Impact of the Kidney Transplantation Moratorium in France Because of the COVID-19 Pandemic: A Cohort-based Study

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2416

Background. The COVID-19 pandemic has resulted in worldwide kidney transplantation (KT) moratoriums. The impacts of these moratoriums on the life expectancy of KT candidates remain unclear. Methods. We simulated the evolution of several French candidate populations for KT using a multistate semi-Markovian approach and according to moratorium durations ranging from 0 to 24 mo. The transition rates were modeled from the 63,927 French patients who began dialysis or were registered on the waiting list for KT between 2011 and 2019. Results. Among the 8350 patients active on the waiting list at the time of the French KT moratorium decided on March 16, 2020, for 2.5 mo, we predicted 4.0 additional months (confidence interval [CI], 2.8-5.0) on the waiting list and 42 additional deaths (CI, –70 to 150) up to March 16, 2030, compared with the scenario without moratorium. In this population, we reported a significant impact for a 9-mo moratorium duration: 135 attributable deaths (CI, 31-257) up to March 16, 2030. Patients who became active on the list after March 2020 were less impacted; there was a significant impact for an 18-mo moratorium (175 additional deaths [CI, 21-359]) in the 10,862 prevalent end-stage renal disease patients on March 16, 2020 and for a 24-mo moratorium (189 additional deaths [CI, 10-367]) in the 16,355 incident end-stage renal disease patients after this date. Conclusion. The temporary moratorium of KT during a COVID-19 peak represents a sustainable decision to free up hospitals’ resources if the moratorium does not exceed a prolonged period. (Transplantation 2022;106: 2416–2425).

INTRODUCTION

As reported by the World Health Organization on February 17, 2022,1 5,978,096 individuals died because of COVID-19. The risk factors for severe COVID-19 included old age and individuals with comorbidities, such as diabetes, obesity, hypertension, immunodeficiency, cardiovascular disease, or renal insufficiency.2 The population with end-stage renal disease (ESRD) is therefore highly impacted.

Y.F. supervised this work. F.L.B. and V.B. performed the simulations and other statistical analyses. C.C. performed the data extraction. All the authors participated in the design of the study and were engaged in the writing of the final proposal.

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At an individual level, the advantages of kidney transplantation (KT) were challenged because of the exposure of recipients to immunosuppressive drugs and their related overmortality after SARS-CoV-2 infection.3,5 At a population level, health care was reorganized to mobilize staff and equipment for patients with severe forms of COVID-19 to the detriment of transplantation activity. Altogether, a number of health decision makers decided on regional or national KT moratoriums.6 In France, this moratorium was decided on March 16, 2020, and KT activity officially stopped until May 2020 and remained limited until June 2020.7

Recent literature has evaluated the impact of the moratorium and ways to improve pandemic preparedness. Thaunat et al8 described comparable 3-mo COVID-19-related mortality between KT recipients and candidates in France, but they reported no long-term outcomes. Aubert et al9 extrapolated a worldwide loss of 37664 patient life-years due to the decrease in the observed KT activity between 2019 and 2020 in 22 national cohorts. Vinson et al10 proposed extrapolations from a study entirely based on United States–centered assumptions: KT was associated with a 5.8-y gain compared with dialysis in a 40-y-old candidate. Massie et al11 performed a simulation-based study from the data of the US scientific registry. They also concluded a benefit of no discontinuity in KT activity compared with delaying KT after the pandemic but with a magnitude lower than the previous listed studies. Considering a proportion of deaths <50% among SARS-CoV-2–infected candidates on the waiting list and KT recipients, they predicted a life expectancy gained due to KT over the first 5 y of 2.9 mo compared with delaying the transplantation up to 12 mo.

Therefore, health decision makers still face a complex situation. On the one hand, the results proposed by Aubert et al9 and Vinson et al10 call for the continuity of the transplantation activity, even if it means straining the resources of hospitals during pandemic peaks. However, the results reported by Massie et al11 support the strategy of temporarily stopping KT activity because of the limited impact on candidate mortality.

In this context, we aimed (i) to describe the multistate evolution of ESRD patients before the COVID-19 pandemic using a multistate model, (ii) to predict from this model the long-term impact of the observed KT moratorium in France, and (iii) to predict the impact of alternative moratorium durations in cases of rebound, seasonality, or even other pandemics.

**MATERIALS AND METHODS**

**Study Population**

We conducted our study using the French Renal Epidemiology and Information Network (REIN) registry. We included children and adults at the time of their first dialysis or candidates for preemptive KT at the time of their registration on the waiting list (active or inactive). We did not include patients from overseas districts and those without follow-up or registered for multiorgan transplantation. Details regarding this exhaustive registry have been described previously.12 The age, sex, body mass index, diabetic status, history of cardiovascular comorbidities, region of residence, and calendar year were collected at the time of entry into the registry. For KT recipients, the donor age, blood type, and donor type were also available. All dates related to registration or removal from waiting list, temporary inactive status, transplantation, dialysis, and death were prospectively collected.

The training cohort, for estimating the predictive models, included all patients meeting the inclusion criteria defined above who entered the registry between September 1, 2011, and December 31, 2019, which was also the date of administrative censoring.

The prevalent cohort, for predicting the impact of the KT moratorium, included all the patients alive on March 16, 2020 (ie, the first day of the French moratorium).

**Statistical Analyses**

**Estimation of the Models Before March 2020**

We estimated from the training cohort the natural history of the disease before the pandemic by using a semi-Markovian approach. The multistate structure is described in Figure 1. We estimated transition-specific multivariate proportional hazard models, and the baseline hazard functions were obtained by using generalized Weibull distributions.13 The goodness-of-fit was investigated by comparison with the Breslow estimator.14 Piecewise exponential distributions were used when necessary. All the quantitative explanatory variables were categorized to avoid the log-linearity assumption. For each transition, patient age was categorized so that at least 20 events were observed in every category. The proportional hazards assumption was verified according to the Schoenfeld residuals and the plots of the log minus log survival. Because of their importance in predicting mortality, we considered patient age, body mass index, diabetes status, and the number of cardiovascular comorbidities. For the other covariates listed in the previous subsection, we performed a backward selection (P < 0.05, likelihood-ratio statistics). The resulting 17 models are presented in Tables S1–S6 (SDC, http://links.lww.com/TP/C585). In addition, we modeled the characteristics of the incident patients at the time of their entry into the registry (Table S7, SDC, http://links.lww.com/TP/C585). Finally, for each KT recipient, we modeled the donor characteristics according to the recipients’ characteristics (Table S8, SDC, http://links.lww.com/TP/C585). We performed these estimations on complete cases without missing data.

**Simulation of the Cohorts After March 2020**

In contrast with the training cohort, which was constituted by incident ESRD patients after 2011 in the registry, the cohort used to evaluate the impact of the KT moratorium was the patients alive in March 2020. Some of these patients were prevalent ESRD patients at the beginning of the registry in 2011. For these prevalent patients, we observed missing data at baseline. Therefore, we first imputed the missing data using multivariate imputation by chained equations.15 Second, we simulated the monthly numbers of incident patients according to a Poisson distribution with expectancy equal to the observed number of incident patients in 2019. The inclusion days of these new patients were obtained by uniform distributions. Their characteristics were generated by using the previous embedded regressions (Table S7, SDC,
http://links.lww.com/TP/C585) with 2019 as the calendar year. Third, we simulated the evolution of each individual by using the previous transition-specific models and the methodology described in Beyersmann in the context of competing events. Left truncations of prevalent patients were considered. We tuned the baseline hazard functions of the models related to the transitions to the graft to ensure 3600 KTs per year, as observed in 2019. For each simulated transition to the graft, the corresponding donor characteristics were simulated by using the regressions described in Table S8 (SDC, http://links.lww.com/TP/C585). We studied different scenarios according to the duration of the KT moratorium: 2.5 mo, as observed in France and from 6 to 24 mo.

Estimations of the Moratorium Impact
We studied 3 complementary populations: (i) the patients active on the waiting list on March 16, 2020 (population A); (ii) the patients inactive or not registered on the waiting list on March 16, 2020, but who will become active before March 16, 2025 (population B); and (iii) the incident patients after March 16, 2020, who will become active candidates for KT before March 16, 2025 (population C). We considered 2 predictive windows of 5 and 10 y, from March 16, 2020, for patients active on the list at this time, or from the registration on the active list for the other 2 populations. The COVID-19–related mortality being correlated to age, we performed subgroup analyses to evaluate the KT moratorium’s impacts in patients older or younger than 60 y. Patient survival was estimated by using the Kaplan-Meier estimator, and the corresponding restricted mean survival time (RMST) was estimated by the area under the curve. All deaths were considered regardless of the transplantation. The cumulative probabilities of transplantation or death on the waiting list were obtained by using the Aalen-Johannsen estimator and the RMST on the waiting list (RMWL) by the area above the sum of the cumulative probability of transplantation and death before transplantation. For each scenario, the previous simulations were performed 1000 times to obtain the 95% confidence intervals (CIs). The statistical analyses were performed with R, version 4.1.2.

RESULTS
Description of the Training Cohort
The characteristics at the time of inclusion in the REIN registry of the training cohort are described in Table 1. Among the 76980 incident ESRD patients between 2011 and 2019 with no missing data, 63927 were included because of dialysis and 13053 because of preemptive registration on the waiting list (4441 active versus 8612

FIGURE 1. Multistate natural history of end-stage renal disease from entry into the REIN registry (CKD). Patients who started a dialysis while being registered on the waitlist at inclusion were considered beginning a dialysis first and being registered on the waitlist afterward. CKD, chronic kidney disease; REIN, Renal Epidemiology and Information Network.
inactive). The characteristics of the 2 cohorts were close (Table S9, SDC, http://links.lww.com/TP/C585). The mean recipient age was 67.2 y (± 16.3), and 64.6% were male. The median follow-up time was 3.87 y. A total of 26 174 patients were registered on the waiting list after their entry into the REIN registry, 14 159 were transplanted, and 2 856 died (193 on the list for a preemptive transplantation, 834 with a functional graft, and 2 6829 in dialysis).

### Prognosis at 5 Y of the Patients Active on the List on March 16, 2020 (Population A)

The 8350 patients are described at the time of their entry into the registry in Table 2. The mean age was 50.6 y (± 17.1), 62.5% of patients were male, 23.9% had diabetes, and 17.4% had cardiovascular comorbidities.

In the case of no KT moratorium, the outcomes are presented in Figure 2 and Table 3. We predicted a 5-y patient survival of 83.2% (CI, 82.5-84.0), corresponding to 1 399 deaths (CI, 1334-1463) and a mean life expectancy (RMST) equal to 4.62 y (CI, 4.60-4.64) up to March 2025. The candidates had a 65.0% chance of being transplanted up to March 2025 (CI, 64.1-66.0), corresponding to 5 430 transplantations (CI, 5333-5511) and a mean survival time on the waiting list (RMWL) equal to 2.61 y (CI, 2.57-2.64).

We then considered the observed 2.5-mo moratorium in France. The impact on the mortality was negligible (the 5-y survival was 83.1% [CI, 82.4-83.9], and the 5-y RMST was 4.62 y [CI, 4.60-4.64]). The 5-y cumulative probability of KT equaled 61.3% (CI, 60.3-62.3), corresponding to 312 KT losses (CI, 196-424) and 2.9 supplementary months (CI, 2.2-3.5) on the list.

We repeated the analyses for moratorium durations from 6 to 24 mo (Tables S10 and S11, SDC, http://links.lww.com/TP/C585). Figure 2C,D presents the results in terms of additional deaths and KT losses. The 5-y mortality remained comparable across all scenarios. The 5-y cumulative probability of KT decreased with moratorium duration and reached 33.0% (CI, 32.1-34.0) for 24 mo, corresponding to 2 672 KT losses (CI, 2 547-2 785), and for 18.0 additional months (CI, 17.5-18.5) on the list up to March 2025.

### Prognosis at 5 Y of Incident ESRD Patients After March 16, 2020, Who Will Become Active Candidates Before March 16, 2025 (Population C)

Population C included an average of 16 355 (28.8%) patients (Table 2). The mean recipient age was 52.4 y (± 18.0),
63.8% of patients were male, 29.0% had diabetes, and 25.1% had cardiovascular comorbidities.

In this population, in the absence of a KT moratorium, the patient survival was estimated to be 86.0% (CI, 85.5-86.5) at 5-y postregistration (Figure 4A). We estimated a 65.4% (CI, 64.6-66.1) chance of being transplanted at 5 y (Figure 4B), corresponding to 10774 transplantations (CI, 10595-10960) and a 5-y RMWL equal to 2.63 y (CI, 2.60-2.66).

For a 2.5-mo moratorium, the 5-y postregistration patient survival remained at 86.0% (CI, 85.5-86.5). The 5-y cumulative probability of KT equaled 64.1% (CI, 63.4-64.8), resulting in 209 KT losses (CI, −40 to 481), and 0.7 additional months (CI, 0.2-1.2) on the waiting list.

The impacts of alternative moratorium durations are illustrated in Figure 4C,D. The 5-y postregistration survival did not vary. For a 24-mo moratorium, the 5-y postregistration cumulative probability of KT was 51.6% (CI, 50.8-52.3).

Results for a Predictive Window at 10 Y

We performed the same analyses with predictions up to 10 y (Table 3; Tables S10 and S11, SDC, http://links.lww.com/TP/C585 and Figures S1–S3, SDC, http://links.lww.com/TP/C585).

In the scenario without KT moratorium, the 8350 patients of the population A had a 10-y survival of 64.6% (CI, 63.7-65.5) and a 10-y cumulative probability of KT of 75.8% (CI, 75.0-76.7). For a 2.5-mo moratorium, the survival decreased to 64.1% (CI, 63.2-65.0) (42 additional deaths [CI, −70 to 150]) and the cumulative probability of
| Outcome              | Moratorium duration | Population       | Prognostic time | Patient survival | Number of deaths | Number of additional deaths | RMST (y) | Decrease in RMST (mo) | Patient life-years lost |
|----------------------|---------------------|------------------|-----------------|------------------|------------------|-----------------------------|----------|----------------------|------------------------|
| **Mortality**        | 0 mo                | Active (N = 8350)| 5 y             | 83.2 (82.5, 84.0) | 1399 (1334, 1463) | –                           | 4.62 (4.60, 4.64) | –                    | –                      |
|                      |                     | Not active (N = 10862) | 5 y             | 78.5 (77.8, 79.2) | 2338 (2242, 2425) | –                           | 4.49 (4.46, 4.51) | –                    | –                      |
|                      |                     | Incidents (N = 16355) | 5 y             | 86.0 (85.5, 86.5) | 2291 (2202, 2376) | –                           | 4.69 (4.67, 4.70) | –                    | –                      |
|                      | 2.5 mo              | Active (N = 8350) | 5 y             | 83.1 (82.4, 83.9) | 1407 (1345, 1469) | 8 (–79, 100)               | 4.62 (4.60, 4.64) | –0.03 (–0.37, 0.32) | –20.9 (–257.5, 222.7) |
|                      |                     | Not active (N = 10862) | 5 y             | 78.4 (77.7, 79.2) | 2341 (2255, 2432) | 4 (–123, 139)              | 4.49 (4.46, 4.51) | 0.16 (–0.36, 0.39) | –27.2 (–330.4, 354.8) |
|                      |                     | Incidents (N = 16355) | 5 y             | 86.0 (85.5, 86.5) | 2291 (2202, 2377) | 0 (–128, 121)              | 4.69 (4.67, 4.70) | –0.01 (–0.24, 0.22) | –13.6 (–327.1, 299.8) |
| **KT activity**      | 0 mo                | Active (N = 8350) | 5 y             | 65.0 (64.1, 66.0) | 5430 (5353, 5511) | –                           | 2.61 (2.57, 2.64) | –                    | –                      |
|                      |                     | Not active (N = 10862) | 5 y             | 62.4 (61.6, 63.2) | 6869 (6746, 6996) | –                           | 2.51 (2.48, 2.55) | –                    | –                      |
|                      |                     | Incidents (N = 16355) | 5 y             | 65.4 (64.6, 66.1) | 10774 (10595, 10960) | –                           | 2.63 (2.60, 2.66) | –                    | –                      |
|                      | 2.5 mo              | Active (N = 8350) | 5 y             | 61.3 (60.3, 62.3) | 5118 (5033, 5201) | 312 (196, 424)            | 2.85 (2.81, 2.88) | 2.85 (2.83, 3.46) | 1983.1 (1551.7, 2407.6) |
|                      |                     | Not active (N = 10862) | 5 y             | 71.8 (71.0, 72.6) | 7900 (7774, 8026) | –                           | 3.30 (3.24, 3.35) | –                    | –                      |
|                      |                     | Incidents (N = 16355) | 5 y             | 65.4 (64.6, 66.1) | 10774 (10595, 10960) | –                           | 2.63 (2.60, 2.66) | –                    | –                      |
|                      | 25 mo               | Active (N = 8350) | 5 y             | 73.3 (72.4, 74.1) | 6120 (6043, 6189) | 213 (114, 323)            | 3.71 (3.64, 3.77) | 3.96 (2.83, 5.00) | 2755.5 (1992.9, 3479.2) |
|                      |                     | Not active (N = 10862) | 5 y             | 60.9 (60.0, 61.8) | 6695 (6563, 6828) | 175 (–1, 351)             | 2.59 (2.56, 2.62) | 0.92 (0.34, 1.49) | 832.8 (307.8, 1348.7) |
|                      |                     | Incidents (N = 16355) | 5 y             | 64.1 (63.4, 64.8) | 10566 (10385, 10752) | 209 (–40, 481)            | 2.69 (2.66, 2.72) | 0.68 (0.18, 1.17) | 926.8 (245.3, 1598.6) |
|                      |                     | 2.5 mo              | (observed in France) | 5 y             | 76.4 (75.7, 77.0) | 12582 (12393, 12787) | 129 (–51, 307) | 3.55 (3.50, 3.60) | 1.11 (0.31, 1.94) |

*95% confidence interval from a to b.

*Time from the beginning of the KT moratorium for patients active on the list at this time or from the registration on the active list for the other 2 populations (not active or incident patients).

KT, kidney transplantation; RMST, restricted mean survival time; RMWL, restricted mean survival time on the waiting list.
KT to 73.3% (CI, 72.4-74.1) (213 KT losses [CI, 114-323] and 4.0 additional months [CI, 2.8-5.0] on the list). We estimated a significant overmortality for a 9-mo moratorium: the patient survival was 63.0% (CI, 62.1-63.9), which represented 135 additional deaths (CI, 31-257) up to March 16, 2030. However, we did not report a significant decrease in the 10-y RMST in any scenario. For instance, for a 24-mo moratorium, the RMST decreased by 0.87 mo (CI, –0.02 to 1.77), corresponding to a total of 605 patient life-years lost (CI, –14 to 1232).

In the 10 862 patients of the population B, we predicted a patient survival at 10 y postregistration equal to 58.7% (CI, 57.8-59.6) and a cumulative probability of KT equal to 71.8% (CI, 71.0-72.6). For a 24-mo moratorium, the patient survival was 57.1% (CI, 56.1-58.0) (175 additional deaths [CI, 21-359]). The 10-y RMST decreased by 0.58 mo (CI, –0.40 to 1.54), that is, a total of 525 patient life-years lost (CI, –362 to 1394).

In the 16 355 patients of the population C, we predicted a patient survival at 10 y postregistration equal to 68.2% (CI, 67.5-68.9) and a cumulative probability of KT of 77.2% (CI, 76.5-77.8). For a 24-mo moratorium, the patient survival was 67.1% (CI, 66.4-67.7), resulting in 189 additional deaths (CI, 10-367). The 10-y RMST decreased by 0.10 mo (CI, –0.54 to 0.78), that is, a total of 136 patient life-years lost (CI, –736 to 1063).

Results According to Patient’s Age

Patients older than 60 were less impacted by KT moratoriums: they had a lower additional time on the waitlist

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**FIGURE 3.** Impact of the KT moratorium on nonactive patients on the waiting list in March 2020 who will become active before March 2025 (n=10 862). A, Overall patient survival. B, Cumulative probability of death and transplantation. C, Decrease in the 5-y life expectancy according to several moratorium durations compared with the scenario with no moratorium. D, Additional months on the waiting list up to 5 y according to several moratorium durations compared with the scenario with no moratorium. KT, kidney transplantation; RMST, restricted mean survival time; RMWL, restricted mean survival time on the waiting list.
and a lower overmortality than younger patients in each of the 3 populations.

In population A, 4124 patients (49.4%) were older than 60. In case of a 9-mo moratorium, we predicted 53 (CI, –27 to 139) additional deaths at a 10-y horizon among these patients versus 80 (CI, 11-150) among younger ones. Meanwhile, patients older than 60 spent 11.8 additional months on the waitlist (CI, 10.4-13.4), whereas that time reached 14.4 mo (CI, 12.8-15.9) for younger patients.

In population B, 5538 patients (51.0%) were older than 60 at that time. In case of an 18-mo moratorium, we predicted 61 (CI, –67 to 198) additional deaths at a 10-y horizon among these patients versus 134 (CI, 19-246) among younger ones. Meanwhile, patients older than 60 spent 11.8 additional months on the waitlist (CI, 10.4-13.4), whereas that time reached 14.4 mo (CI, 12.8-15.9) for younger patients.

In population C, 6932 patients (42.4%) were older than 60 at that time. In case of a 24-mo moratorium, we predicted 55 (CI, –98 to 207) additional deaths at a 10-y horizon among these patients versus 134 (CI, 19-246) among younger ones. Meanwhile, patients older than 60 spent 12.0 additional months on the waitlist (CI, 10.7-13.4), whereas that time reached 15.5 mo (CI, 14.2-16.9) for younger patients.

Extensive results of this subgroup analysis can be found in Tables S12 to S14 (SDC, http://links.lww.com/TP/C585).

DISCUSSION

Normally, the time to transplantation should be as short as possible. However, the current COVID-19 pandemic questions temporally this certainty. Based on the French REIN registry, we extrapolated the impact of
the French KT moratorium initiated on March 16, 2020, for 3 complementary populations: (i) the patients active on the waiting list on March 16, 2020; (ii) the patients inactive or not registered on the waiting list on March 16, 2020 but who will become active before March 16, 2025; (iii) and the simulated incident patients after March 16, 2020, who will become active candidates for KT before March 16, 2025.

Overall, we reported nonsignificant impacts on 5-y patient survival. Our results illustrated that the impact of the moratorium should be observed over 10 y. For a 2.5-mo moratorium, that is, the interruption observed in France, the most impacted population was the 8350 patients active on the waiting list on March 2020, for whom we predicted 42 attributable deaths (CI, −70 to 150) up to March 2030 and 4.0 supplementary months (CI, 2.8–5.0) on the waiting list. In this population, we reported a significant impact on the 10-y mortality for a 9-mo moratorium duration: 135 attributable deaths (CI, 31–257) up to March 16, 2030. For patients who would become active candidates after the KT moratorium, we reported no significant impact of a <18-mo moratorium. In each population, patients younger than 60 were the most impacted, both in terms of mortality and time spent on the waitlist.

Our results did not confirm the important impact of the KT moratorium outlined by Aubert et al. However, the authors extrapolated the mortality from a biased difference in life expectancy between KT recipients versus dialyzed patients. They overestimated the KT benefit by ignoring the immortal time bias and time-dependent confounders. Our results are more concordant with those proposed by Massie et al, although they estimated a higher impact of a 12-mo moratorium than we did. This difference may be explained by them ignoring the informative censoring at KT and assuming the removals from the active list as deaths. Regardless of these differences, our results and those proposed by Massie et al tend to validate the decision of temporary KT moratorium. Alternatively, our subgroup results (more or < 90 y old) raise the question of age-driven moratorium strategies, given that older patients who have the highest COVID-19–related mortality are also the less impacted by the KT moratorium. Additional works on that matter with higher focus on COVID-19–related mortality would be useful to answer this question.

A strength of our study is that we performed individual simulations to reconstruct the prospective evolution of the French ESRD population, considering both the evolutions of the prevalent and the incident patients at the date of the KT moratorium. This method allowed us to estimate the long-term impact of the KT moratorium on the evolution of the waiting list and its consequences on the life expectancy of present and future generations. Another strength was the unselected nature of the study population, which was based on an exhaustive national registry.

However, our study must be understood in the context of its limitations. Extrapolating the evolution of populations is always associated with assumptions. First, we estimated our models based on incident patients in the REIN registry between 2011 and 2019. We selected this training cohort because of the lower frequency of missing data for incident ESRD patients who entered the registry after 2011. Our choice is open to criticisms, especially the possible bias of predictive models for extrapolations. For instance, future downward variation in incidence trends may be expected, already observed in nondiabetic patients. Second, we arbitrarily tuned the baseline hazard functions of transplantation so that the number of transplantations each year is realistic regarding the previous organ procurement. A possible improvement of our study would be to avoid such manual tuning by modeling the incidence of donations and the matching between grafts and candidates. It would then be relevant to allow a gradual reduction and then a gradual increase in the number of transplantations. We took as a reference a scenario with no moratorium corresponding to the transplant activity observed before the pandemic. An improvement of our study could be to consider a more realistic scenario where, despite the absence of a moratorium, transplantation activity would have been reduced (staff at hospitals and retrieval teams, limitation on the donor’s pool, etc). One can note that such analyses would have resulted in the estimation of smaller impacts of the KT moratoriums, which reinforce our conclusions. Third, we did not add an excess of mortality related to COVID-19 in our simulations. Even if the literature reported small differences or even comparable COVID-19–related mortality among KT infected candidates versus recipients, a perspective of our work for health crisis preparedness is to allow scenarios depending on the incidence of a novel pathogen or variants and the related mortality postinfection. Again, for the present study, one can note that, if we had simulated an excess of posttransplant mortality, our results in favor of a temporary KT moratorium would have been reinforced. Fourth, we assumed that dialysis patients who have temporarily no access to KT continue their dialysis treatment. However, the moratorium can lead to an increase in the number of dialysis patients potentially outnumbering the available capacity. Fifth, we presented results up to 5 and 10 y. These prognostic times influenced the results. This dependence must be considered by the readers. Moreover, the longest follow-up time in our training cohort was 8.3 y, which calls for caution when interpreting 10-y outcomes. Sixth, we used the French national registry. Other countries have different waitlist managements. Especially, a practice in France is to first register KT candidates as inactive on the waiting list. These patients are mostly waiting for their pretransplant evaluation and searching for a potential living donor. The extrapolation of our results to different countries can be discussed. Finally, we did not study the quality of life. A perspective of our work is to extend the results in terms of quality-adjusted life-years, but additional assumptions are needed because information on the quality of life is not collected in the REIN registry. In particular, despite our model accounting for the duration since entry into the registry, we may consider finer modeling of the potential effect of extending pretransplant dialysis duration on quality of life, as well as on mortality after transplantation.

In conclusion, our results offer arguments in support of the temporary KT moratorium during the first COVID-19 pandemic peaks. A temporary KT moratorium represents a sustainable decision to free up hospital resources if it does not exceed a prolonged period. By further predicting the impacts of several moratorium durations, we additionally believe that our results could help in future decision making and improving pandemic preparedness.
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