COVID-19 pandemic and worldwide organ transplantation: a population-based study

Olivier Aubert, Daniel Yoo*, Dina Zielinski*, Emanuele Cozzi*, Massimo Cardillo, Michael Dürr, Beatriz Domínguez-Gil, Elisabeth Coll, Margarida Ivo Da Silva, Ville Sallinen, Karl Lemström, Karsten Midtvedt, Camilo Ulloa, Franz Immer, Annemarie Weissenbacher, Natalie Vallant, Nikolina Basic-Jukic, Kazunari Tanabe, Georgios Papatheodoridis, Georgia Menoudakou, Martin Torres, Carlos Soratti, Daniela Hansen Krogh, Carmen Lefaucheur, Gustavo Ferreira, Helio Tedesco Silva Jr, David Hartell, John Forsythe, Lisa Mumford, Peter P Reese, François Kerbaul, Christian Jacquelinet*, Serge Vogelaar*, Vassilios Papalois*, Alexandre Loupy**

Summary

Background Preliminary data suggest that COVID-19 has reduced access to solid organ transplantation. However, the global consequences of the COVID-19 pandemic on transplantation rates and the effect on waitlisted patients have not been reported. We aimed to assess the effect of the COVID-19 pandemic on transplantation and investigate if the pandemic was associated with heterogeneous adaptation in terms of organ transplantation, with ensuing consequences for waitlisted patients.

Methods In this population-based, observational, before-and-after study, we collected and validated nationwide cohorts of consecutive kidney, liver, lung, and heart transplants from 22 countries. Data were collected from Jan 1 to Dec 31, 2020, along with data from the same period in 2019. The analysis was done from the onset of the 100th cumulative COVID-19 case through to Dec 31, 2020. We assessed the effect of the pandemic on the worldwide organ transplantation rate and the disparity in transplant numbers within each country. We estimated the number of waitlisted patient life-years lost due to the negative effects of the pandemic. The study is registered with ClinicalTrials.gov, NCT04416256.

Findings Transplant activity in all countries studied showed an overall decrease during the pandemic. Kidney transplantation was the most affected, followed by lung, liver, and heart. We identified three organ transplant rate patterns, as follows: countries with a sharp decrease in transplantation rate with a low COVID-19-related death rate; countries with a moderate decrease in transplantation rate with a moderate COVID-19-related death rate; and countries with a slight decrease in transplantation rate despite a high COVID-19-related death rate. Temporal trends revealed a marked worldwide reduction in transplant activity during the first 3 months of the pandemic, with losses stabilising after June, 2020, but decreasing again from October to December, 2020. The overall reduction in transplants during the observation time period translated to 48 239 waitlisted patient life-years lost.

Interpretation We quantified the impact of the COVID-19 pandemic on worldwide organ transplantation activity and revealed heterogeneous adaptation in terms of organ transplantation, both at national levels and within countries, with detrimental consequences for waitlisted patients. Understanding how different countries and health-care systems responded to COVID-19-related challenges could facilitate improved pandemic preparedness, notably, how to safely maintain transplant programmes, both with immediate and non-immediate life-saving potential, to prevent loss of patient life-years.

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Introduction

The COVID-19 pandemic has placed a tremendous burden on health-care systems worldwide, which have struggled to address the surge of critically ill patients and protect health-care workers from undue risk of infection. Solid organ transplantation provides major benefits to patients with end-stage organ disease, including longer survival and better quality of life.[1,2] Despite the urgent need for many waitlisted patients worldwide to receive transplants, preliminary data suggest substantial reductions in transplantation procedures in some countries since the COVID-19 outbreak.[3–11] However, there is a paucity of available data concerning the effects of the pandemic on worldwide transplantation rates and how transplantation policies have changed in response to risk of infection and death associated with COVID-19.[12–14]

The consequences of COVID-19 are not only due to infectious deaths but also the impact of the pandemic on diverse health-care services, including disruptions to or delays in cancer treatment.[15] However, the overall burden of the COVID-19 pandemic on health care is difficult to capture since, for many health-care domains in different

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*Contributed equally

Université de Paris, INSERM, PARCC, Paris Translational Research Centre for Organ Transplantation, Paris, France (O Aubert MD, D Yoo MPH, D Zielinski PhD, C Lefaucheur MD, P P Reese MD, A Loupy MD); **Kidney Transplant Department, Necker Hospital, Assistance Publique—Hôpitaux de Paris, Paris, France** (O Aubert, A Loupy); **Transplant Immunology Unit, Department of Cardio-Thoracic, Vascular Sciences and Public Health, University of Padova, Padua, Italy** (E Cozzi MD); **Italian National Transplant Center, Istituto Superiore di Sanità, Rome, Italy** (E Cozzi, M Cardillo MD); **Division of Nephrology and Internal Intensive Care Medicine, Charité-Universitätsmedizin, Berlin, Germany** (M Dürr MD); **Organización Nacional de Transplantes, Madrid, Spain** (B Domínguez-Gil MD, E Coll MD); **Instituo portuges de sangue e da transplantacao, Lisbon, Portugal** (M I Da Silva MD); **Department of Transplantation and Liver Surgery** (V Sallinen MD) **and Department of Cardiothoracic Surgery** (K Lemström MD), **University of Helsinki and Helsinki University Hospital, Helsinki, Finland; Department of Transplant Medicine, Oslo University Hospital, Rikshospitalet, Oslo, Norway** (K Midtvedt MD); **Nephrology Department, Clínica Alemana de Santiago—UDD, Santiago, Chile** (C Ulloa MD); **Swisstransplant, Bern, Switzerland** (F Immer MD); **Department of Visceral, Transplant and Thoracic**

Surgery, Center of Operative Medicine, Medical University of Innsbruck, Innsbruck, Austria (A Weissenbacher MD); **Department of Transplant Surgery** (N Vallant MD) **and Department of Surgery** (V Papalois MD), **Faculty of Medicine, Imperial College London, London, UK; Department of Nephrology, Arterial Hypertension, Dialysis and Transplantation, University Hospital Centre Zagreb, School of Medicine, University of Zagreb, Zagreb, Croatia** (N Basic-Jukic MD); **Department of Urology, Tokyo Women's Medical University, Tokyo, Japan** (K Tanabe MD); **Hellenic Transplant Organization, Athens, Greece** (G Papatheodoridis PhD, G Menoudakou MSc); **Instituto Nacional Central Único Coordinador de Ablación e Implante (INCUCAI), Buenos Aires, Argentina** (M Torres MD, C Soratti MD, D Hansen Krogh); **Department of Nephrology and Kidney Transplantation, Saint-Louis Hospital, Assistance Publique-Hôpitaux de Paris, Paris, France** (C Lefaucheur); **Department of Medicine, Santa Casa de Juiz de Fora, Juiz de Fora, Brazil** (G Ferreira MD); **Division of Nephrology, Hospital do Rim, Universidade Federal de São Paulo, São Paulo, Brazil** (H T Silva Jr MD); **Canadian Blood Services, Ottawa, ON, Canada** (D Hartell MA); **NHS Blood and Transplant, Stoke Gifford, Bristol, UK** (J Forsythe MD); **Statistics and Clinical Studies, NHS Blood and Transplant, Bristol, UK** (L Mumford MSc); **Department of Medicine, Renal-Electrolyte and Hypertension Division** (P P Reese) **and Center for Clinical Epidemiology and Biostatistics, Perelman School of Medicine** (P P Reese), **University of Pennsylvania, Philadelphia, PA, USA; Agence de la Biomédecine, Saint Denis la Plaine, France** (F Kerbaul MD, C Jacquelinet MD); **Eurotransplant International Foundation, Leiden, Netherlands** (S Vogelaar MD)

Correspondence to:
Prof Alexandre Loupy, Paris Translational Research Center for Organ Transplantation, Paris 75015, France
alexandre.loupy@inserm.fr

Research in context

Evidence before this study

We searched PubMed on May 3, 2021, using the following search terms: (transplantation) AND (donation) AND (COVID* OR SARS-CoV-2 OR SARS-CoV), with no language restrictions, and summarised the results. We identified 43 regional or national transplant publications comprising preliminary reports, opinion pieces, correspondence, and letters. To our knowledge, no study measured the global and systemic impact of the pandemic on organ transplantation, assessed the regional and national disparities in organ transplantation, revealed the temporal trends in organ transplantation between the COVID-19 pandemic waves, or assessed the consequences for waitlisted patients.

Added value of this study

To our knowledge, this is the first study to include nationwide data from 22 countries depicting the temporal trend between the COVID-19 outbreak and overall organ transplantation activities across and within countries since the start of the pandemic from Jan 1 to Dec 31, 2020. We observed a sharp decrease in overall organ transplantations and transplants with immediate life-saving impact, such as liver, lung, and heart transplantation. We found that an estimated 48 000 patient life-years were lost overall during the observation time. Given the disparities between countries in terms of COVID-19 incidence and the impact on solid organ transplantation, as well as the dynamic nature of transplant data across countries over time, we created an open-access website: covidtransplants.org. This website will allow researchers and clinicians to compare the impact of COVID-19 on transplantation rates worldwide, which could inform national and regional decision making.

Implications of all the available evidence

We investigated the global impact of the COVID-19 pandemic on organ transplantation, laying the groundwork to understand how health-care systems adapted to the pandemic and improve decision making if the pandemic persists, particularly given the emergence of new SARS-CoV-2 variants of concern.

nations, there are no structured data registries. Organ transplantation is well regulated in many countries, with a specific nationwide day-to-day reporting scheme, offering a unique opportunity to assess the effect of the pandemic on health-care systems.[16] Changes in the number of transplants compared with the previous year could reveal the consequences associated with the pandemic.

Worldwide assessment and comparison of organ transplantation also offers valuable insight into the effects of the pandemic because of the heterogeneity of responses to the challenge. For example, in the USA, public health regulations are often imposed at the state level, whereas in smaller countries more direct federal coordination initiatives were established. This variation could help define which approach offers the best chance of adapting to the burden of the pandemic and improving systems in response to both ongoing and future crises, especially given the emergence of new SARS-CoV-2 variants of concern.[17,18]

The variability in worldwide health-care system structure and function, as well as in COVID-19 prevalence, offers an opportunity to compare the differential effects of the pandemic on transplantation rates, the impact of which will continue after the pandemic has subsided. Furthermore, it is important to evaluate the cost of the cessation of transplantation due to the pandemic, which can be quantified as the number of life-years lost for patients who could not benefit from transplants because of the pandemic. The aim of this study was to assess the impact of the COVID-19 pandemic on transplantation and if the pandemic would be associated with heterogeneous adaptation in terms of organ transplantation, with ensuing consequences for waitlisted patients.

Methods

Study population

This cohort study in 22 countries comprised all consecutive organ transplants, including kidney, liver, lung, and heart allografts, done during the COVID-19 outbreak and the year before the pandemic. Multiorgan transplants were counted separately. For example, one liver–kidney transplant was considered one liver transplant and one kidney transplant. Transplanted organs included both adult and paediatric transplants from deceased and living donors. Transplant data were collected from the beginning of the COVID-19 outbreak in 2020 (the study inclusion period was from Jan 1 to Dec 31, 2020), along with data from the same time period in 2019.[19] The 22 countries included 16 in Europe (Austria, Belgium, Croatia, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Norway, Portugal, Slovenia, Spain, Switzerland, and the UK), two in North America (Canada and the USA), three in South America (Argentina, Brazil, and Chile), and Japan. For each country, the type of organ, type of donor, date of transplant, and region of transplantation (regional data were only available for the USA, by state) were accessed.

Country inclusion rationale

The European Society for Organ Transplantation (ESOT) taskforce on COVID-19 initiated the study on Feb 1, 2020. A dedicated working group guided the initiative with the aim of addressing the impact of the pandemic on organ donation and transplantation. 46 countries were contacted, including members of the American Society of Transplantation, Asian Society of Transplantation, ESOT, and The Transplantation Society. After the collaboration proposal, a protocol including study aims,

data template, definition of variables, data dictionary, and data curation process, including creation of a General Data Protection Regulation-compliant server to house the data, was sent to organ procurement agencies on behalf of the ESOT taskforce and COVID-19 working group. Among all contacted countries, seven did not respond, 12 declined to collaborate, and five responded positively but were unable to obtain necessary data. Based on the annual data available from the official WHO and Global Observatory on Donation and Transplantation (GODT), the 22 countries included had 86 942 solid organs procured for transplantation in 2019, which represented 62·4% of the total worldwide transplant activity.

Organ transplant and COVID-19 data sources

We obtained data related to the number of solid organ transplants from national transplant authorities and Eurotransplant (an international organ exchange organisation), which prospectively record these data (appendix p 2). Sources include centralised systems such as NHS Blood and Transplant in the UK, Eurotransplant in Europe, Agence de la Biomédecine in France, and the United Network for Organ Sharing in the USA. Data procurement systems used by the relevant competent authorities are described in more detail in the appendix (p 2). The data for national and regional COVID-19 cumulative prevalence and related deaths were obtained from the Center for Systems Science and Engineering at Johns Hopkins University.[20] Disparities in COVID-19-related data collection and reporting have been reported and the definition of cases has been updated by each country since the onset of the pandemic, with discrepancies in testing accuracy and reporting. The Johns Hopkins database is one of three key sources providing regular updates of global COVID-19 cases and deaths, in addition to WHO and the European Centre for Disease Prevention and Control. Overall, the trends are highly similar among these data sources. Johns Hopkins numbers are higher than those reported by WHO and the European Centre for Disease Prevention and Control, which might be due to the inclusion of presumptive positive cases (ie, those confirmed by local but not national laboratories). Furthermore, the Johns Hopkins data have been widely used by many national agencies and institutions and in peer-reviewed publications.[21–24]

Study timeline

Different testing capacities have resulted in delayed reporting and under-reporting of COVID-19 cases. As the scope of this study included organ transplantation during the pandemic, it was necessary to apply a uniform definition of the beginning of the disease outbreak in each country. However, for emerging diseases, there are no criteria to determine how many infected individuals are needed to declare that an outbreak is occurring,[25] and there is no standard consensus for establishing a timeline regarding the study of COVID-19-related data. Given the pandemic did not start spreading in all countries at the same moment, it would not be appropriate to use the same start date for the inclusion period for all countries. Therefore, we used the 100th reported cumulative COVID-19 case as a proxy for the spread to account for the disparate timepoints in different countries. We observed changes in transplant activity across all 22 countries after applying this threshold.

We did not have access to historical monthly data before 2019 in some countries. However, we compared the overall annual totals across all 22 included countries for kidney, liver, lung, and heart transplants and observed a steady increase from 2010 to 2019 according to annual transplant data from the GODT (appendix p 5). Several countries showed slight variation in transplant activity from 2010 to 2019 (Austria, Croatia, Portugal, and Germany showed a steady decrease). However, given the overall increasing trend worldwide, we compared transplant numbers in 2020 with the same time interval in 2019, rather than using a measure of central tendency because of insufficient daily and monthly data.

See Online for appendix

Outcomes

The primary objective was to assess the effect of the COVID-19 pandemic on worldwide organ transplantation activity based on the number of kidney, liver, lung, and heart transplants from deceased and living donors compared with the same period of time the previous year. The secondary objective was the regional effect of the COVID-19 pandemic defined by the disparity in transplant numbers within each country.

Statistical analysis

All transplant data were smoothed in two steps: first, by calculating a 14-day moving average—14-day moving average was selected instead of 7-day because of the sparsity of data for some countries—and second, by applying locally estimated scatterplot smoothing to the 14-day moving average.[26] Additionally, we compared the trends and diminutions in the number of transplants in 2019 and 2020 by country, continent, and across all 22 countries. Starting from the date of the 100th recorded COVID-19 case for each country until the end of follow-up, the LOESS smoothed 14-day moving average of transplants for each country was included in the analysis.

The correlation between COVID-19-related deaths and worldwide organ transplant activity is represented by bubble charts, which include the following information: x-axis, COVID-19 deaths per million inhabitants calculated from data retrieved from the Johns Hopkins COVID-19 Data Repository and the World Bank (population size per country in 2019); y-axis, percent diminution of transplant rate in 2020 from the 100th cumulative COVID-19 case to Dec 31, 2020, compared with the same period of time in 2019; bubble size, number of transplants in 2019 according to the

	Overall	Kidney	Liver	Lung	Heart
Argentina*	−564 (−60·91%)	−429 (−64·32%)	−107 (−56·61%)	−8 (−47·06%)	−20 (−37·74%)
Austria	−56 (−10·22%)	−53 (−17·91%)	6 (5·08%)	0	−9 (−16·36%)
Belgium	−166 (−22·46%)	−78 (−22·67%)	−49 (−20·68%)	−16 (−17·39%)	−23 (−34·85%)
Brazil	−2174 (−28·9%)	−1735 (−32·89%)	−307 (−16·51%)	−50 (−56·82%)	−82 (−27·42%)
Canada	−227 (−9·86%)	−229 (−16·29%)	5 (1·09%)	4 (1·47%)	−7 (−4·24%)
Chile*	−47 (−54·02%)	−23 (−46·94%)	−10 (−45·45%)	−6 (−85·71%)	−8 (−88·89%)
Croatia	−85 (−37·28%)	−35 (−36·84%)	−34 (−33·01%)	0	−16 (−53·33%)
Finland	−48 (−13·68%)	−38 (−15·38%)	5 (9·26%)	−5 (−20·83%)	−10 (−38·46%)
France	−1410 (−28·96%)	−1041 (−34·28%)	−219 (−19·04%)	−101 (−31·27%)	−49 (−13·65%)
Germany	−328 (−10·53%)	−236 (−13·15%)	−46 (−6·5%)	−36 (−11·32%)	−10 (−3·4%)
Greece*	−11 (−12·22%)	−6 (−8·7%)	−2 (−14·29%)	1†	−4 (−57·14%)
Hungary	−132 (−37·29%)	−79 (−37·26%)	−27 (−39·71%)	0	−26 (−43·33%)
Italy	−525 (−16·18%)	−296 (−16·17%)	−162 (−15·25%)	−40 (−30·08%)	−27 (−12·27%)
Japan	−1413 (−66·71%)	−1112 (−69·63%)	−257 (−67·45%)	−18 (−26·47%)	−26 (−36·11%)
Netherlands	−187 (−17·64%)	−166 (−21·15%)	−7 (−4·46%)	−19 (−21·35%)	5 (17·24%)
Norway	−24 (−7·12%)	−6 (−2·99%)	3 (4·11%)	−6 (−22·22%)	−15 (−41·67%)
Portugal	−156 (−24·19%)	−67 (−19·76%)	−75 (−33·63%)	−10 (−15·62%)	−4 (−21·05%)
Slovenia	7 (8·43%)	7 (21·21%)	−2 (−9·52%)	6 (66·67%)	−4 (−20%)
Spain	−1033 (−24·02%)	−745 (−26·89%)	−176 (−18·6%)	−88 (−26·19%)	−24 (−9·68%)
Switzerland	−6 (−1·34%)	−7 (−2·69%)	−15 (−11·63%)	6 (20%)	10 (34·48%)
UK	−1298 (−31·31%)	−1076 (−35·54%)	−147 (−17·95%)	−69 (−47·92%)	−6 (−3·87%)
USA	−1370 (−4·13%)	−1110 (−5·44%)	−91 (−1·23%)	−237 (−10·18%)	68 (2·25%)
Overall	−11 253 (−15·92%)	−8560 (−19·14%)	−1714 (−10·57%)	−692 (−15·51%)	−287 (−5·44%)

Data are n (%). *Follow-up in Argentina, Chile, and Greece ended earlier than other countries because of data availability. Argentina follow-up ended on Aug 18, 2020, Chile ended on May 27, 2021, and Greece ended on July 28, 2020. The remaining countries include follow-up to Dec 31, 2020. †There were no lung transplants in Greece in 2019.

Table: **Change in overall observed solid organ transplant counts between 2020 from the date of the first 100 reported cumulative COVID-19 cases until the end of follow-up (latest date of available data to Dec 31, 2020) and the same period of time in 2019**

GODT; and label, country name. The total number of transplants includes solid organs (kidney, liver, lung, and heart). We counted each organ in a multiorgan transplant separately to ascertain the total number of transplants for each organ type.

We estimated the number of patient life-years lost during the COVID-19 pandemic compared with the same time period in 2019 due to the reduced number of transplants. We first calculated the reduction in transplants in 2020 for each organ compared with 2019. For each organ lost, the total life-years lost for a patient was assigned based on the methodology applied by Rana and colleagues[27] by calculating the gain of life-years for patients transplanted versus patients who were placed on the waiting list but did not undergo a transplantation.

We developed a web-based dashboard that provides three data visualisations: line graphs displaying total COVID-19 cases and total transplants over time (2019, 2020, or ratio of 2020 to 2019); bubble charts (three-dimensional scatter plots) displaying the percent diminution in transplants between 2020 and the same time period in 2019 versus the total COVID-19-related deaths per million inhabitants with bubble size determined by the total number of transplants in 2019; and geographical heatmaps displaying transplant totals in 2019 and 2020, as well as total COVID-19 cases by region for each country with available data. The dashboard was developed using JavaScript and Python 3.

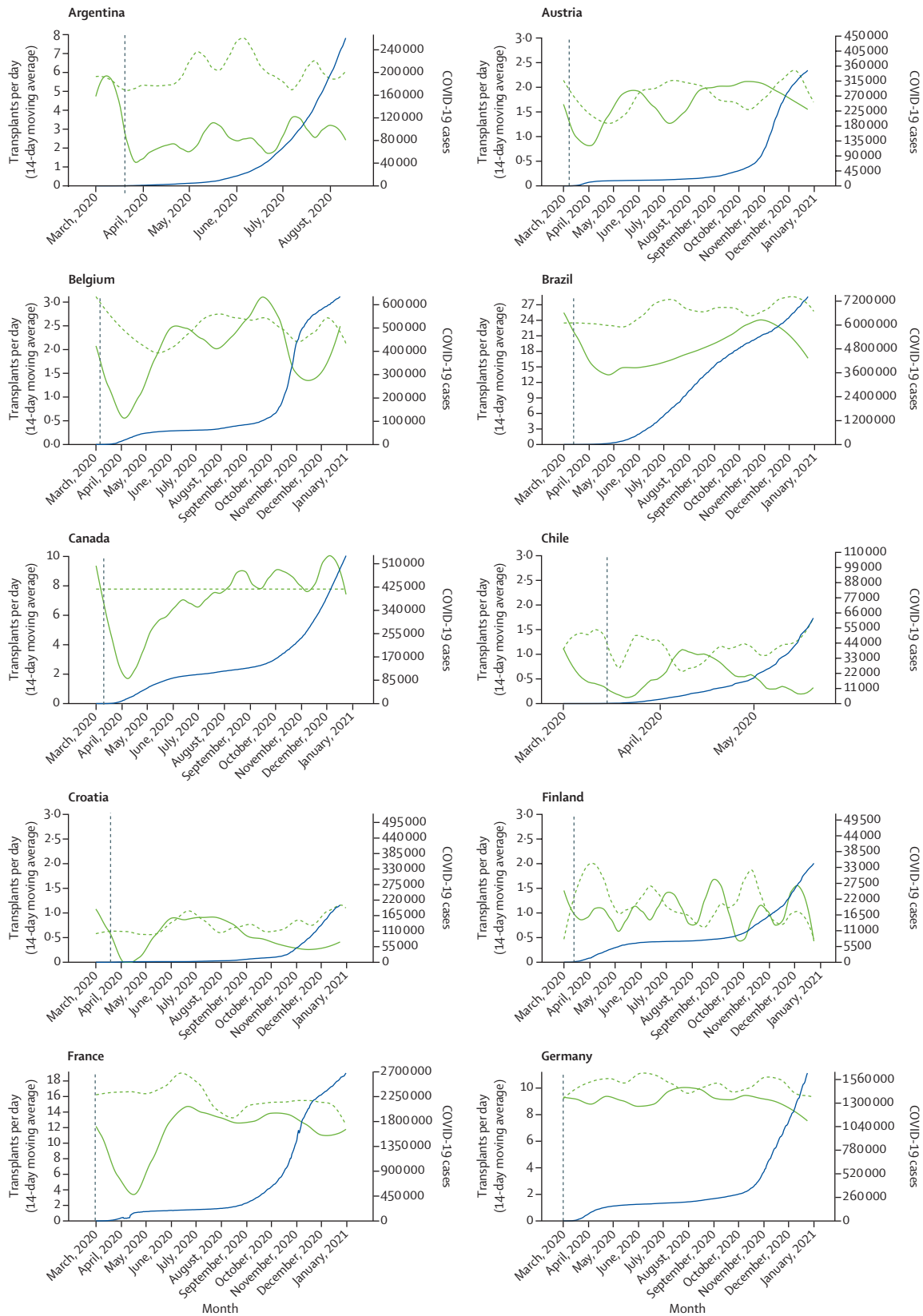
We used R (version 4.0.0) and STATA (version 14) for the analyses. The study is registered with ClinicalTrials.gov, NCT04416256.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

We assessed overall transplant activity by organ, including kidney, liver, lung, and heart. We compared transplant activities in 2020 from the date of the 100th reported cumulative COVID-19 case to Dec 31, 2020 (or the end of follow-up, whichever was earlier) to the same period of time in 2019. We observed an overall decrease of 11 253 (–15·92%) organ transplants across all 22 countries. This decrease can be stratified to –8560 (–19·14%), –1714 (–10·57%), –692 (–15·51%), and –287 (–5·44%) for kidney, liver, lung, and heart, respectively. Decreases in organ transplant activity varied according to country and organ (table).



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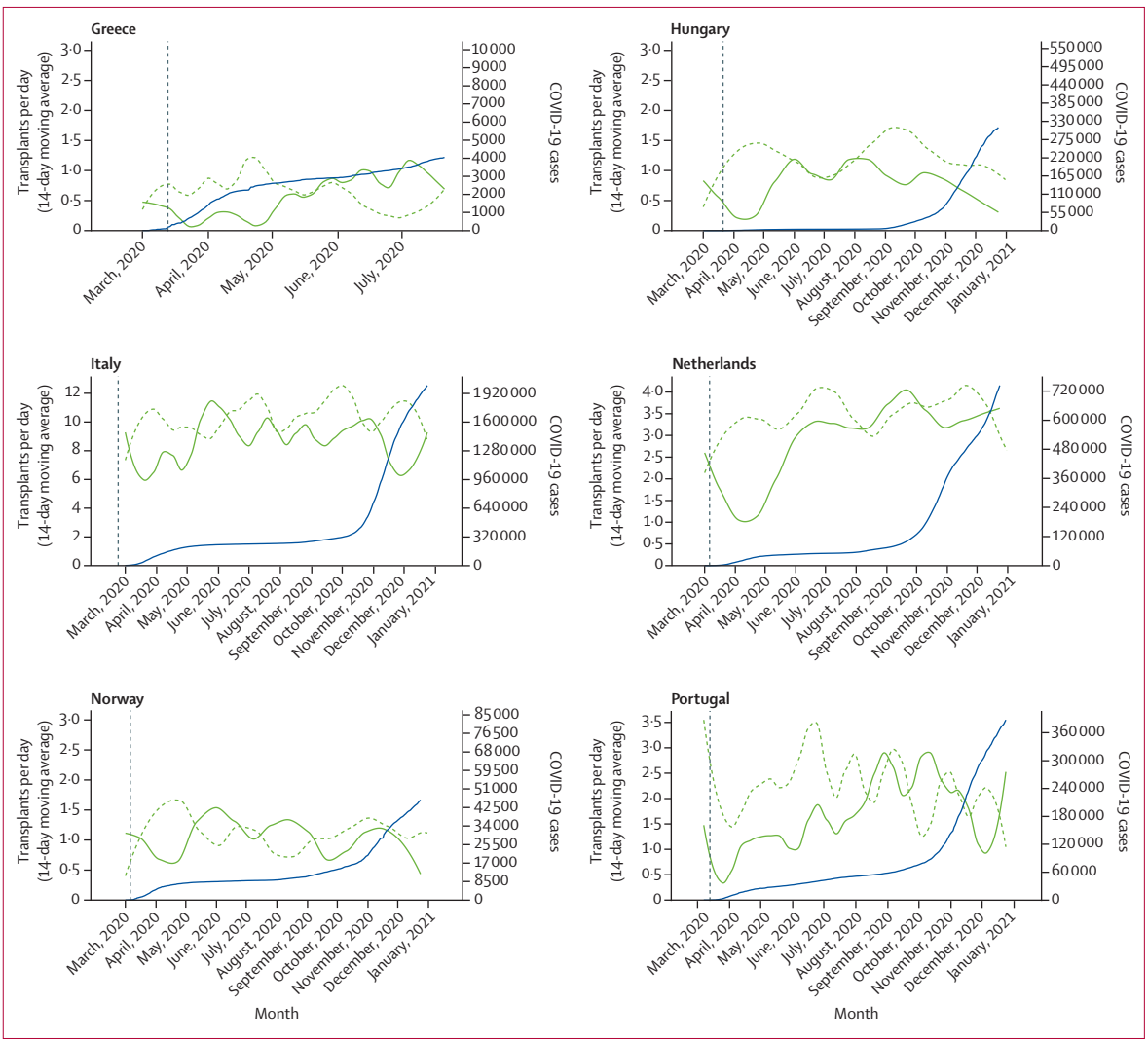

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When we assessed deceased donor transplant activity using the same timeline as above, we observed an overall decrease of 6169 (–11%) organs transplanted across all countries, excluding Canada because the data could not be stratified by donor type. Deceased donor transplant activity was decreased with –3823 (–11·91%), –1370 (–9·33%), –697 (–16·64%), and –279 (–5·46%) for kidney, liver, lung, and heart, respectively.

We also assessed living donor transplant activity overall and by organ (kidney and liver) using the same timeline as previously and observed an overall decrease across all 22 countries of 4857 (–39·52%) transplants, excluding Canada because the data could not be stratified by donor type. 4508 (–40·19%) and 349 (–32·53%) living donor transplant reductions were observed for kidney and liver, respectively. COVID-19-related changes in transplant activities from deceased donors and living donors by country are summarised in the appendix (pp 3–4).

To assess trends in COVID-19 over time and recovery in transplantation rates, we calculated the 14-day moving averages for deceased and living donor transplants with respect to the number of COVID-19 cases (figure 1). Overall, there was a strong temporal association between increased COVID-19 infection rates and reductions in deceased and living donor solid organ transplants. This trend varied by country, with an overall reduction in deceased donor transplantations since the COVID-19 outbreak. Although there was a sharp decrease in total transplantation procedures during the first wave of the COVID-19 pandemic compared with 2019, most of the countries later normalised daily transplant activity to their 2019 levels.

We assessed geographical and regional changes in overall transplant activity, including living and deceased donor transplants, with respect to the number of COVID-19 deaths per million inhabitants (figure 2).

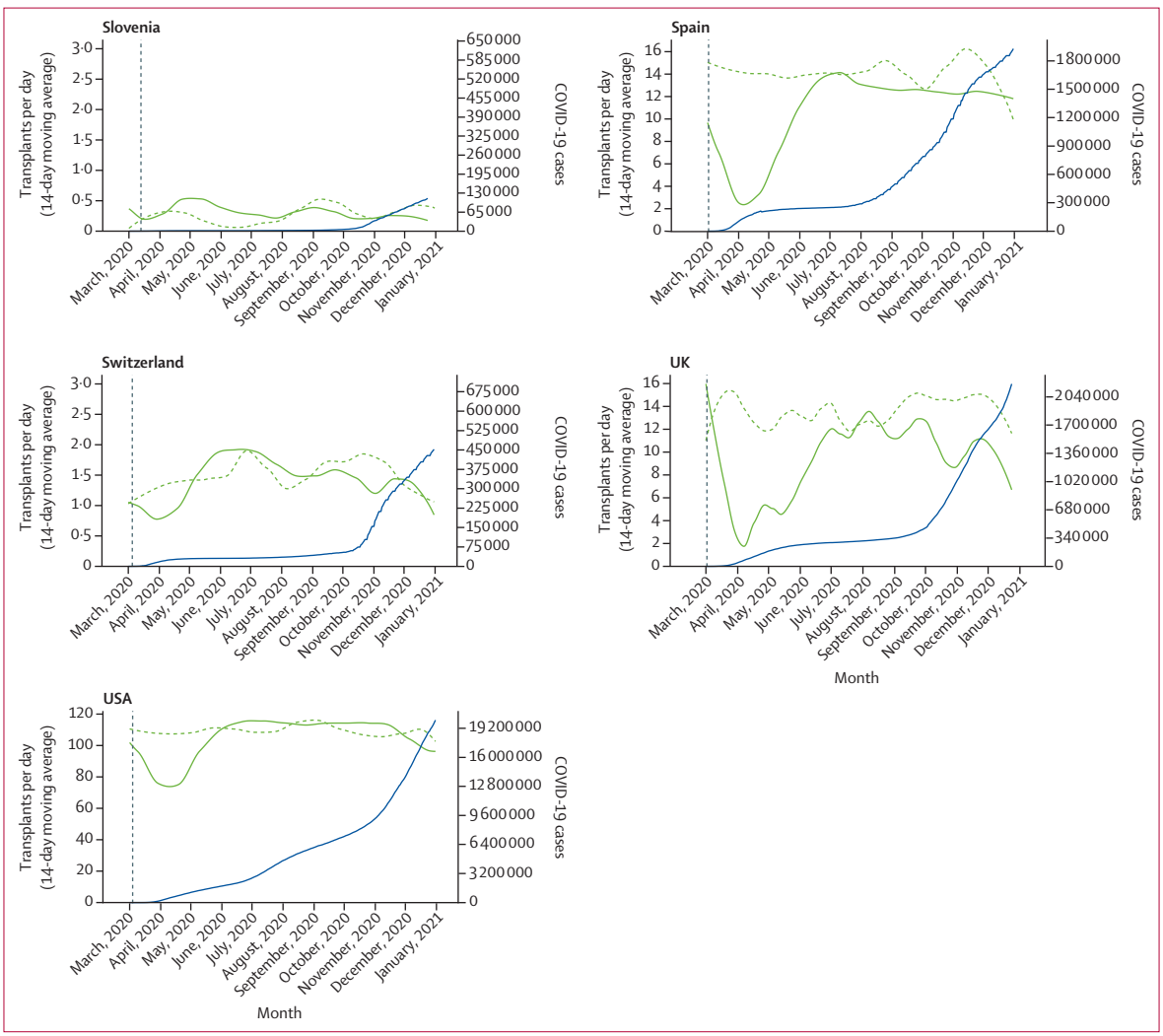

Figure 1: **Worldwide solid organ transplantation activity and COVID-19 cases over time**
Vertical dotted lines represent the onset of COVID-19, defined as the 100th recorded case for each country. Green lines (dotted for 2019 and solid for 2020) and blue lines represent the number of organ transplants (kidney, liver, lung, and heart) and cumulative COVID-19 cases, respectively. Japan was excluded from the figure because the transplant data were not temporal.

Three patterns emerged as follows: a sharp decrease in organ transplant activity despite a low number of COVID-19-related deaths in Argentina, Japan, and Chile; a decrease in organ transplantation concomitant with the incidence of deaths in Norway, Germany, Canada, Portugal, The Netherlands, Austria, Hungary, Croatia, Brazil, France, the UK, Spain, Greece, and Finland; and a smaller than expected decrease in organ transplant activity despite a high number of COVID-19-related deaths in the USA, Italy, Switzerland, Slovenia, and Belgium. We observed a similar trend when we measured the association by organ type (appendix p 6).

We evaluated changes in transplant activity worldwide and for each country during and after the first COVID-19 pandemic wave (from March to December, 2020). Overall, most of the countries increased the number of transplants after the first wave to around normal activity compared with the previous year (figure 1). The reduction in the number of organ transplants by month and by organ is shown in figure 3. Although the number of organ transplants decreased rapidly during the first 3 months of the pandemic, this decrease stabilised after June, 2020, as transplantation centres presumably learned to adapt after the first pandemic wave. A new sharp decrease in organ transplant activity was observed from October to December, 2020.

Based on the reduced number of transplants during the COVID-19 pandemic compared with 2019, we calculated the number of patient life-years lost by comparing patients remaining waitlisted with those transplanted for each organ. The estimated numbers of life-years lost were 37 664 years for patients waitlisted for a kidney, 7370 years for patients waitlisted for a liver, 1799 years for patients waitlisted for a lung, and 1406 for

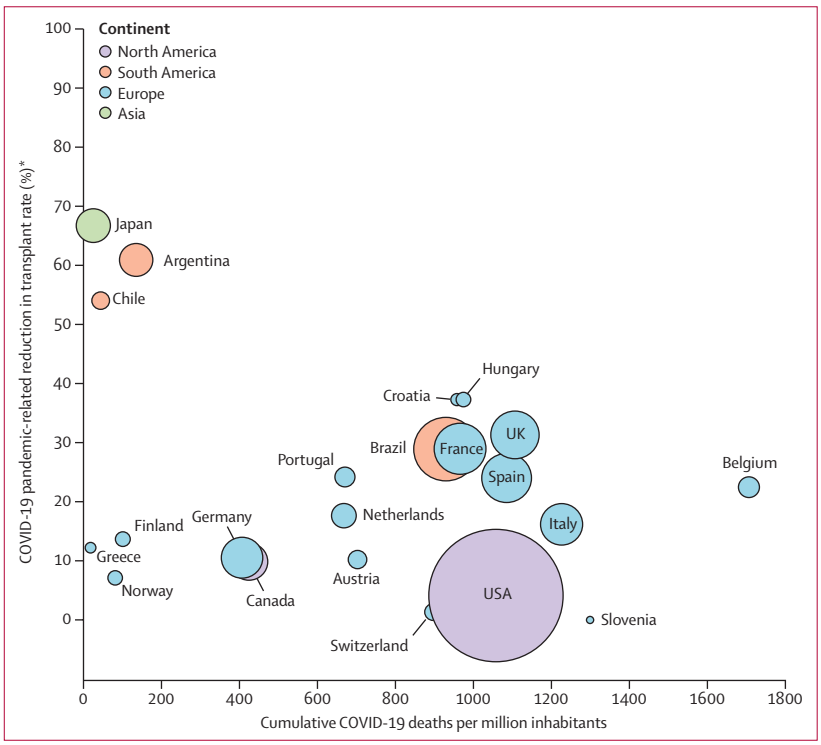

Figure 2: **Diminution of total transplants from the date of the first 100 reported cumulative COVID-19 cases until Dec 31, 2020, and the same period of time in 2019 according to the number of COVID-19-related deaths per million inhabitants in each country**

Bubble size indicates 2019 total number of transplants (kidney, liver, lung, and heart from both living and deceased donors). Follow-up went to Dec 31, 2020, with the exception of Argentina, Chile, and Greece due to data availability. *In 2020 compared with 2019.

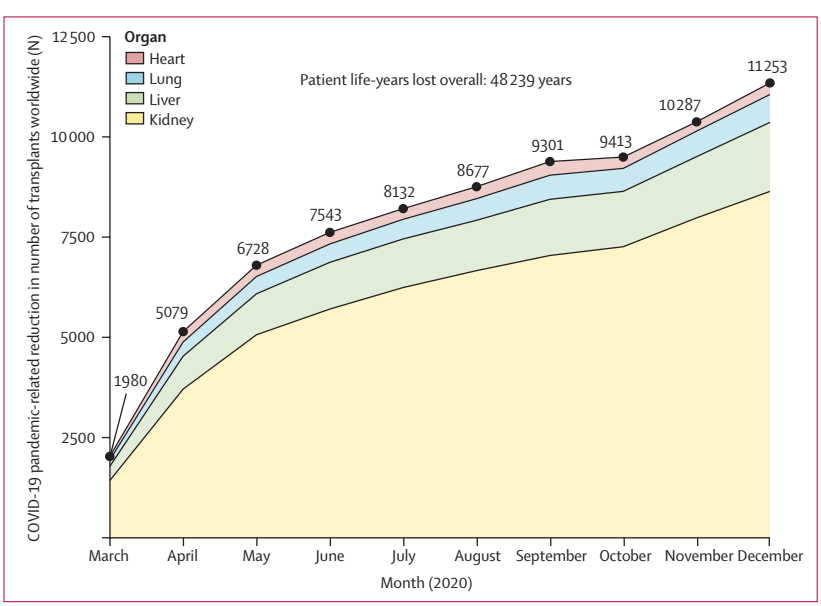

Figure 3: **Cumulative reduction in the number of organ transplants during the COVID-19 pandemic in 2020 compared with 2019 by month and by organ, and consequences for waitlisted patient mortality (estimated patient life-years lost)**

Data show the cumulative reduction in the number of transplants by month from March to December, 2020, compared with 2019.

patients waitlisted for a heart, corresponding to a total of 48 239 life-years lost (figure 3).

To facilitate understanding of the temporal trends and consequences of the pandemic on worldwide, national, and regional solid organ transplant activities for researchers, clinicians, and public health authorities, we created an open-access dashboard that presents data interactively for solid organ transplant activities and COVID-19 cases (appendix p 7).

Discussion

Solid organ transplantation often provides remarkable improvements in survival and quality of life for patients with end-stage organ disease. However, transplant procedures involve increased susceptibility to infection and substantial investment of health-care system resources, posing major challenges during a pandemic. To our knowledge, this is the first study to analyse correlations beyond a single country and not limited to mortality related to the COVID-19 pandemic.[28,29] This study leveraged international data from 22 countries with comprehensive ascertainment of transplant events, revealing major variation in the response of transplant programmes to the COVID-19 pandemic. Kidney transplantation showed the largest reduction across nearly all countries, probably due to the non-immediate life-saving nature of this surgery and the possibility to postpone procedures. We found that some countries, such as the USA, Switzerland, Belgium, and Italy, managed to sustain the rate of transplant procedures, whereas other countries had serious reductions in the number of transplants compared with the previous year. In some areas, living donor kidney and liver transplantation ceased. Finally, we estimated that the negative effect of the COVID-19 pandemic on organ transplantation was associated with more than 48 000 patient life-years lost.

The COVID-19 pandemic poses unique ethical problems for living donor transplantation, which could explain the more pronounced reduction in these procedures. Living organ donation is considered ethically acceptable in the context of a well-informed donor who accepts health risks, and in some cases emotional or psychosocial risks, to improve recipient health.[30] Given the extensive procedures already in place to limit the risks attributable to living donations, transplant programmes and donors were probably hesitant for living donors to be exposed to COVID-19 in hospital settings. Living donor transplantation requires elective allocation of substantial resources and planning compared with deceased donor transplantation, which is extremely difficult during a pandemic when resources are being used for acute care and staff are redeployed. Furthermore, for living donor transplants, there is an additional major ethical concern for the wellbeing of the donor. Paired kidney exchange, which depends on major operational complexities in ensuring compatibility

between donor–recipient pairs, often across different hospitals, was especially vulnerable to COVID-19-related disruptions in living donor transplantation. Fortunately, living organ donation can, in many cases, be postponed. Therefore, we would expect robust numbers of living donor transplants to take place in countries where COVID-19 infection rates remain under control and confinement measures instituted by public health authorities are relaxed.

The ability of specific countries, such as Germany and certain regions in the USA, to maintain transplant volume despite the urgency of controlling COVID-19 spread holds an important lesson for future waves of COVID-19 infection and other pandemics. Likewise, countries such as Belgium and Italy showed efforts to sustain transplant volume despite a relatively higher number of deaths per million from COVID-19. Specifically, a pandemic might affect different areas to substantially different degrees. Providing some autonomy to individual hospital systems to adapt to specific circumstances could enable life-saving procedures like transplantation to continue, even as other important restrictions—such as limiting travel or closing non-essential commercial businesses—are imposed.[31]

This study shows how international variation in medical practice can reveal opportunities to improve public health.[32] Our research highlights the value of national transplant registries that provide an exhaustive record of transplant procedures and enable scrutiny of organ use and transplant outcomes across borders.[33–35]

We acknowledge certain study limitations. The data sources do not provide granular information on why reductions in transplant volume took place in specific regions. Also, the transplant reduction might have been due to reasons other than the COVID-19 pandemic. For example, Croatia had two earthquakes during the study period, which might have had an additional effect on organ donation and transplantation.[36] Additionally, we did not consider the different baseline transplant rates for each country. For example, Germany, which is presumed to have one of the best transplantation responses to the COVID-19 crisis in our study, showed a decrease in transplant activity before the pandemic.[37] This factor could account for some of the small observed effect on the transplant activity in Germany. However, our findings could motivate follow-up studies that might require additional investigative methods, such as qualitative data collection, to fully understand decision making by transplant providers and patients as the pandemic unfolded and system structure and organisational aspects that were particularly vulnerable to this health-care crisis. We also acknowledge the possibility of inaccurate ascertainment of COVID-19 infections in some countries due to test accuracy and unavailability. Nonetheless, we used the best available data for this purpose. We are aware that selecting the study period is non-trivial regarding the COVID-19 pandemic. Although there is no standard rule to define an index date and timeline for COVID-19 studies, we established the 100th COVID-19 case as the starting point for our analysis.[19] Finally, we acknowledge the absence of many countries, including all of Africa, for which we were unable to obtain relevant data; the inclusion of nations in Africa and elsewhere should be a priority for future studies. However, we observed consistent results among the included countries from four continents, suggesting that our findings can be generalised to promote awareness of pandemic preparedness and associated challenges in organ transplantation.

The primary observations from our study included changes in solid organ transplantation during and before the pandemic, as well as estimated life-years lost. These findings should motivate improved pandemic preparedness for both life-saving procedures and those that can be postponed, but not without detriment to patient health and wellbeing. Indeed, kidney transplantation is perceived as a quality-of-life treatment, as a patient can undergo dialysis while awaiting a transplant. However, the marked reduction in the number of transplants and life-years lost has major implications for both the health sector and society, with loss of life that could have been saved due to the difficult decision to stop a programme because of a lack of resources or to avoid the imminent risk of SARS-CoV-2 infection. Beyond the near universal reduction in transplant activity, certain countries and regions managed to carry out procedures despite major challenges and increased risks to patients. These findings warrant follow-up analyses on a regional, country, and global level, with qualitative approaches to question key players in the health-care sector, to understand why reductions in transplants and transplantations did or did not occur. Understanding how different countries and health-care systems responded to COVID-19-related challenges could improve pandemic preparedness, most notably, how to safely maintain transplant programmes, both those with immediate and non-immediate life-saving potential, to prevent loss of patient life-years.

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Contributors

OA, DY, DZ, and AL designed the study, curated the data, analysed and interpreted the data, and wrote and edited the manuscript. All authors had access to the data and four authors (OA, DY, DZ, and AL) verified the data. All authors contributed to the interpretation of the data and edited the manuscript. The corresponding author (AL) was responsible for the decision to submit the manuscript for publication.

Declaration of interests

We declare no competing interests.

Data sharing

The data analysed during the current study are available from the corresponding author on reasonable request including standards for General Data Protection Regulation and Institutional Review Board approval.

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