.	Patients, No.	Mortality Rate, %
1	Gavriilidis et al. [9]	April 2020	Liver	06/25/2020	5	12	33.3
2	Hage et al. [11]	04/08/2020	SOT	05/07/2020	5	8	n.d.
3	Nacif et al. [16]	04/20/2020	SOT	06/03/2020	24	39	25.6
4	Imam et al. [12]	05/06/2020	Kidney	07/24/2020	21	58	15.5
5	González et al. [10]	05/15/2020	Kidney	06/05/2020	34	184	n.d.
6	Moosavi et al. [15]	05/22/2020	SOT	07/24/2020	50	337	22.8
7	Oltean et al. [17]	06/04/2020	Kidney	07/13/2020	12	204	21.2
8	Aziz et al. [7]	06/06/2020	SOT	09/15/2020	49	403	21
9	Fraser et al. [8]	06/15/2020	Liver	07/30/2020	15	223	19.3
10	Marinaki et al. [14]	07/07/2020	Kidney	09/16/2020	63	420	22.1
11	Mahaling-asivam et al. [13]	08/04/2020	Kidney	11/03/2020	20	1955	n.d.
12	Raja et al. [19]	10/09/2020	SOT	11/14/2020	60	2772	18.6
13	Phanish et al. [18]	10/15/2020	Kidney	12/19/2020	16	1494	24

n.d., no data; SOT, solid organ transplant.

Patient Demographics

Most included patients had received a kidney allograft (n = 2439; 70.7%), followed by liver (n = 499; 14.5%), heart (n = 274; 7.9%), and lung (n = 170; 4.9%) transplants. Only a minor fraction had multiple organ (n = 59; 1.7%) transplants (Fig 2A). An analysis of the global distribution revealed that the largest proportion of included patients were treated either in Europe (n = 1481; 42.9%) or North America (n = 1279; 37.1%), whereas a smaller number of patients was reported from countries located in Asia (538; 15.6%). Additionally, 153 patients (4.4%) were reported from other countries/regions or could not be allocated. Overall, only 2 patients were reported from South American countries (Fig 2B).

Clinical Course and Outcome

Among 3451 patients reported with confirmed SARS-CoV-2 infection and/or COVID-19, data on the clinical course and outcome were available for 3353 patients (97.2%). According to this, 84% required hospitalization, whereas the remaining 536 patients were treated in an outpatient setting. For one study, respective data were unavailable [156] and hospitalization was assumed as the default option. Among all included 2817 hospitalized patients, 53.6% recovered from SARS-CoV-2 infection or could be discharged. Altogether 21.1% (n = 709) of patients were deceased at the time of data reporting and 10.2% of the patients remained affected by the disease, whereas 15.1% remained with an unknown outcome (Fig 2C). For 57.9% of the patients, changes in immunosuppressive medication were reported, and for at least 22.6% of SOT recipients disease progression involved an impaired allograft function (Fig 2D).

Development of Publications on COVID-19 and Transplantation Over Time

We further analyzed the types of publications and the geographical origin of the included studies throughout the year 2020, thereby revealing clear longitudinal trends for both origin and publication type. Starting with the SARS-CoV-2 outbreak, first reports on disease outcomes in SOT recipients became available

from Asia. In spring 2020, when Europe was severely hit by a first SARS-CoV-2 wave, this resulted in increasing publication numbers reporting on SOT recipients. By mid-April 2020, also sizeable numbers of publications on SARS-CoV-2 and SOT recipients from North America were published. Relevant publications from other continents were only published late in 2020 and remained scarce compared with the publication output from Asia, Europe, and North America (Fig 3A).

Similar longitudinal trends can also be shown when analyzing the type of data published. Although early in the pandemic data on SARS-CoV-2 in SOT recipients were derived mainly from case reports, this was later followed by case series, with steadily increasing patient numbers reported in each publication and then succeeded by publications of cohort studies starting in late April 2020. Ultimately, also case-control studies became available but only in the second half of the year. However, their number remained small, thus accounting only for a minor proportion of patients reported (Fig 3A, B).

Management of Immunosuppressive Therapy

Among a subgroup of 1192 transplant recipients from 5 large cohorts [119,132,164,177,179], we analyzed the available data on modification and management of the immunosuppressive therapies. Accordingly, the most frequent measure mentioned was the reduction or withdrawal of antimetabolites in 81.9% of SOT recipients with SARS-CoV-2 infection initially receiving this treatment. Reduction or withdrawal of calcineurin inhibitors was also reported frequently (48.9%). In contrast, steroids have been increased in 46.8% of respective patients, while reporting a reduction or withdrawal remained an exception (1.3%) (Table 3).

To obtain a more conclusive picture, we additionally screened the most recent recommendations from national and international transplantation societies regarding the immunosuppressive management of SOT recipients with SARS-CoV-2 infection. We identified 6 clinical guidelines generally based on expert opinion and summarized their

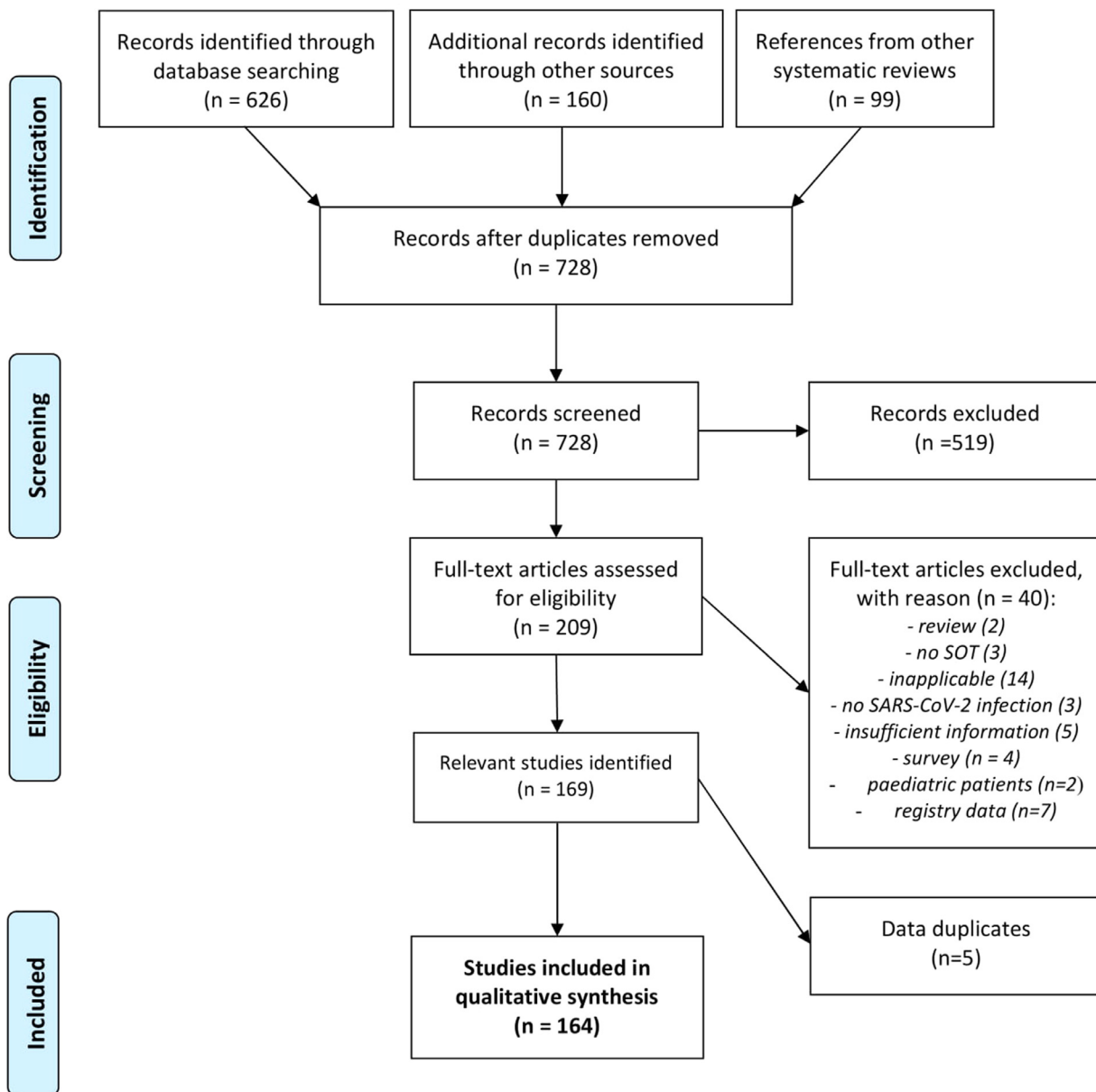


Fig 1. Flow diagram outlining the literature search strategy and selection of articles. The diagram depicts the different stages of our structured review including identification, screening, and selection of suitable articles. Articles were identified through searching MEDLINE, PubMed, and Cochrane databases, as well as additional sources for articles reporting on SOT recipients with SARS-CoV-2 infection or COVID-19. The used search strategy conforms to PRISMA guidelines [6]. Precise search terms and a PRISMA checklist as well as extracted data are available from the authors of this article on request. COVID-19, coronavirus disease 2019; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; SOT, solid organ transplant.

recommendations (Table 4) [188-193]. A broad consensus prevails, suggesting a critical consideration of the overall level of immunosuppression in SARS-CoV-2–infected SOT recipients based on established principles for managing infections in those patients. In patients with low risk of allograft rejection, decreasing immunosuppressive medication should be considered, especially in patients with severe

COVID-19 disease. Here, guidelines consistently recommend withdrawal or reduction of antimetabolites as a first step, followed by reduction of calcineurin inhibitors. Although no guideline recommends the reduction of steroids, some do recommend the administration of dexamethasone (6 mg daily) for up to 10 days in patients who require oxygen supplementation or are mechanically ventilated.

Table 2. Overview of Cohort Studies and Largest Published Data Sets on Kidney, Liver, Heart, and Lung Transplant Recipients Infected With SARS-CoV-2

Author	Study Design	Origin	Patients, No.	Transplanted Organ(s)	Mortality Rate, %
Coll et al. [177]	Multicenter cohort study	Europe	665	Kidney/liver/heart/lung/other	23.5
Kute et al. [179]	Multicenter cohort study	Asia	250	Kidney	11.6
Azzi et al. [118]	Cohort study	North America	229	Kidney	20.5
Webb et al. [184]	Multicenter cohort study	Other	151	Liver	18.5
Cravedi et al. [127]	Cohort study	North America	144	Kidney	31.9
Favà et al. [131]	Cohort study	Europe	104	Kidney	26.9
Molnar et al. [180]	Cohort study	North America	98	Kidney/liver/heart/lung/other	39.8
Ozturk et al. [181]	Multicenter cohort study	Asia	81	Kidney	11.1
Craig-Schapiro et al. [126]	Cohort study	North America	80	Kidney	16.3
Ali et al. [117]	Cohort study	Asia	67	Kidney/liver/lung	3.0

SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

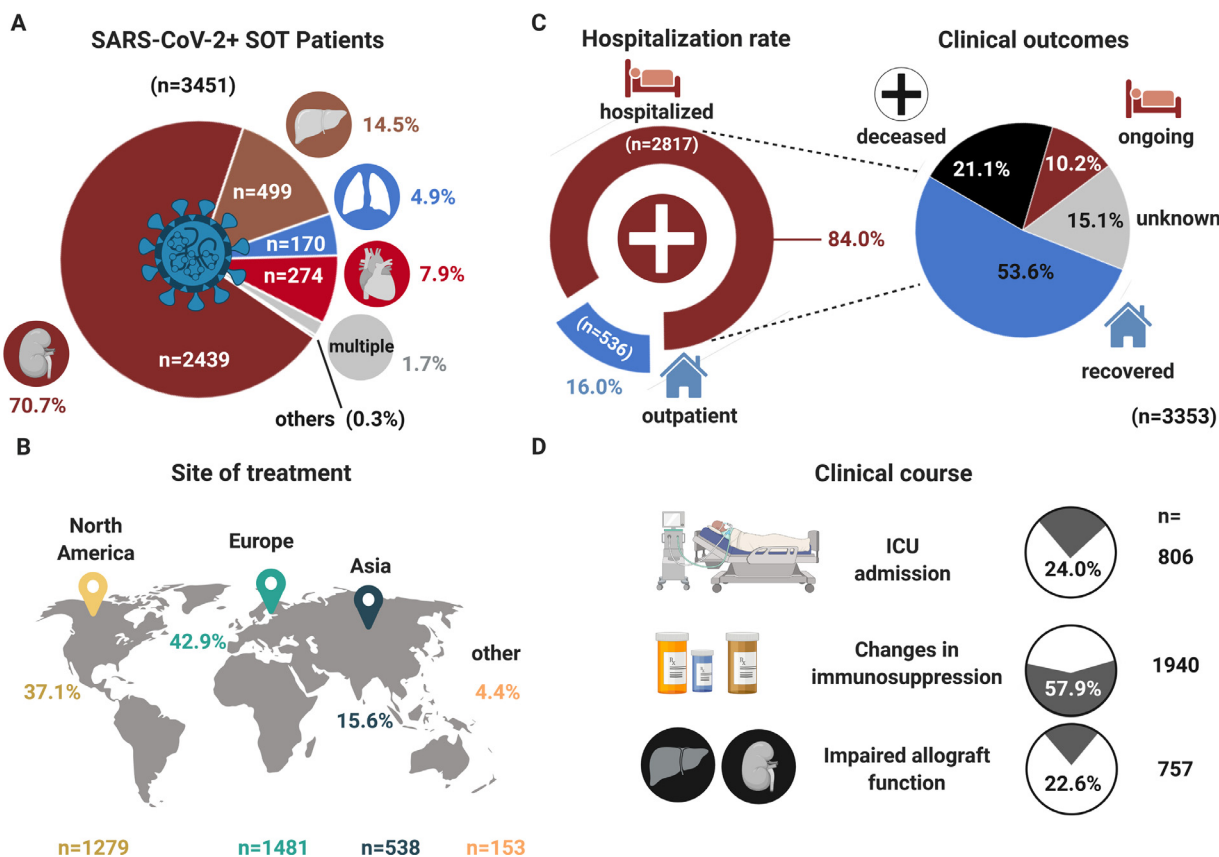


Fig 2. Synthesis of structured review results assessing SARS-CoV-2 infections in solid organ transplant recipients. Our structured review comprises 3451 cases of SOT recipients with confirmed SARS-CoV-2 infection (SARS-CoV-2+) and/or COVID-19 presented as a synopsis (respective source data are available from the authors). **(A)** The pie chart depicts % fractions of infected SOT recipients (subdivided into liver, lung, heart, and multiple organs). **(B)** Assigns numbers and % fractions of infected SOT recipients according to the local origin of the reports/their site of treatment. **(C)** Presents respective SOT recipients according to treatment, categorized either as hospitalized or as outpatient, as well as outcomes at the time of reporting, categorized into deceased/recovered and ongoing treatment. **(D)** Clinical outcomes of SOT recipients are presented as % fractions and numbers of patients among all cases requiring ICU admission, changes in immunosuppression, and patients experiencing an impaired transplant function linked to infection. COVID-19, coronavirus disease 2019; ICU, intensive care unit; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; SOT, solid organ transplant.

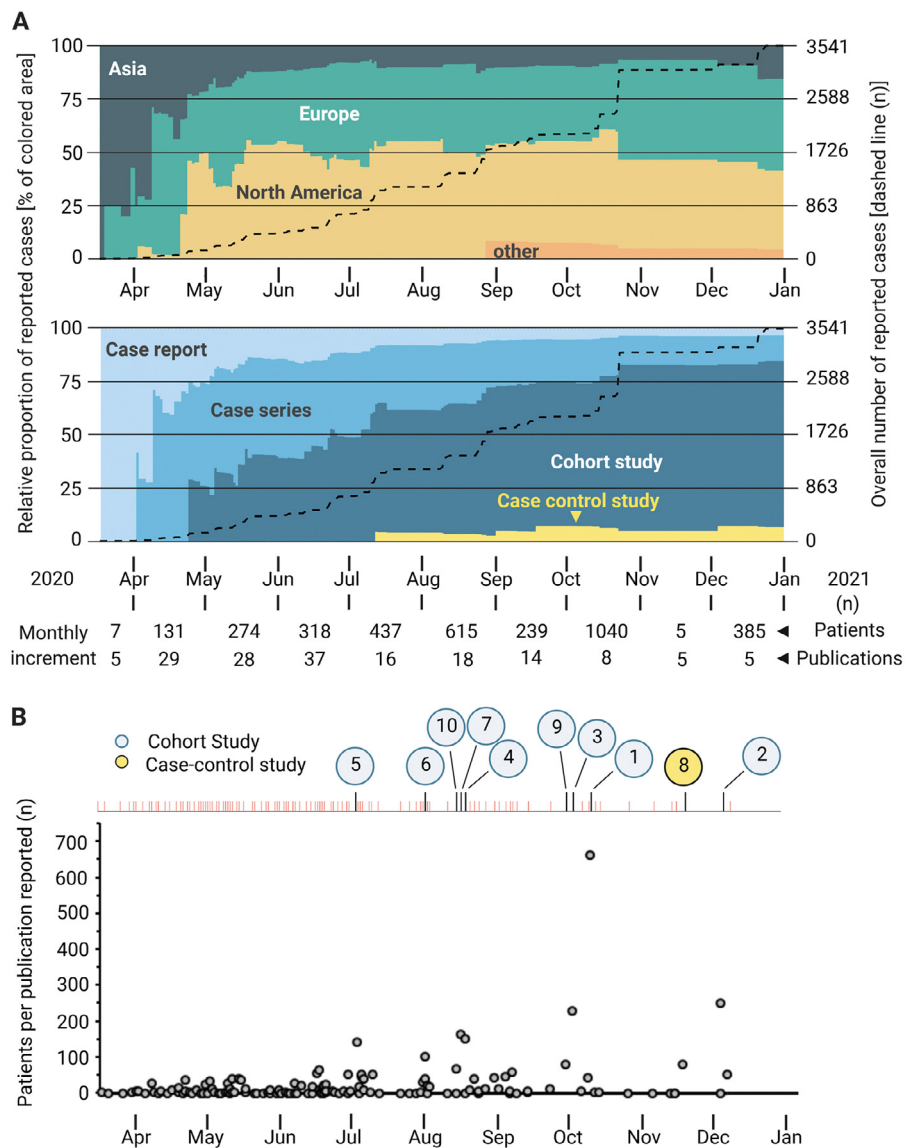


Fig 3. Comparison of publications on COVID-19 and transplantation over time. **(A)** The diagram illustrates the course of scientific information about COVID-19 made available (dates of first publication). A distinction is made between the origin of the studies (graph above) the types of publication (graph below). The dashed line represents overall numbers of patients; the colored area represents the relative number of patients reported until that time. **(B)** The graph depicts the number of patients per publication reported over time. The numbers from 1 to 10 illustrate the 10 studies with the largest patient collective, as presented in Table 2. COVID-19, coronavirus disease 2019.

DISCUSSION

Based on data from other patient cohorts, it was reasonable to assume early on in the pandemic that SOT recipients do also exhibit a high-risk profile after infection with SARS-CoV-2 because of indispensable immunosuppressive medication and a high rate of additional medical risk factors. Data from first small cohort studies that had become available in kidney transplant recipients confirmed this notion, with reported mortality rates of up to 30% [168]. A case-control study with a more robust study design conducted in 151 liver transplant recipients and 627 hospitalized control patients who were not transplant recipients surprisingly concluded that SOT status by itself was not independently associated with higher mortality. Instead, multivariate analysis established that mortality was primarily

associated with age and disease severity [184]. These two examples may demonstrate the broad range of published information on SARS-CoV-2 in SOT recipients, while at the same time calling for careful synoptic assessment of the available literature to support a better understanding of the overall risk involved for SARS-CoV-2–infected SOT recipients.

Here, our comprehensive evaluations confirm that during the course of 2020 better studies with a more robust scientific design have increasingly become available. However, the SARS-CoV-2 pandemic has also fundamentally impacted research publishing, as reflected by increasing submission numbers, preprint rush, expedited review, and in some cases retractions, even in high-profile peer-reviewed journals [5]. Therefore, our work may provide a robust overview and facilitate orientation within the tsunami of information linked to COVID-19.

Table 3. Adjustments of Immunosuppressive Drug Regimen in Selected Cohort Studies/Case Series of Transplant Recipients Infected With SARS-CoV-2

Author	Transplanted Organ(s)	Study Cohort, No.†	Antimetabolites, n/N (%)‡			Calcineurin Inhibitors, n/N (%)‡			Steroids, n/N (%)‡				
			X	↓	↑↔	X	↓	↑	X	↓	↑		
Coll et al. [177]	Kidney, HSCT, liver, lung, pancreas, multivisceral	92/389 (23.7)	273/389 (70.2)	24/389 (6.2)	0175/495 (35.4)	181/495 (36.6)	134/495 (27.1)	5/495 (1)	197/460 (42.8)	8/460 (1.7)	2/460 (0.4)	253/460 (55)	
Kute et al. [179]	Kidney	0	188/250 (75.2)	62/250 (24.8)	0165/236 (69.9)	21/236 (8.9)	50/236 (21.2)	0	150/250 (60)	0	0	100/250 (40)	
Bechetti et al. [119]	Liver	57	15/26 (57.7)	1/26 (3.8)	031/50 (62)	7/50 (14)	12/50 (24)	0	10/10 (100)	0	0	0	
Lubetzky et al. [164]	Kidney	54	13/52 (25)	24/52 (46.2)	15/52 (28.8)	035/52 (67.3)	0	17/52 (32.7)	0	22/27 (81.5)	0	5/27 (18.5)	
Felidin et al. [132]	Kidney, liver, heart, lung, liver-kidney, kidney-heart	53	17/41 (41.5)	19/41 (46.3)	5/41 (12.2)	042/53 (79.2)	3/53 (5.7)	8/53 (15.1)	0	30/40 (75)	0	10/40 (25)	
Total		1192	137/758 (18.1)	514/758 (67.8)	107/758 (14.1)	0448/886 (50.6)	212/886 (23.9)	221/886 (24.9)	5/886 (0.6)	409/787 (52)	8/787 (1)	2/787 (0.3)	368/787 (46.8)

↔, no (substantial) change; ↓, dose reduction; ↑, dose increase; HSCT, hematopoietic stem cell transplant; n, quantity; N, patient population among study cohort that initially received the respective treatment; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; X, withdrawal.

* Azathioprine and/or mycophenolate mofetil.

† Cyclosporine and/or tacrolimus.

‡ No reduction/≤50% reduction.

Our synoptic review incorporates 3451 cases of SOT recipients with confirmed SARS-CoV-2 infection and/or COVID-19, predominantly from the United States and Europe, and therefore sheds additional light on key issues in SOT recipients exposed to SARS-CoV-2, facilitating an easy overview. In contrast, the largest patient cohort previously reported on in a systematic review were considerably smaller with 2772 SOT recipients [19] and 1955 and 223 for kidney [13] and liver [8] transplant recipients, respectively. About 70.7% of patients included by us were kidney transplant recipients, which is relevant since chronic kidney disease has been implicated in COVID-19–related mortality [194]. The overall mortality in our data set was 21.1%, which is well in line with previous work [7,8,14,15,17]. Compared with the status quo before the pandemic, these data are alarming, even when assuming the very low end of estimates concerning the COVID-19–related case fatality rate reported at only 8.1% and 4.6% in men and women, respectively [195]. However, a large observational study in more than 10,000 hospitalized patients in Germany found in-hospital mortality rates at 22% among the general population [196], which is in line with our review findings among SOT recipients.

Our compiled data suggest that SARS-CoV-2 infection and COVID-19 resulted in a hospitalization rate of 84% with 24% of patients requiring intensive care unit admission. We may speculate that the hospitalization rate derived from respective articles published in 2020 is most likely an overestimation resulting from reporting bias, which is inherent to this kind of evaluation. Nonetheless, our findings tend to concur with previous reports, for example, in 36 infected adult kidney transplant recipients from the United States, where the hospitalization rate was 78%, and 39% of patients required mechanical ventilation, with a resulting mortality rate of 28% [114]. Then again, a single-center report from Italy, which had been severely impacted early on in the pandemic, has reported unanimous hospitalization (100%), frequent occurrence of acute respiratory distress syndrome (55%), and 25% mortality among 20 SARS-CoV-2–infected renal allograft recipients [152], suggesting the local situation may likely have impacted reporting.

The management of immunosuppressive therapies in COVID-19–positive SOT recipients is crucial but has not been conclusively addressed until now. Here, balancing the risks of allograft rejection and viral infection is paramount for the affected patients, yet the available data are scarce and scattered so far. Therefore, current guidelines from transplantation societies are mainly based on expert opinion, consistently recommending the withdrawal or reduction of antimetabolites followed by a reduction in calcineurin inhibitor dosage, depending on disease severity. Those recommendations are in line with the summary results of our literature overview, considering available retrospective clinical evidence.

Along the same lines, tacrolimus could be linked with a positive independent effect on survival in liver transplant recipients [197], whereas baseline immunosuppression containing mycophenolate mofetil was an independent predictor of severe COVID-19 [198].

Table 4. Recommendations From National and International Transplantation Societies

Society/Reference	Origin	Date	Guideline	Recommendation
British Transplantation Society [188]	UK	January 2021	Guidance on the management of transplant recipients diagnosed as having or suspected of having COVID-19	<p>Outpatients:</p> <ul style="list-style-type: none"> - Stop antiproliferative agents (MMF/azathioprine) - Review total burden of immunosuppression and consider reduction of CNIs - High or increased dose steroid is NOT recommended at this stage <p>Hospitalized patients:</p> <ul style="list-style-type: none"> - Stop antiproliferative agents (MMF/azathioprine) - Consider reducing or stopping CNIs - Dexamethasone 6 mg daily for 10 d <p>Patients requiring ventilatory support:</p> <ul style="list-style-type: none"> - Stop antiproliferative agents (MMF/azathioprine) - Dramatically reduce or stop CNIs - Consider dexamethasone, as above
International Society of Heart and Lung Transplantation [189]	International	February 2021	Guidance from the International Society of Heart and Lung Transplantation regarding the SARS-CoV-2 pandemic	<ul style="list-style-type: none"> - For transplant recipients, consider holding MMF, mTOR inhibitors, or azathioprine while admitted with moderate/severe illness.
Transplantation Society [190]	International	March 2021	Guidance on Coronavirus Disease 2019 (COVID-19 for Transplant Clinicians	<ul style="list-style-type: none"> - Dexamethasone 6 mg daily for up to 10 d can be considered in patients who require supplemental oxygen or are mechanically ventilated. - Attention should be paid to the potential drug interactions with current immunosuppression and the potential for increased risk of infectious complications when immunomodulatory agents are added to existing immunosuppressive therapy.
American Association for the Study of Liver Diseases [191]	US	March 2021	Clinical Best Practice Advice for Hepatology and Liver transplant Providers During the COVID-19 Pandemic: AASLD Expert Panel Consensus Statement	<ul style="list-style-type: none"> - Consider lowering the overall level of immunosuppression, particularly antimetabolite dosages (eg, azathioprine or MMF) based on general principles for managing infections in transplant recipients and to decrease the risk of superinfection. - Monitor kidney function and CNI levels. - Adjust immunosuppressive medications based on severity of COVID-19 and risk of graft rejection and renal injury.
Canadian Society of Transplantation [192]	Canada	April 2021	Consensus guidance and recommendations for organ donation and transplantation services during COVID-19 pandemic	<ul style="list-style-type: none"> - Based on current evidence, we suggest a temporary adjustment of maintenance immune suppression for hospitalized patients with severe COVID-19. - Data on optimal immune-suppression adjustment in patients with COVID-19 are lacking, may vary, and may not be required depending on disease severity and physician judgment.
American Society of Transplantation [193]	US	June 2021	2019-nCoV (Coronavirus): FAQs for Organ Transplantation	<ul style="list-style-type: none"> - The impact of immunosuppression on COVID-19 is not currently known but decreasing immunosuppression may be considered for infected recipients who have not had recent rejection episodes. - Many providers have decreased or discontinued cell cycle inhibitors or reduced CNI levels, but comparative data regarding these interventions are not yet available. - Whether adjunctive corticosteroid therapy for patients with severe ARDS may be beneficial is also unknown.

AASLD, American Association for the Study of Liver Diseases; ARDS, acute respiratory distress syndrome; CNI, calcineurin inhibitor; COVID-19, coronavirus disease 2019; FAQs, frequently asked questions; MMF, mycophenolate mofetil; mTOR, mammalian target of rapamycin; UK, United Kingdom; US, United States of America; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

Some guidelines even recommend dexamethasone administration for up to 10 days in patients who require supplemental oxygen or are mechanically ventilated, thus conforming with the Randomised Evaluation of COVID-19 Therapy Trial (RECOVERY) results [199] and treatment guidelines for the general population. The only review of guidelines addressing the use of immunosuppressants during the coronavirus pandemic for diverse indications also concluded that steroid use should not be stopped and emphasized the role of an individualized risk-benefit assessment, weighing the risk of COVID-19 infection and drug-induced immunosuppression for each patient [200].

Another critical aspect in COVID-19–diseased SOT recipients is the preservation of transplant function. Graft impairment or failure has been reported for about 22.6% of the cases we have compiled. Such complications were frequently reported for kidney and liver transplant recipients. Corresponding data for acute kidney injury have been reported to range between 25% and 57% in COVID-19–diseased kidney transplant recipients [41,65,152,154,185], linking it with a particularly poor prognosis [201].

We believe that the presented overview should be fairly comprehensive because of the amount of data compiled, while at the same time providing a representative number regarding clinical outcomes and in-hospital mortality rates that may be expectable in COVID-19–diseased SOT patients. Our data are unfortunately not suitable for a general assessment because of inherent study limitations. Here, especially asymptomatic SARS-CoV-2–infected SOT recipients may not be reflected by our evaluations, and any deductive conclusions should therefore be avoided.

As a potential limitation of our aggregate findings, a relevant selection bias is probable because of the design of our work. In detail, we assume, for example, mortality rates may be overestimated and most probably apply only to the in-hospital setting. Another limitation is that follow-up duration was inhomogeneous and ranged widely, with many included cases having ongoing disease at time of reporting or unknown outcomes, which may render results premature. Nevertheless, most patients had a sufficiently long follow-up period in our view, considering mortality in infected SOT recipients is mainly observed within the first 15 days after hospitalization [185]. We intentionally refrained from any meta-analyses of data or reporting estimates of uncertainty, which was deliberately not within the scope of our work. We believe that preceding publications have proven this attempt to be most likely futile, while at the same time lacking significant added value [19]. Hence, the aggregated data presented here come with limitations that are defined by the nature of the available data and should therefore be considered as rough ballpark estimates rather than detailed outcomes.

CONCLUSIONS

In conclusion, we provide a topical, comprehensive overview of the literature on SARS-CoV-2 and/or COVID-19 comprising

more than 3400 SOT recipients, aggregating their clinical outcomes, setting the available findings into a larger context, and providing entry points to a vast body of results published over one year.

Therefore, this overview adds substantially to the hitherto available studies and comparable previous work. Because the data support the notion that clinical outcomes after SARS-CoV-2 infections in SOT recipients are poor, maintaining adequate precautionary measures seems reasonable.

REFERENCES

- [1] Lu L, Zhong W, Bian Z, Li Z, Zhang K, Liang B, et al. A comparison of mortality-related risk factors of COVID-19, SARS, and MERS: a systematic review and meta-analysis. *J Infect* 2020;81:e18–25.
- [2] COVIDSurg Collaborative. Mortality and pulmonary complications in patients undergoing surgery with perioperative SARS-CoV-2 infection: an international cohort study. *Lancet* 2020;396:27–38.
- [3] Williamson EJ, Walker AJ, Bhaskaran K, Bacon S, Bates C, Morton CE, et al. Factors associated with COVID-19-related death using OpenSAFELY. *Nature* 2020;584:430–6.
- [4] Chen Q, Allot A, Lu Z. Keep up with the latest coronavirus research. *Nature* 2020;579:193.
- [5] Else H. How a torrent of COVID science changed research publishing - in seven charts. *Nature* 2020;588:553.
- [6] Ritschl PV, Nevermann N, Wiering L, Wu HH, Moroder P, Brandl A, et al. Solid organ transplantation programs facing lack of empiric evidence in the COVID-19 pandemic: a by-proxy society recommendation consensus approach. *Am J Transplant* 2020;20:1826–36.
- [7] Aziz H, Lashkari N, Yoon YC, Kim J, Sher LS, Genyk Y, et al. Effects of coronavirus disease 2019 on solid organ transplantation. *Transplant Proc* 2020;52:2642–53.
- [8] Fraser J, Mousley J, Testro A, Smibert OC, Koshy AN. Clinical presentation, treatment, and mortality rate in liver transplant recipients with coronavirus disease 2019: a systematic review and quantitative analysis. *Transplant Proc* 2020;52:2676–83.
- [9] Gavriliadis P, Pai M. The impact of COVID-19 global pandemic on morbidity and mortality of liver transplant recipients children and adults: a systematic review of case series. *J Clin Med Res* 2020;12:404–8.
- [10] Gonzalez J, Ciancio G. Early experience with COVID-19 in kidney transplantation recipients: update and review. *Int Braz J Urol* 2020;46:145–55.
- [11] Hage R, Steinack C, Benden C, Schuurmans MM. COVID-19 in patients with solid organ transplantation: a systematic review. *Transplantation* 2020;1:1–15.
- [12] Imam A, Abukhalaf SA, Imam R, Abu-Gazala S, Merhav H, Khalailah A. Kidney transplantation in the times of COVID-19 - a literature review. *Ann Transplant* 2020;25:e925755.
- [13] Mahalingasivam V, Craik A, Tomlinson LA, Ge L, Hou L, Wang Q, et al. A systematic review of COVID-19 and kidney transplantation. *Kidney Int Rep* 2021;6:24–45.
- [14] Marinaki S, Tsiakas S, Korogiannou M, Grigorakos K, Pappalios V, Boletis I. A systematic review of COVID-19 infection in kidney transplant recipients: a universal effort to preserve patients' lives and allografts. *J Clin Med* 2020;9:2986.
- [15] Moosavi SA, Mashhadiagha A, Motazedian N, Hashemazar A, Hoveidaei AH, Bolignano D. COVID-19 clinical manifestations and treatment strategies among solid-organ recipients: a systematic review of cases. *Transpl Infect Dis* 2020;22:e13427.
- [16] Nacif LS, Zanini LY, Waisberg DR, Pinheiro RS, Galvao F, Andraus W, et al. COVID-19 in solid organ transplantation patients: a systematic review. *Clinics (Sao Paulo)* 2020;75:e1983.

- [17] Oltean M, Softeland JM, Bagge J, Ekelund J, Felldin M, Schult A, et al. COVID-19 in kidney transplant recipients: a systematic review of the case series available three months into the pandemic. *Infect Dis (Lond)* 2020;52:830–7.
- [18] Phanish M, Ster IC, Ghazanfar A, Cole N, Quan V, Hull R, et al. Systematic review and meta-analysis of COVID-19 and kidney transplant recipients, the South West London Kidney Transplant Network experience. *Kidney Int Rep* 2021;6:574–85.
- [19] Raja MA, Mendoza MA, Villavicencio A, Anjan S, Reynolds JM, Kittipibul V, et al. COVID-19 in solid organ transplant recipients: a systematic review and meta-analysis of current literature. *Transplant Rev (Orlando)* 2021;35:100588.
- [20] Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement. *PLoS Med* 2009;6:e1000097.
- [21] R Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2018.
- [22] Fantini D. EasyPubMed: search and retrieve scientific publication records from PubMed. 2019.
- [23] Wickham H. ggplot2: elegant graphics for data analysis. New York, NY: Springer-Verlag; 2016.
- [24] Abuzeineh M, Desai N, Brennan DC, Alasfar S. COVID-19 early after a deceased donor kidney transplant surgery. *Transplantation* 2020;104:e354–5.
- [25] Abuzeineh M, Muzaale AD, Crews DC, Avery RK, Brotman DJ, Brennan DC, et al. Telemedicine in the care of kidney transplant recipients with coronavirus disease 2019: case reports. *Transplant Proc* 2020;52:2620–5.
- [26] Adapa S, Konala VM, Naramala S, Daggubati SR, Koduri NM, Gayam V, et al. COVID-19 in renal transplant patient presenting with active typical symptoms and resolved atypical symptoms. *J Investig Med High Impact Case Rep* 2020;8:2324709620949307.
- [27] Adroque AH, Mithani F, Ibrahim HN, Schwartz MR, Gaber L, Hebert SA, et al. A kidney transplant recipient with coronavirus disease 2019: utility of a prognostication score. *Transplant Proc* 2020;52:2688–92.
- [28] Ahmad SH, Smith R, Camilleri B. Belatacept, kidney transplantation and COVID-19: successful management of the first reported case within the United Kingdom. *Clin Transplant* 2020;34:e14026.
- [29] Aigner C, Dittmer U, Kamler M, Collaud S, Taube C. COVID-19 in a lung transplant recipient. *J Heart Lung Transplant* 2020;39:610–1.
- [30] Allam SR, Dao A, Madhira MM, Antiporta PB, Nair RR, Guiteau JJ, et al. Interleukin-6 receptor antagonist therapy to treat SARS-CoV-2 driven inflammatory syndrome in a kidney transplant recipient. *Transpl Infect Dis* 2020;22:e13326.
- [31] Antony SJ, Singh J, de Jesus M, Lance J. Early use of tocilizumab in respiratory failure associated with acute COVID-19 pneumonia in recipients with solid organ transplantation. *IDCases* 2020;21:e00888.
- [32] Arpali E, Akyollu B, Yelken B, Tekin S, Turkmen A, Kocak B. Case report: a kidney transplant patient with mild COVID-19. *Transpl Infect Dis* 2020;22:e13296.
- [33] Athanazio RA, Costa AN, Carraro RM, Gonzalez D, Rached SZ, Samano MN, et al. Early COVID-19 infection after lung transplantation in a patient with cystic fibrosis. *Clinics (Sao Paulo)* 2020;75:e2274.
- [34] Bartiromo M, Borchi B, Botta A, Bagala A, Lugli G, Tilli M, et al. Threatening drug-drug interaction in a kidney transplant patient with coronavirus disease 2019 (COVID-19). *Transpl Infect Dis* 2020;22:e13286.
- [35] Billah M, Santeusano A, Delaney V, Cravedi P, Farouk SS. A catabolic state in a kidney transplant recipient with COVID-19. *Transpl Int* 2020;33:1140–1.
- [36] Bussalino E, De Maria A, Russo R, Paoletti E. Immunosuppressive therapy maintenance in a kidney transplant recipient with SARS-CoV-2 pneumonia: a case report. *Am J Transplant* 2020;20:1922–4.
- [37] Chen D, Yang B, Zhang Y, Chen L, Wei L, Zhang W, et al. Withdrawing mycophenolate mofetil in treating a young kidney transplant recipient with COVID-19: a case report. *Medicine (Baltimore)* 2020;99:e20481.
- [38] Chen S, Yin Q, Shi H, Du D, Chang S, Ni L, et al. A familial cluster, including a kidney transplant recipient, of coronavirus disease 2019 (COVID-19) in Wuhan, China. *Am J Transplant* 2020;20:1869–74.
- [39] Cheng D, Wen J, Liu Z, Lv T, Chen JS. Coronavirus disease 2019 in renal transplant recipients: report of two cases. *Transpl Infect Dis* 2020;22:e13329.
- [40] Chenna A, Konala VM, Gayam V, Naramala S, Adapa S. Coronavirus disease 2019 (COVID-19) in a renal transplant patient. *Cureus* 2020;12:e8038.
- [41] Columbia University Kidney Transplant Program. Early description of coronavirus 2019 disease in kidney transplant recipients in New York. *J Am Soc Nephrol* 2020;31:1150–6.
- [42] Cozzi E, Faccioli E, Marinello S, Loy M, Congedi S, Calabrese F, et al. COVID-19 pneumonia in lung transplant recipients: report of 2 cases. *Am J Transplant* 2020;20:2933–7.
- [43] Dahl Mathiasen V, Jensen-Fangel S, Skov K, Leth S. Uneventful case of COVID-19 in a kidney transplant recipient. *BMJ Case Rep* 2020;13:e237427.
- [44] De Gottardi A, Fratila C, Bertoli R, Cerny N, Magenta L, Giannella P, et al. Clinical characteristics and management of a liver transplanted patient admitted with SARS-CoV-2 infection. *Clin Res Hepatol Gastroenterol* 2020;44:e141–4.
- [45] De Souza L, Nwanji V, Kaur G. An auspicious triumph of recovery from dialysis-requiring acute kidney injury in COVID-19 in a patient with chronic kidney disease, alpha-1 antitrypsin deficiency, and liver transplant: a case report. *Clin Nephrol* 2020;94:297–306.
- [46] Decker A, Welzel M, Laubner K, Grundmann S, Kochs G, Panning M, et al. Prolonged SARS-CoV-2 shedding and mild course of COVID-19 in a patient after recent heart transplantation. *Am J Transplant* 2020;20:3239–45.
- [47] Dirim AB, Demir E, Ucar AR, Garayeva N, Safak S, Oto OA, et al. Fatal SARS-CoV-2 infection in a renal transplant recipient. *CEN Case Rep* 2020;9:409–12.
- [48] Farfour E, Picard C, Beaumont L, Lesprit P, Ballester MC, Ackermann F, et al. SARS-CoV-2 Foch Hospital study, COVID-19 in lung-transplanted and cystic fibrosis patients: be careful. *J Cyst Fibros* 2020;19:e16–7.
- [49] Fontana F, Alfano G, Mori G, Amurri A, Tei L, Ballestri M, et al. COVID-19 pneumonia in a kidney transplant recipient successfully treated with tocilizumab and hydroxychloroquine. *Am J Transplant* 2020;20:1902–6.
- [50] Fried JA, Ramasubbu K, Bhatt R, Topkara VK, Clerkin KJ, Horn E, et al. The variety of cardiovascular presentations of COVID-19. *Circulation* 2020;141:1930–6.
- [51] Gandolfini I, Delsante M, Fiaccadori E, Zaza G, Manenti L, Degli Antoni A, et al. COVID-19 in kidney transplant recipients. *Am J Transplant* 2020;20:1941–3.
- [52] Gao F, Zheng KI, Gu JY, George J, Zheng MH. COVID-19 and liver transplantation: lessons learned from three reported cases. *Transpl Infect Dis* 2020;22:e13335.
- [53] Gautier-Vargas G, Baldacini C, Benotmane I, Keller N, Perrin P, Moulin B, et al. Rapid resolution of cytokine release syndrome and favorable clinical course of severe COVID-19 in a kidney transplant recipient treated with tocilizumab. *Kidney Int* 2020;98:508–9.
- [54] Guillen E, Pineiro GJ, Revuelta I, Rodriguez D, Bodro M, Moreno A, et al. Case report of COVID-19 in a kidney transplant recipient: does immunosuppression alter the clinical presentation? *Am J Transplant* 2020;20:1875–8.
- [55] Hammami MB, Garibaldi B, Shah P, Liu G, Jain T, Chen PH, et al. Clinical course of COVID-19 in a liver transplant recipient on

hemodialysis and response to tocilizumab therapy: a case report. *Am J Transplant* 2020;20:2254–9.

- [56] Holzhauser L, Lourenco L, Sarswat N, Kim G, Chung B, Nguyen AB. Early experience of COVID-19 in 2 heart transplant recipients: case reports and review of treatment options. *Am J Transplant* 2020;20:2916–22.
- [57] Hsu JJ, Gaynor P, Kamath M, Fan A, Al-Saffar F, Cruz D, et al. COVID-19 in a high-risk dual heart and kidney transplant recipient. *Am J Transplant* 2020;20:1911–5.
- [58] Huang J, Lin H, Wu Y, Fang Y, Kumar R, Chen G, et al. COVID-19 in posttransplant patients-report of 2 cases. *Am J Transplant* 2020;20:1879–81.
- [59] Huang JF, Zheng KI, George J, Gao HN, Wei RN, Yan HD, et al. Fatal outcome in a liver transplant recipient with COVID-19. *Am J Transplant* 2020;20:1907–10.
- [60] Italiano J, Bush R, Acharya R, Upadhyay K. Persistent viral shedding despite seroconversion in a kidney transplant recipient with severe extrapulmonary COVID-19. *BMJ Case Rep* 2020;13:e239612.
- [61] Jang K, Khatri A, Majure DT. COVID-19 leading to acute encephalopathy in a patient with heart transplant. *J Heart Lung Transplant* 2020;39:853–5.
- [62] Jiang J, Miao Y, Zhao Y, Lu X, Zhou P, Zhou X, et al. Convalescent plasma therapy: helpful treatment of COVID-19 in a kidney transplant recipient presenting with severe clinical manifestations and complex complications. *Clin Transplant* 2020;34:e14025.
- [63] Johnson KM, Belfer JJ, Peterson GR, Boelkins MR, Dumkow LE. Managing COVID-19 in renal transplant recipients: a review of recent literature and case supporting corticosteroid-sparing immunosuppression. *Pharmacotherapy* 2020;40:517–24.
- [64] Kadosh BS, Pavone J, Wu M, Reyentovich A, Gidea C. Collapsing glomerulopathy associated with COVID-19 infection in a heart transplant recipient. *J Heart Lung Transplant* 2020;39:855–7.
- [65] Kates OS, Fisher CE, Stankiewicz-Karita HC, Shepherd AK, Church EC, Kapnadak SG, et al. Earliest cases of coronavirus disease 2019 (COVID-19) identified in solid organ transplant recipients in the United States. *Am J Transplant* 2020;20:1885–90.
- [66] Keller BC, Le A, Sobhanie M, Colburn N, Burcham P, Rose-nheck J, et al. Early COVID-19 infection after lung transplantation. *Am J Transplant* 2020;20:2923–7.
- [67] Kim Y, Kwon O, Paek JH, Park WY, Jin K, Hyun M, et al. Two distinct cases with COVID-19 in kidney transplant recipients. *Am J Transplant* 2020;20:2269–75.
- [68] Kocak B, Arpali E, Akyollu B, Yelken B, Tekin S, Kanbay M, et al. Oligosymptomatic kidney transplant patients with COVID-19: do they pose a risk to other recipients? *Transplant Proc* 2020;52:2663–6.
- [69] Koczulla RA, Szczepanski B, Koteczki A, Kuhnert S, Hecker M, Askevold I, et al. SARS-CoV-2 infection in two patients following recent lung transplantation. *Am J Transplant* 2020;20:2928–32.
- [70] Kumar RN, Tanna SD, Shetty AA, Stosor V. COVID-19 in an HIV-positive kidney transplant recipient. *Transpl Infect Dis* 2020;22:e13338.
- [71] Lauterio A, Valsecchi M, Santambrogio S, De Carlis R, Merli M, Calini A, et al. Successful recovery from severe COVID-19 pneumonia after kidney transplantation: the interplay between immunosuppression and novel therapy including tocilizumab. *Transpl Infect Dis* 2020;22:e13334.
- [72] Lazareth H, Pere H, Binois Y, Chabannes M, Schurder J, Brunneau T, et al. COVID-19-related collapsing glomerulopathy in a kidney transplant recipient. *Am J Kidney Dis* 2020;76:590–4.
- [73] Li F, Cai J, Dong N. First cases of COVID-19 in heart transplantation from China. *J Heart Lung Transplant* 2020;39:496–7.
- [74] Li J, Chen G, Zhang M, Tu S, Chen C. Different clinical presentations of two renal transplant recipients with coronavirus disease 2019: a case report. *BMC Infect Dis* 2020;20:707.
- [75] Li Q, Cheng Q, Zhao Z, Dai N, Zeng L, Zhu L, et al. Novel coronavirus infection and acute kidney injury in two renal transplant recipients: a case report. *J Int Med Res* 2020;48:300060520964009.
- [76] Liu B, Wang Y, Zhao Y, Shi H, Zeng F, Chen Z. Successful treatment of severe COVID-19 pneumonia in a liver transplant recipient. *Am J Transplant* 2020;20:1891–5.
- [77] Ma BA, Hung IFN, Chan GCW, Tam AR, Chan SSK, Wong BCK, et al. Case of “relapsing” COVID-19 in a kidney transplant recipient. *Nephrology (Carlton)* 2020;25:933–6.
- [78] Machado DJB, Ianhez LE. COVID-19 pneumonia in kidney transplant recipients-where we are? *Transpl Infect Dis* 2020;22:e13306.
- [79] Maggi U, De Carlis L, Yiu D, Colledan M, Regalia E, Rossi G, et al. The impact of the COVID-19 outbreak on liver transplantation programs in Northern Italy. *Am J Transplant* 2020;20:1840–8.
- [80] Man Z, Jing Z, Huibo S, Bin L, Fanjun Z. Viral shedding prolongation in a kidney transplant patient with COVID-19 pneumonia. *Am J Transplant* 2020;20:2626–7.
- [81] Marx D, Moulin B, Fafi-Kremer S, Benotmane I, Gautier G, Perrin P, et al. First case of COVID-19 in a kidney transplant recipient treated with belatacept. *Am J Transplant* 2020;20:1944–6.
- [82] Massoumi H, Rocca J, Frager S, Kinkhabwala M. Changes in liver transplant center practice in response to coronavirus disease 2019: unmasking dramatic center-level variability. *Liver Transpl* 2020;26:1198–9.
- [83] Mathiasen VD, Oversoe SK, Ott P, Jensen-Fangel S, Leth S. Recovery of moderate coronavirus disease 2019 in a liver transplant recipient on continued immunosuppression: a case report. *Transplant Proc* 2020;52:2703–6.
- [84] Mathies D, Rauschnig D, Wagner U, Mueller F, Maibaum M, Binnemann C, et al. A case of SARS-CoV-2 pneumonia with successful antiviral therapy in a 77-year-old man with a heart transplant. *Am J Transplant* 2020;20:1925–9.
- [85] Meziyerh S, Zwart TC, van Etten RW, Janson JA, van Gelder T, Alwayn IPJ, et al. Severe COVID-19 in a renal transplant recipient: a focus on pharmacokinetics. *Am J Transplant* 2020;20:1896–901.
- [86] Modi AR, Koval CE, Taeye AJ, Modaresi Esfeh J, Egtesad B, Narayanan Menon KV, et al. Coronavirus disease 2019 in an orthotopic liver transplant recipient living with human immunodeficiency virus. *Transpl Infect Dis* 2020;22:e13351.
- [87] Mohamed MA, Kaur J, Wani F, Kichloo A, Bhanot R. Renal transplant recipient with concurrent COVID-19 and *Stenotrophomonas maltophilia* pneumonia treated with trimethoprim/sulfamethoxazole leading to acute kidney injury: a therapeutic dilemma. *Am J Case Rep* 2020;21:e926464.
- [88] Monne M, Asproni R, Fancello T, Piras G, Sulis V, Floris AR, et al. SARS-CoV-2 systemic infection in a kidney transplant recipient: sequence analysis in clinical specimens. *Eur Rev Med Pharmacol Sci* 2020;24:11914–8.
- [89] Namazee N, Mahmoudi H, Afzal P, Ghaffari S. Novel coronavirus 2019 pneumonia in a kidney transplant recipient. *Am J Transplant* 2020;20:2599–601.
- [90] Nikoupour H, Arasteh P, Gholami S, Nikeghbalian S. Liver transplantation and COVID-19: a case report and cross comparison between two identical twins with COVID-19. *BMC Surg* 2020;20:181.
- [91] Ning L, Liu L, Li W, Liu H, Wang J, Yao Z, et al. Novel coronavirus (SARS-CoV-2) infection in a renal transplant recipient: case report. *Am J Transplant* 2020;20:1864–8.
- [92] Qin J, Wang H, Qin X, Zhang P, Zhu L, Cai J, et al. Perioperative presentation of COVID-19 disease in a liver transplant recipient. *Hepatology* 2020;72:1491–3.
- [93] Renaud-Picard B, Gallais F, Ohana M, Zeyons F, Kretz B, Andre J, et al. Bilateral acute cardioembolic limb ischemia after coronavirus disease 2019 pneumonia in a lung transplant recipient: a case report. *Transplant Proc* 2020;52:2715–8.
- [94] Sakulkonkij P, Bruminhent J, Pankongngam C, Chalerm-phunchai N. A family cluster of diagnosed coronavirus disease 2019

(COVID-19) kidney transplant recipient in Thailand. *Immun Inflamm Dis* 2020;8:534–43.

[95] Seminari E, Colaneri M, Sambo M, Gallazzi I, Di Matteo A, Roda S, et al. SARS CoV-2 infection in a renal-transplanted patient: a case report. *Am J Transplant* 2020;20:1882–4.

[96] Serrano OK, Kutzler HL, Rochon C, Radojevic JA, Lawlor MT, Hammond JA, et al. Incidental COVID-19 in a heart-kidney transplant recipient with malnutrition and recurrent infections: implications for the SARS-CoV-2 immune response. *Transpl Infect Dis* 2020;22:e13367.

[97] Sessa A, Mazzola A, Lim C, Atif M, Pappatella J, Pourcher V, et al. COVID-19 in a liver transplant recipient: could iatrogenic immunosuppression have prevented severe pneumonia? A case report. *World J Gastroenterol* 2020;26:7076–84.

[98] Shingare A, Bahadur MM, Raina S. COVID-19 in recent kidney transplant recipients. *Am J Transplant* 2020;20:3206–9.

[99] Soquet J, Rousse N, Moussa M, Goeminne C, Deblauwe D, Vuotto F, et al. Heart retransplantation following COVID-19 illness in a heart transplant recipient. *J Heart Lung Transplant* 2020;39:983–5.

[100] Sperry BW, Khumri TM, Kao AC. Donor-derived cell-free DNA in a heart transplant patient with COVID-19. *Clin Transplant* 2020;34:e14070.

[101] Suwanwongse K, Shabarek N. Fatal outcome in a kidney-pancreas transplant recipient with COVID-19. *Cureus* 2020;12:e8691.

[102] Taha M, Sharma A, Taha M, Samavati L. Coronavirus disease 2019 in immunocompromised organ transplant recipients: a case report and review of the literature. *Transplant Proc* 2020;52:2698–702.

[103] Tantisattamo E, Reddy UG, Duong DK, Ferrey AJ, Ichii H, Dafoe DC, et al. Hyponatremia: a possible immuno-neuroendocrine interface with COVID-19 in a kidney transplant recipient. *Transpl Infect Dis* 2020;22:e13355.

[104] Tatar E, Karatas M, Bozaci I, Ari A, Acar T, Simsek C, et al. Intravenous immunoglobulin and favipiravir treatment for a kidney transplant patient with severe COVID-19 pneumonia. *Transfus Apher Sci* 2020;59:102904.

[105] Thammathiwat T, Tungsanga S, Tiankanon K, Torvorapanit P, Chumpangern W, Udomkarnjananun S, et al. A case of successful treatment of severe COVID-19 pneumonia with favipiravir and tocilizumab in post-kidney transplant recipient. *Transpl Infect Dis* 2021;23:e13388.

[106] Velioglu A, Tuglular S. Care of asymptomatic SARS-CoV-2 positive kidney transplant recipients. *Transpl Int* 2020;33:1331–2.

[107] Wang J, Li X, Cao G, Wu X, Wang Z, Yan T. COVID-19 in a kidney transplant patient. *Eur Urol* 2020;77:769–70.

[108] Westhoff TH, Seibert FS, Bauer F, Stervbo U, Anft M, Doevelaar AAN, et al. Allograft infiltration and meningoencephalitis by SARS-CoV-2 in a pancreas-kidney transplant recipient. *Am J Transplant* 2020;20:3216–20.

[109] Xu JJ, Samaha D, Mondhe S, Massicotte-Azarniouch D, Knoll G, Ruzicka M. Renal infarct in a COVID-19-positive kidney-pancreas transplant recipient. *Am J Transplant* 2020;20:3221–4.

[110] Yamada M, Rastogi P, Ince D, Thayyil A, Adela Mansilla M, Smith RJH, et al. Minimal change disease with nephrotic syndrome associated with coronavirus disease 2019 after apolipoprotein L1 risk variant kidney transplant: a case report. *Transplant Proc* 2020;52:2693–7.

[111] Zhong Z, Zhang Q, Xia H, Wang W, Liang W, Zhou W, et al. Clinical characteristics and immunosuppressant management of coronavirus disease 2019 in solid organ transplant recipients. *Am J Transplant* 2020;20:1916–21.

[112] Zhu L, Xu X, Ma K, Yang J, Guan H, Chen S, et al. Successful recovery of COVID-19 pneumonia in a renal transplant recipient with long-term immunosuppression. *Am J Transplant* 2020;20:1859–63.

[113] Ahluwalia M, Givertz MM, Mehra MM. A proposed strategy for management of immunosuppression in heart transplant patients with COVID-19. *Clin Transplant* 2020;34:e14032.

[114] Akalin E, Azzi Y, Bartash R, Seethamraju H, Parides M, Hemmige V, et al. COVID-19 and kidney transplantation. *N Engl J Med* 2020;382:2475–7.

[115] Akdur A, Karakaya E, Ayvazoglu Soy EH, Alshalabi O, Kirnap M, Arslan H, et al. Coronavirus disease (COVID-19) in kidney and liver transplant patients: a single-center experience. *Exp Clin Transplant* 2020;18:270–4.

[116] Al-Darzi W, Aurora L, Michaels A, Cowger J, Grafton G, Selektor Y, et al. Heart transplant recipients with confirmed 2019 novel coronavirus infection: the Detroit experience. *Clin Transplant* 2020;34:e14091.

[117] Ali T, Al-Ali A, Fajji L, Hammad E, Nazmi A, Alahmadi I, et al. Coronavirus disease-19: disease severity and outcomes of solid organ transplant recipients: different spectrums of disease in different populations? *Transplantation* 2021;105:121–7.

[118] Azzi Y, Parides M, Alani O, Loarte-Campos P, Bartash R, Forest S, et al. COVID-19 infection in kidney transplant recipients at the epicenter of pandemics. *Kidney Int* 2020;98:1559–67.

[119] Becchetti C, Zambelli MF, Pasulo L, Donato MF, Invernizzi F, Detry O, et al. COVID-19 in an international European liver transplant recipient cohort. *Gut* 2020;69:1832–40.

[120] Bosch F, Borner N, Kemmner S, Lampert C, Jacob S, Koliogiannis D, et al. Attenuated early inflammatory response in solid organ recipients with COVID-19. *Clin Transplant* 2020;34:e14027.

[121] Bossini N, Alberici F, Delbarba E, Valerio F, Manenti C, Posenti S, et al. Kidney transplant patients with SARS-CoV-2 infection: the Brescia Renal COVID task force experience. *Am J Transplant* 2020;20:3019–29.

[122] Caraffa R, Bagozzi L, Fiocco A, Bifulco O, Nadali M, Ponzoni M, et al. Coronavirus disease 2019 (COVID-19) in the heart transplant population: a single-centre experience. *Eur J Cardiothorac Surg* 2020;58:899–906.

[123] Carey SA, Afzal A, Jamil A, Williams S, Gottlieb RL. Outpatient COVID-19 surveillance testing in orthotopic heart transplant recipients. *Clin Transplant* 2020;34:e14105.

[124] Chen TY, Farghaly S, Cham S, Tatem LL, Sin JH, Rauda R, et al. COVID-19 pneumonia in kidney transplant recipients: focus on immunosuppression management. *Transpl Infect Dis* 2020;22:e13378.

[125] Christensen J, Kumar D, Moinuddin I, Bryson A, Kashi Z, Kimball P, et al. Coronavirus disease 2019 viremia, serologies, and clinical course in a case series of transplant recipients. *Transplant Proc* 2020;52:2637–41.

[126] Craig-Schapiro R, Salinas T, Lubetzky M, Abel BT, Sultan S, Lee JR, et al. COVID-19 outcomes in patients waitlisted for kidney transplantation and kidney transplant recipients. *Am J Transplant* 2021;21:1576–85.

[127] Cravedi P, Mothi SS, Azzi Y, Haverly M, Farouk SS, Perez-Saez MJ, et al. COVID-19 and kidney transplantation: results from the TANGO International Transplant Consortium. *Am J Transplant* 2020;20:3140–8.

[128] Demir E, Uyar M, Parmaksiz E, Sinangil A, Yelken B, Dirim AB, et al. COVID-19 in kidney transplant recipients: a multicenter experience in Istanbul. *Transpl Infect Dis* 2020;22:e13371.

[129] Devresse A, Belkhir L, Vo B, Ghaye B, Scohy A, Kabamba B, et al. COVID-19 infection in kidney transplant recipients: a single-center case series of 22 cases from Belgium. *Kidney Med* 2020;2:459–66.

[130] Elias M, Pievani D, Randoux C, Louis K, Denis B, Delion A, et al. COVID-19 infection in kidney transplant recipients: disease incidence and clinical outcomes. *J Am Soc Nephrol* 2020;31:2413–23.

[131] Fava A, Cucchiari D, Montero N, Toapanta N, Centellas FJ, Vila-Santandreu A, et al. Clinical characteristics and risk factors for severe COVID-19 in hospitalized kidney transplant recipients: a multicentric cohort study. *Am J Transplant* 2020;20:3030–41.

[132] Felldin M, Softeland JM, Magnusson J, Ekberg J, Karason K, Schult A, et al. Initial report from a Swedish high-volume transplant

center after the first wave of the COVID-19 pandemic. *Transplantation* 2021;105:108–14.

- [133] Garcia-Cosio MD, Flores Hernan M, Caravaca Perez P, Lopez-Medrano F, Arribas F, Delgado Jimenez J. Heart transplantation during the COVID-19 pandemic: follow-up organization and characteristics of infected patients. *Rev Esp Cardiol (Engl Ed)* 2020;73:1077–80.
- [134] Ghaffari Rahbar M, Nafar M, Khoshdel A, Dalili N, Abrishami A, Firouzan A, et al. Low rate of COVID-19 pneumonia in kidney transplant recipients—a battle between infection and immune response? *Transpl Infect Dis* 2020;22:e13406.
- [135] Hartzell S, Bin S, Benedetti C, Haverly M, Gallon L, Zaza G, et al. Evidence of potent humoral immune activity in COVID-19-infected kidney transplant recipients. *Am J Transplant* 2020;20:3149–61.
- [136] Husain SA, Dube G, Morris H, Fernandez H, Chang JH, Paget K, et al. Early outcomes of outpatient management of kidney transplant recipients with coronavirus disease 2019. *Clin J Am Soc Nephrol* 2020;15:1174–8.
- [137] Lum E, Bunnapradist S, Multani A, Beaird OE, Carlson M, Gaynor P, et al. Spectrum of coronavirus disease 2019 outcomes in kidney transplant recipients: a single-center experience. *Transplant Proc* 2020;52:2654–8.
- [138] Mehta SA, Leonard J, Labella P, Cartiera K, Soomro I, Neumann H, et al. Outpatient management of kidney transplant recipients with suspected COVID-19—single-center experience during the New York City surge. *Transpl Infect Dis* 2020;22:e13383.
- [139] Miarons M, Larrosa-Garcia M, Garcia-Garcia S, Los-Arcos I, Moreso F, Berastegui C, et al. COVID-19 in solid organ transplantation: a matched retrospective cohort study and evaluation of immunosuppression management. *Transplantation* 2021;105:138–50.
- [140] Mucchegiani F, Baroni GS, Vivarelli M. Mild impact of SARS-CoV-2 infection on the entire population of liver transplant recipients: the experience of an Italian centre based in a high-risk area. *Updates Surg* 2020;72:1291–3.
- [141] Montagud-Marrahi E, Cofan F, Torregrosa JV, Cucchiari D, Ventura-Aguir P, Revuelta I, et al. Preliminary data on outcomes of SARS-CoV-2 infection in a Spanish single center cohort of kidney recipients. *Am J Transplant* 2020;20:2958–9.
- [142] Patrono D, Lupo F, Canta F, Mazza E, Mirabella S, Corcione S, et al. Outcome of COVID-19 in liver transplant recipients: a preliminary report from Northwestern Italy. *Transpl Infect Dis* 2020;22:e13353.
- [143] Rivinius R, Kaya Z, Schramm R, Boeken U, Provaznik Z, Heim C, et al. COVID-19 among heart transplant recipients in Germany: a multicenter survey. *Clin Res Cardiol* 2020;109:1531–9.
- [144] Roberts MB, Izzy S, Tahir Z, Al Jarrah A, Fishman JA, El Khoury J. COVID-19 in solid organ transplant recipients: dynamics of disease progression and inflammatory markers in ICU and non-ICU admitted patients. *Transpl Infect Dis* 2020;22:e13407.
- [145] Rodriguez-Cubillo B, de la Higuera MAM, Lucena R, Franci EV, Hurtado M, Romero NC, et al. Should cyclosporine be useful in renal transplant recipients affected by SARS-CoV-2? *Am J Transplant* 2020;20:3173–81.
- [146] Travi G, Rossotti R, Merli M, Sacco A, Perricone G, Lauterio A, et al. Clinical outcome in solid organ transplant recipients with COVID-19: a single-center experience. *Am J Transplant* 2020;20:2628–9.
- [147] Trujillo H, Caravaca-Fontan F, Sevillano A, Gutierrez E, Fernandez-Ruiz M, Lopez-Medrano F, et al. Tocilizumab use in kidney transplant patients with COVID-19. *Clin Transplant* 2020;34:e14072.
- [148] Tschopp J, L'Huillier AG, Mombelli M, Mueller NJ, Khanna N, Garzoni C, et al. First experience of SARS-CoV-2 infections in solid organ transplant recipients in the Swiss Transplant Cohort Study. *Am J Transplant* 2020;20:2876–82.
- [149] Varghese J, Malleeswaran S, Patcha RV, Appusamy E, Karnan P, Kapoor D, et al. A multicentric experience on living donor liver transplantation in coronavirus disease 2019 hotspots in India. *Liver Transpl* 2021;27:1334–8.
- [150] Yi SG, Rogers AW, Saharia A, Aoun M, Faour R, Abdelrahim M, et al. Early experience with COVID-19 and solid organ transplantation at a US high-volume transplant center. *Transplantation* 2020;104:2208–14.
- [151] Abrishami A, Samavat S, Behnam B, Arab-Ahmadi M, Nafar M, Sanei Taheri M. Clinical course, imaging features, and outcomes of COVID-19 in kidney transplant recipients. *Eur Urol* 2020;78:281–6.
- [152] Alberici F, Delbarba E, Manenti C, Econimo L, Valerio F, Pola A, et al. A single center observational study of the clinical characteristics and short-term outcome of 20 kidney transplant patients admitted for SARS-CoV2 pneumonia. *Kidney Int* 2020;97:1083–8.
- [153] Aversa M, Benvenuto L, Anderson M, Shah L, Robbins H, Pereira M, et al. COVID-19 in lung transplant recipients: a single center case series from New York City. *Am J Transplant* 2020;20:3072–80.
- [154] Banerjee D, Popoola J, Shah S, Ster IC, Quan V, Phanish M. COVID-19 infection in kidney transplant recipients. *Kidney Int* 2020;97:1076–82.
- [155] Benotmane I, Gautier-Vargas G, Wendling MJ, Perrin P, Velay A, Bassand X, et al. In-depth virological assessment of kidney transplant recipients with COVID-19. *Am J Transplant* 2020;20:3162–72.
- [156] Dhampalwar S, Saigal S, Choudhary N, Saraf N, Bhangui P, Rastogi A, et al. Outcomes of coronavirus disease 2019 in living donor liver transplant recipients. *Liver Transpl* 2020;26:1665–6.
- [157] Fung M, Chiu CY, DeVoe C, Doernberg SB, Schwartz BS, Langelier C, et al. Clinical outcomes and serologic response in solid organ transplant recipients with COVID-19: a case series from the United States. *Am J Transplant* 2020;20:3225–33.
- [158] Ketcham SW, Adie SK, Malliett A, Abdul-Aziz AA, Bitar A, et al. Coronavirus disease-2019 in heart transplant recipients in southeastern Michigan: a case series. *J Card Fail* 2020;26:457–61.
- [159] Kolonko A, Dudzicz S, Wiecek A, Krol R. COVID-19 infection in solid organ transplant recipients: a single-center experience with patients immediately after transplantation. *Transpl Infect Dis* 2021;23:e13381.
- [160] Latif F, Farr MA, Clerkin KJ, Habal MV, Takeda K, Naka Y, et al. Characteristics and outcomes of recipients of heart transplant with coronavirus disease 2019. *JAMA Cardiol* 2020;5:1165–9.
- [161] Lee BT, Perumalswami PV, Im GY, Florman S, Schiano TD, Study Group COBE. COVID-19 in liver transplant recipients: an initial experience from the US epicenter. *Gastroenterology* 2020;159:1176–8.
- [162] Lima B, Gibson GT, Vullaganti S, Malhame K, Maybaum S, Hussain ST, et al. COVID-19 in recent heart transplant recipients: clinicopathologic features and early outcomes. *Transpl Infect Dis* 2020;22:e13382.
- [163] Loinaz C, Marcacuzco A, Fernandez-Ruiz M, Caso O, Cambra F, San Juan R, et al. Varied clinical presentation and outcome of SARS-CoV-2 infection in liver transplant recipients: initial experience at a single center in Madrid, Spain. *Transpl Infect Dis* 2020;22:e13372.
- [164] Lubetzky M, Aull MJ, Craig-Schapiro R, Lee JR, Marku-Podvorica J, Salinas T, et al. Kidney allograft recipients, immunosuppression, and coronavirus disease-2019: a report of consecutive cases from a New York City transplant center. *Nephrol Dial Transplant* 2020;35:1250–61.
- [165] Maritati F, Cerutti E, Zuccatosta L, Fiorentini A, Finale C, Ficosco M, et al. SARS-CoV-2 infection in kidney transplant recipients: experience of the Italian Marche region. *Transpl Infect Dis* 2020;22:e13377.
- [166] Mella A, Mingozzi S, Gallo E, Lavacca A, Rossetti M, Clari R, et al. Case series of six kidney transplanted patients with COVID-19 pneumonia treated with tocilizumab. *Transpl Infect Dis* 2020;22:e13348.

- [167] Morillas JA, Marco Canosa F, Srinivas P, Asadi T, Calabrese C, Rajendram P, et al. Tocilizumab therapy in 5 solid and composite tissue transplant recipients with early ARDS due to SARS-CoV-2. *Am J Transplant* 2020;20:3191–7.
- [168] Nair V, Jandovitz N, Hirsch JS, Nair G, Abate M, Bhaskaran M, et al. COVID-19 in kidney transplant recipients. *Am J Transplant* 2020;20:1819–25.
- [169] Rahman F, Liu STH, Taimur S, Jacobs S, Sullivan T, Dunn D, et al. Treatment with convalescent plasma in solid organ transplant recipients with COVID-19: experience at large transplant center in New York City. *Clin Transplant* 2020;34:e14089.
- [170] Silva F, Cipriano A, Cruz H, Tavares J, Fragoso J, Malheiro J, et al. SARS-CoV-2 infection in kidney transplant recipients: early report of five cases. *Transpl Infect Dis* 2021;23:e13394.
- [171] Singhvi A, Barghash M, Lala A, Mitter SS, Parikh A, Oliveros E, et al. Challenges in heart transplantation during COVID-19: a single-center experience. *J Heart Lung Transplant* 2020;39:894–903.
- [172] Trujillo H, Caravaca-Fontan F, Sevillano A, Gutierrez E, Caro J, Gutierrez E, et al. SARS-CoV-2 infection in hospitalized patients with kidney disease. *Kidney Int Rep* 2020;5:905–9.
- [173] Tzuket K, Abel R, Mor Yosef Levi I, Gork I, Yosha Orpaz L, Azmanov H, et al. The challenge of treating kidney transplant recipients infected with COVID-19: report of the first cases in Israel. *Isr Med Assoc J* 2020;22:602–4.
- [174] Verleden GM, Godinas L, Lorent N, Van Bleyenbergh P, Dupont L, Delcroix M, et al. COVID-19 in lung transplant patients: a case series. *Am J Transplant* 2020;20:3234–8.
- [175] Zhang H, Chen Y, Yuan Q, Xia QX, Zeng XP, Peng JT, et al. Identification of kidney transplant recipients with coronavirus disease 2019. *Eur Urol* 2020;77:742–7.
- [176] Zhu L, Gong N, Liu B, Lu X, Chen D, Chen S, et al. Coronavirus disease 2019 pneumonia in immunosuppressed renal transplant recipients: a summary of 10 confirmed cases in Wuhan, China. *Eur Urol* 2020;77:748–54.
- [177] Coll E, Fernandez-Ruiz M, Sanchez-Alvarez JE, Martinez-Fernandez JR, Crespo M, Gayoso J, et al. COVID-19 in transplant recipients: the Spanish experience. *Am J Transplant* 2020;21:1825–37.
- [178] Iacovoni A, Boffini M, Pidello S, Simonato E, Barbero C, Sebastiani R, et al. A case series of novel coronavirus infection in heart transplantation from 2 centers in the pandemic area in the North of Italy. *J Heart Lung Transplant* 2020;39:1081–8.
- [179] Kute VB, Bhalla AK, Guleria S, Ray DS, Bahadur MM, Shingare A, et al. Clinical profile and outcome of COVID-19 in 250 kidney transplant recipients: a multicenter cohort study from India. *Transplantation* 2021;105:851–60.
- [180] Molnar MA, Bhalla A, Azhar A, Tsujita M, Talwar M, Balaraman V, et al. Outcomes of critically ill solid organ transplant patients with COVID-19 in the United States. *Am J Transplant* 2020;20:3061–71.
- [181] Ozturk S, Turgutalp K, Arici M, Odabas AR, Altiparmak MR, Aydin Z, et al. Mortality analysis of COVID-19 infection in chronic kidney disease, haemodialysis and renal transplant patients compared with patients without kidney disease: a nationwide analysis from Turkey. *Nephrol Dial Transplant* 2020;35:2083–95.
- [182] Passamonti SM, Cannavo A, Trunzo V, Caporale V, Buoncore R, DeFeo TM. Solid organ transplantation in the coronavirus disease 2019 era: “The Great Bet” in the North Italy Transplant Program area. *Transplant Proc* 2020;52:2631–6.
- [183] Saez-Gimenez B, Berastegui C, Barrecheguren M, Revilla-Lopez E, Los Arcos I, Alonso R, et al. COVID-19 in lung transplant recipients: a multicenter study. *Am J Transplant* 2020;21:1816–24.
- [184] Webb GJ, Marjot T, Cook JA, Aloman C, Armstrong MJ, Brenner EJ, et al. Outcomes following SARS-CoV-2 infection in liver transplant recipients: an international registry study. *Lancet Gastroenterol Hepatol* 2020;5:1008–16.
- [185] Chaudhry ZS, Williams JD, Vahia A, Fadel R, Parraga Acosta T, Prashar R, et al. Clinical characteristics and outcomes of COVID-19 in solid organ transplant recipients: a cohort study. *Am J Transplant* 2020;20:3051–60.
- [186] Pereira MR, Aversa MM, Farr MA, Miko BA, Aaron JG, Mohan S, et al. Tocilizumab for severe COVID-19 in solid organ transplant recipients: a matched cohort study. *Am J Transplant* 2020;20:3198–205.
- [187] Sharma P, Chen V, Fung CM, Troost JP, Patel VN, Combs M, et al. COVID-19 outcomes among solid organ transplant recipients: a case-control study. *Transplantation* 2021;105:128–37.
- [188] British Transplantation Society. Guidance on the management of transplant recipients diagnosed with or suspected of having COVID-19. <https://bts.org.uk/wp-content/uploads/2021/01/Clinical-management-of-transplants-and-immunosuppression-22nd-January-2021-FINAL.pdf> [accessed 07.01.21].
- [189] International Society of Heart and Lung Transplantation. Guidance from the International Society of Heart and Lung Transplantation regarding the SARS CoV-2 pandemic. https://ishlt.org/ishlt/media/documents/SARS-CoV-2_Guidance-for-Cardiothoracic-Transplant-and-VAD-centers.pdf [accessed 07.01.21].
- [190] Transplantation Society. Guidance on coronavirus disease 2019 (COVID-19) for transplant clinicians. <https://tts.org/23-tid/tid-news/657-tid-update-and-guidance-on-2019-novel-coronavirus-2019-ncov-for-transplant-id-clinicians> [accessed 07.01.21].
- [191] American Association for the Study of Liver Diseases. Clinical best practice advice for hepatology and liver transplant providers during the COVID-19 pandemic: AASLD Expert Panel Consensus Statement. <https://www.aasld.org/sites/default/files/2021-03/AASLD-COVID19-ExpertPanelConsensusStatement-March92021.pdf> [accessed 07.01.21].
- [192] Canadian Society of Transplantation. Consensus guidance and recommendations for organ donation and transplantation services during COVID-19 pandemic. https://professionaleducation.blood.ca/sites/msi/files/20210406_covid-19_consensus_guidance.pdf [accessed 07.01.21].
- [193] American Society of Transplantation. 2019-nCoV (coronavirus): FAQs for organ transplantation. <https://www.myast.org/sites/default/files/COVID19%20FAQ%20Tx%20Centers%2004.12.2021.pdf> [accessed 07.01.21].
- [194] Fang X, Li S, Yu H, Wang P, Zhang Y, Chen Z, et al. Epidemiological, comorbidity factors with severity and prognosis of COVID-19: a systematic review and meta-analysis. *Aging (Albany NY)* 2020;12:12493–503.
- [195] Alkhoul M, Nanjundappa A, Annie F, Bates MC, Bhatt DL. Sex differences in case fatality rate of COVID-19: insights from a multinational registry. *Mayo Clin Proc* 2020;95:1613–20.
- [196] Karagiannidis C, Mostert C, Hentschker C, Voshaar T, Malzahn J, Schillinger G, et al. Case characteristics, resource use, and outcomes of 10 021 patients with COVID-19 admitted to 920 German hospitals: an observational study. *Lancet Respir Med* 2020;8:853–62.
- [197] Belli LS, Fondevila C, Cortesi PA, Conti S, Karam V, Adam R, et al. Protective role of tacrolimus, deleterious role of age and comorbidities in liver transplant recipients with COVID-19: results from the ELITA/ELTR multi-center European study. *Gastroenterology* 2021;160:1151–63.
- [198] Colmenero J, Rodríguez-Perálvarez M, Salcedo M, Arias-Milla A, Muñoz-Serrano A, Graus J, et al. Epidemiological pattern, incidence, and outcomes of COVID-19 in liver transplant patients. *J Hepatol* 2021;74:148–55.
- [199] RECOVERY Collaborative Group; Horby P, Lim WS, Emberson JR, Mafham M, Bell JL, et al. Dexamethasone in hospitalized patients with COVID-19. *N Engl J Med* 2021;384:693–704.
- [200] Barlow-Pay F, Htut TW, Khezrian M, Myint PK. Systematic review of immunosuppressant guidelines in the COVID-19 pandemic. *Ther Adv Drug Saf* 2021;12:2042098620985687.
- [201] Hirsch JS, Ng JH, Ross DW, Sharma P, Shah HH, Barnett RL, et al. Acute kidney injury in patients hospitalized with COVID-19. *Kidney Int* 2020;98:209–18.