Long-term Outcome Reporting in Older Kidney Transplant Recipients and the Limitations of Conventional Survival Metrics

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Introduction: The kidney transplant recipient population in the United States is aging rapidly, which may exacerbate some of the limitations of conventional outcome metrics.

Methods: Using data from the Scientific Registry of Transplant Recipients (SRTR), age-stratified unadjusted Kaplan-Meier and competing risk survival analyses were performed on a cohort of 238,123 adult recipients of a first-time single kidney transplant between 2000 and 2017. These were compared with a multistate model incorporating 5 post-transplant states (alive with functioning graft, death with functioning graft, graft failed (alive), retransplanted, and death after graft failure).

Results: Kaplan-Meier resulted in an age-dependent overestimation of the risks of graft failure and death with functioning graft, compared with competing risk or multistate models. In elderly (≥75 years old) recipients, the absolute overestimation of the risk of death with functioning graft was 4-fold higher than in those younger than 55 years. The multistate model demonstrated that for patients transplanted at age 55 years and older, the probability of being back on dialysis was never more than 4% at any point post-transplant. The underlying reasons were low graft failure rates and high mortality after resuming dialysis as follows: 2-year mortality after graft failure was 38%, 54%, and 67% in recipients aged from 55 to 64 years, from 65 to 74 years, and those aged 75 years and older, versus 20% in those younger than 55 years.

Conclusion: Multistate models provide an accurate and comprehensive assessment of the life course of kidney transplant recipients. This may be particularly relevant in older recipients, who are more prone to event rate overestimation and for whom outcomes after graft failure are substantially worse than for younger recipients.

Kidney Int Rep (2022) 7, 2397–2409; https://doi.org/10.1016/j.ekir.2022.08.010

KEYWORDS: competing risk; elderly; graft failure; kidney transplantation; multistate models; survival analysis

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In the US, older adults (≥65 years old) are not only the fastest growing group in the general population, but also the fastest growing group of patients with end-stage renal disease and of candidates on the kidney transplant waitlist.1-3 The kidney transplant recipient population is also aging rapidly.3 The proportion of kidney transplant recipients who were aged 65 years and older at the time of transplant was 21% in 2018, up from 8% in 1998.4 Outcomes were relatively poor for older (≥65 years old) and particularly for elderly (≥75 years old) kidney recipients in the early 1990s but have improved significantly over time.5 As a result of excellent graft survival among older patients and, inevitably, relatively high mortality, most older kidney recipients can expect to die with a functioning graft.2,5-8 Also noteworthy is the fact that there is an increased rate of early graft failure among elderly patients, at least in part due to higher use of expanded criteria kidneys in this age group.1,9 These observations convey a relatively straightforward message about the expected post-transplant trajectory in older recipients as follows: a somewhat higher risk of early
graft failure compared with younger recipients but, otherwise, a high probability of the graft lasting for the rest of their life.

It is likely, however, that some of the limitations of conventional outcome metrics (particularly death with functioning graft and death-censored graft failure) are amplified in older patients, with possible implications for the accuracy and comprehensiveness of these metrics. First, because graft failure and death are competing events, Kaplan-Meier analyses can result in an overestimation of event rates, particularly in high-risk (including older) recipients.10 Second, the course after graft failure (e.g., time spent on dialysis before death) is not routinely reported but arguably relevant and most likely also strongly dependent on age. Competing risk methods, increasingly used in outcome reporting,3 address the first issue, but not the second. Multistate models, however, allow for the simultaneous incorporation of multiple competing events, including those after graft failure, in a single analysis. We will argue that they can be used to intuitively convey information that is relevant but not systematically reported, are robust to the rapidly changing demographics of kidney transplant recipients and, as such, may be a useful adjunct to traditional survival analyses.

The current study has 3 aims. First, to describe the relationship between kidney transplant recipient age and the degree of event rate overestimation resulting from Kaplan-Meier analyses. Second, to examine how age affects the entire post-transplant trajectory using multistate models, with a focus on the course after graft failure. Third, to be an applied and visual introduction to the use of multistate models for reporting transplant outcomes.

**METHODS**

**Study Population**

This study used data from the (SRTR). The SRTR data system includes data on all donors, waitlisted candidates, and transplant recipients in the US, submitted by the members of the Organ Procurement and Transplantation Network. The Health Resources and Services Administration, US Department of Health and Human Services provides oversight to the activities of the Organ Procurement and Transplantation Network and SRTR contractors. Analyses were restricted to adult (≥18 years old) first-time kidney-only recipients transplanted between January 1, 2000 and December 31, 2017 (except for Figure 1, Supplementary Figure S1 and S2, which plot data from transplants performed between January 1, 1990 through December 31, 2019). Last day of follow-up was June 2, 2020. The flowchart of patient selection is shown in Supplementary Figure S3. Patients were stratified into 4 age groups using the cut-off age points of 55 years (the median age of kidney recipients from 2015 onwards), 65 years and 75 years (commonly used cut-offs to define older and very old adults, respectively, in census reports and transplant literature7,11-14). This study was approved by the Massachusetts General Hospital Institutional Review Board (protocol number 2020P002874). The data reported here have been supplied by the Hennepin Healthcare Research Institute as the contractor for the SRTR. The interpretation and reporting of these data are the responsibility of the author(s) and in no way should be seen as an official policy of or interpretation by the SRTR or the US government.

We use the term all-cause graft survival, commonly called “uncensored graft survival” or “overall graft survival,” to refer to the outcome of graft failure or death, whichever happened first. Overall patient survival refers to the outcome of death, regardless of when it occurred (prior to or after graft failure). The date of death was based on the Social Security Death Master File or, if this was unavailable, the death date reported by the transplant center to the Organ Procurement and Transplantation Network. Recipients not having a death recorded as of June 2, 2020 were not necessarily considered alive and followed through June 2, 2020, but rather were considered followed only through the last Organ Procurement and Transplantation Network member-reported follow-up.

**Primer on Multistate Models**

A multistate model describes the process where subjects transition between a finite number of states.15 All commonly used survival analyses in the context of transplantation can be understood as multistate models. Standard (Kaplan-Meier) survival curves are very simple multistate models, with a single transition between 2 states (e.g., going from “alive with functioning graft” to “death”). Using a diagram to visualize which states or transitions a model incorporates, helps to understand the model’s assumptions and what question it ultimately answers (Figure 2). For example, the multistate model representation of death-censored graft failure has states for “alive with functioning graft” and “graft failure,” but no state for death. In the model, patients cannot die.16 Technically, it answers the question of “What would graft survival be if patients were immortal?” Specifically, censoring for death means treating death the same way “loss to follow-up” is treated and assuming that, like patients who are lost to follow-up, deceased patients will go on to experience graft failure at the same rate as patients who are still alive. Because graft failure and death are competing
events, whereby the occurrence of one event alters the probability of the other event occurring, their cumulative incidences are more accurately estimated using a competing risk analysis (Figure 2e). The most common competing risk analysis for kidney transplant outcomes has 3 states as follows: alive with functioning graft, graft failure, and death. Because there is no transition (no arrow) from graft failure to death, the competing risk analysis does not take death after graft failure into account. In statistical jargon, both graft failure and death are treated as terminal or “absorptive” states, from which it is impossible to leave. It is often more informative to treat graft failure as a transient state that patients leave when they die or are retransplanted, which requires a proper multistate model.

### Statistical Analysis

Unadjusted Kaplan-Meier, competing risk and multistate model analyses were performed with R version 4.0.1 (R Core Team, Vienna, Austria) using the “survival” package. For competing risk and multistate models, the R survival package uses the nonparametric Aalen-Johansen estimator to calculate the probability of subjects being in each of the different states at all time points (essentially, the same estimator also handles Kaplan-Meier calculations). Figures were generated using R and Graphpad Prism version 6 (San Diego, CA, USA). Some minor graphical editing was performed using the open-source program GIMP, version 2.10.20 (The GIMP Team).

### RESULTS

#### Study Population

Between 1990 and 2019, the proportion of single kidney transplant recipients aged 65 years and older at transplant increased from to 2.7% to 19.8% (Figure 1). The change in age distribution at the time of graft loss and of patient death is shown in Supplementary Figure S2 and S3, and illustrates an even higher increase in the proportion of patients aged 65 years and older over the past 3 decades. The 1990 to 2019 interval was only used to generate Figure 1, as well as Supplementary Figure S2 and S3, to illustrate how
significantly the transplant population has aged over a period of 3 decades. All analyses, tables and figures beyond this point are limited to transplants performed during the period 2000 to 2017. A total of 238,123 first-time adult single kidney recipients were included. Characteristics of the study population by age group are summarized in Table 1.

Median time to last recorded follow-up was 6.0 years (range 1 day–20.2 years). At last follow-up, patient status could be alive with functioning graft, graft failed (alive), retransplanted, deceased, or lost to follow-up. The time of last recorded follow-up for all patients is shown in Supplementary Figure S4. The number of patients “at risk” of graft failure or death at each time point after transplant within each age group are presented in Supplementary Table S1. This information was not added to individual survival curves, to maintain readability.

Unadjusted Kaplan-Meier and Competing Risk Survival Analyses
Standard Kaplan-Meier survival curves for death-censored graft failure, death with functioning graft, all-cause (uncensored) graft failure, and overall patient
survival, stratified by age, are presented in Figure 3. Early death-censored graft survival was lowest in patients aged 75 years and older, but after 3.6 years, these were overtaken by patients younger than 55 years, who then had the worst death-censored graft survival (Figure 3 Panel a). As expected, all other survival

| Characteristic                  | Total (N = 238,123) | 18-54 yr (n = 139,516) | 55-64 yr (n = 63,579) | 65-74 yr (n = 32,128) | ≥ 75 yr (n = 2900) |
|--------------------------------|---------------------|------------------------|-----------------------|----------------------|--------------------|
| Gender                         |                     |                        |                       |                      |                    |
| Male                           | 0.61                | 0.60                   | 0.61                  | 0.63                 | 0.72               |
| Female                         | 0.39                | 0.40                   | 0.39                  | 0.37                 | 0.28               |
| Race                           |                     |                        |                       |                      |                    |
| White                          | 0.66                | 0.64                   | 0.67                  | 0.72                 | 0.80               |
| Black                          | 0.26                | 0.29                   | 0.26                  | 0.20                 | 0.14               |
| Asian                          | 0.06                | 0.06                   | 0.06                  | 0.06                 | 0.05               |
| Other                          | 0.02                | 0.02                   | 0.02                  | 0.01                 | 0.01               |
| Ethnicity                      |                     |                        |                       |                      |                    |
| Hispanic                       | 0.15                | 0.17                   | 0.14                  | 0.11                 | 0.08               |
| Non-Hispanic                   | 0.85                | 0.83                   | 0.86                  | 0.89                 | 0.92               |
| BMI, mean (SD)                 | 27.9 (5.5)          | 27.6 (5.8)             | 28.5 (5.3)            | 28.0 (4.9)           | 26.8 (4.4)         |
| Prior dialysis                 | 0.82                | 0.81                   | 0.83                  | 0.81                 | 0.82               |
| Dialysis duration in years, a  | 3.5 (2.9)           | 3.5 (3.0)              | 3.6 (2.8)             | 3.3 (2.5)            | 3.1 (2.2)          |
| Diabetic nephropathy           | 0.27                | 0.20                   | 0.39                  | 0.37                 | 0.23               |
| Donor type                     |                     |                        |                       |                      |                    |
| Deceased                       | 0.62                | 0.57                   | 0.68                  | 0.72                 | 0.77               |
| Living                         | 0.38                | 0.43                   | 0.32                  | 0.28                 | 0.23               |
| KDPI (in case of deceased donor), median % (IQR) | 43 (20–68) | 36 (17–60) | 49 (24–74) | 59 (29–81) | 70 (40–87) |

BMI, body mass index; IQR, interquartile range; KDPI, kidney donor risk index.

*Of patients with prior dialysis.

Numbers are proportions unless otherwise indicated.
analyses show worse outcomes for the older cohorts (Figure 3 Panels b, c, and d). Next, a competing risk analysis for graft failure and death with functioning graft was performed (corresponding to Figure 2e), stratified by age groups. The resulting cumulative incidence functions (CIFs) are shown in Figure 4. Cumulative incidence simply means cumulative probability here, and the CIF plots the probability of patients being in each of the possible states at any point in time. Probabilities always sum to 1 in a CIF, (i.e., every patient must always be in 1 of the states).

The discrepancy between Kaplan-Meier and competing risk estimates of graft failure and death with functioning graft at 10 years post-transplant are shown in Figure 5. The overestimation of event rates increased with recipient age, leading to an absolute overestimation of the risk of death with functioning graft of 9.9% (± 3.4%) in patients aged 75 years and older at the time of transplant. Because this overestimation is known to be strongly dependent on the duration of follow-up, The relationship between recipient age and absolute overestimation of event rates for follow-up times ranging from 1 year to 15 years is plotted in Figure 6. For a 5-year follow-up period, the Kaplan-Meier estimated rate of death with functioning graft in patients aged 75 years and older was 32.7% (± 2.6%), compared with the competing risk estimate of 29.9% (± 2.6%), corresponding with an absolute overestimation of 2.8% (± 2.6%). The estimated 5-year rate of graft failure was 12.8% (± 1.8%) (Kaplan-Meier) versus 11.4% (± 1.8%) (competing risk), an absolute overestimation of 1.4% (± 1.3%). In those younger than 55 years, the overestimation of 5-year rates for death with functioning graft was 0.5% (± 0.2%) and that of graft failure 0.4% (± 0.3%).

Unadjusted Multistate Models
A multistate model with the following post-transplant states: “alive with functioning graft,” “death with functioning graft,” “graft failed, alive,” “retransplanted” and “death after graft failure” was constructed. This is a variant of the model depicted in diagram f of Figure 2, differing in that there are 2 separate states for death (before and after graft failure) and retransplanted patients do not return to the baseline state of “alive with functioning graft.” The reason...
Figure 5. Discrepancy between Kaplan-Meier and competing risk estimates of graft failure and death with functioning graft at 10 years post-transplant. Black lines indicate the absolute overestimation of risk by Kaplan-Meier analysis (calculated by subtracting the competing risk estimate from the Kaplan-Meier estimate for each age group).

Figure 6. Relationship between duration of post-transplant follow-up and absolute risk overestimation by Kaplan-Meier analysis, compared with competing risk analysis.
for the latter is that this would make it difficult to separate outcomes of the first and second transplant. The probabilities of each of these states, stratified by age group, are shown in Figure 7. An alternative way of visualizing the same information using CIFs for each age group is presented in Figure 8. A multistate model calculates the proportion of patients in each state at every time point (probability in state, used to construct the CIF) and the mean time spent in each state. In the current cohort, mean time in the state “alive with functioning graft” was 12.1 years, 10.0 years, 8.1 years, and 6.4 years for age groups 18 to 54 years, 55 to 64 years, 65 to 74 years, and 75 years and older, respectively. For all patients transplanted at the age of 55 or older, the probability of being in the state “graft failed, alive” (resumed dialysis) was never more than 4% at any point after transplant. In addition, patients transplanted at the age of 65 and older were almost never retransplanted. Because the low probability of being alive with a failed graft in older patients was indicative of high mortality after graft failure, we performed a second multistate analysis of the subgroup of patients who had suffered graft failure (n = 45,772). This model included the post-transplant states “graft failed, alive,” “relisted” (placed on the waitlist for a second kidney), and “retransplanted” and “death.” Age groups for this analysis refer to age at the time of graft failure, not age at first transplant. Survival curves are presented in Figure 9 and demonstrate high early mortality among older patients. One-year mortality after graft loss was 11.5% (95% confidence interval, 10.9–12.1%), 24.4% (23.5–25.4%), 37.0% (35.8–38.4%) and 50.2% (47.4–53.3%) in patients aged 18 to 54 years, 55 to 64 years, 65 to 74 years, and 75 years and older at the time of graft failure, respectively. At 2 years, mortality in these groups was 19.8% (18.9–20.6), 38.0% (36.7–39.1), 54.0%
(52.6–55.4) and 67.2% (64.3–70.1), respectively. Mean combined time in the states “graft failed, alive” or “relisted” (i.e., time alive before retransplant or death) was 4.1 years, 2.8 years, 2.1 years and 1.6 years for age groups 18 to 54 years, 55 to 64 years, 65 to 74 years, and 75 years and older, respectively. These numbers could theoretically be inflated by significant and/or unbalanced loss to follow-up, because the multistate model might extrapolate high early mortality rates to the group of patients who were lost to follow-up. Nevertheless, rates of loss to follow-up were low among older patients (less than 10% over 15 years; see Supplementary Figure S5) and “observed” mortality rates based only on patients for whom a death date was available were also very high (see Supplementary Table S2).

For patients aged 18 to 54 years, 55 to 64 years, 65 to 74 years, and 75 years and older at the time of graft failure, the proportions relisted were 58%, 41%, 23%, and 7%, respectively. Outcomes after graft failure differed significantly between patients who were never relisted and those who were relisted for a second kidney (see Supplementary Figure S6 and Supplementary Table S3). In patients who were relisted, 2-year patient survival after graft failure was 92.1% (91.2–93.0), 84.9% (83.4–86.3), 77.9% (75.2–80.4), and 77.4% (67.1–84.5) for those aged 18 to 54 years, 55 to 64 years, 65 to 74 years, and 75 years and older versus 54.0% (52.5–55.4), 40.4% (38.8–42.0), 33.7% (32.1–35.2), and 27.3% (24.3–30.1) for those in the same age groups who were never relisted. Mean time spent in the state “graft failed, alive” prior to retransplant was 3.2, 2.2, 1.7 and 1.2 years for patients aged 18 to 54 years, 55 to 64 years, 65 to 74 years, and 75 years and older, indicating that the small subgroup of older patients who were retransplanted received their second kidney shortly after graft failure.

Figure 8. Stacked cumulative incidence function of multistate model with 5 possible states, by patient age at the time of transplant. The information presented here is the same as in Figure 7, but organized differently. For each of the age groups, this Figure shows the probabilities of being in each of the 5 possible states, stacked on top of each other (compare with Figure 4).
after losing the first. As an additional illustration of the utility of multistate models to visualize differences between patient groups, how the post-transplant course differed between recipients of living and deceased donor kidneys across the age groups is presented in Supplementary Figure S7.

**DISCUSSION**

This analysis of SRTR data comprising 238,123 adults who received a first-time single kidney transplant between 2000 and 2017 demonstrated that conventional outcome metrics, such as death-censored graft failure and death with functioning graft, are both less accurate (in estimating cumulative incidence) and less informative in older (≥65 years) and elderly (≥75 years) recipients. It is less accurate, because Kaplan-Meier analyses resulted in an age-related overestimation of the rates of graft failure and death with functioning graft, compared with methods that account for competing risks. It is well-known that censoring for death in the presence of competing risks can result in an overestimation of event rates, particularly with extended follow-up and in high-risk patient groups.\(^{10,15,19}\) Though it was therefore to be expected that older recipients, being at high risk of death, would be significantly affected by this bias, this study is the first to quantify the overestimation across the age spectrum and across a range of different follow-up times. Event rate overestimation was disproportionately high among older recipients, particularly with regards to death with functioning graft. As a result, Kaplan-Meier survival analyses with a time frame of more than 2 years (and certainly more than 5 years) are likely to result in inaccurately inflated rates of graft failure and death with functioning graft for older recipients. This in turn could negatively affect the likelihood of older patients being considered for transplantation. Furthermore, this overestimation complicates outcome comparisons between patient cohorts with different age distributions, including comparisons with historical cohorts that will likely have been younger on average. This issue can be avoided by using competing risk methodology for outcome reporting, as SRTR now routinely does,\(^3\) but the practice is not universal.

In addition, a multistate model analysis demonstrated that for kidney transplant recipients aged 55 years and older at the time of transplant, the probability of being in the state “graft failed, alive” (back on

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**Figure 9.** Multistate model (4 possible states) of course after graft failure, by age at the time of graft failure. The baseline state of ‘graft failed, alive’ is not shown here. Note that since the states sum to 1, the full set is redundant. The number of patients who experienced graft failure and were included in this model was 24,441; 11,597; 7936 and 1798 in age categories 18–54, 55–64, 65–74 and ≥75 years, respectively.
dialysis) was never more than 4% at any point after transplant. The reasons were 2-fold as follows: graft failure was relatively uncommon in older recipients, and the subgroup that did return to dialysis suffered very high early mortality rates, so generally did not remain on dialysis for long. Although mortality after graft failure is known to be high,20-23 the current analysis is the first to demonstrate how strongly mortality after graft failure correlates with age in a contemporary cohort. Mortality in the first year after graft failure was 11.7% among patients younger than 55 years, very similar to the reported aggregate rate of 12% in a 2014 meta-analysis of studies published between 1975 and 2013.23 For older patients, who were underrepresented in historical cohorts, mortality was much higher in the current analysis. In the first 30 days after graft failure (a period often excluded from analysis), 11% of patients aged 65 to 74 years and 15% of those aged 75 years and older died. Mortality after 2 years was 53% and 66%, respectively. It is likely that older recipients often lose their grafts in the context of serious illness, which may drive both graft failure and early mortality. In addition, reporting to SRTR and coding may become challenging when graft failure is rapidly followed by death, as it is not always clear whether a patient who was started on dialysis a few days or weeks prior to death truly experienced graft function, had they survived. Other factors, such as high infection rates related to persistent effects of immunosuppression, likely play a role.24 At any rate, the current analysis demonstrates that graft failure in older recipients has very different prognostic implications compared with younger recipients. Furthermore, the fact that the temporal distinction between graft failure and death may be ambiguous in many older recipients is an argument for the systematic reporting of death after graft failure together with other outcome metrics, especially as the transplant population continues to age.

In the kidney transplant literature multistate models have mainly, but not exclusively, been applied in studies of outcomes of waitlisted patients.25-28 They are a natural fit here, because waitlisted patients can transition between several different states (e.g., listed active, listed inactive, death on the waitlist, removed from waitlist, transplanted). Multistate models can also be a useful adjunct to traditional survival analyses in several ways. Like competing risk analyses, multistate models do not suffer from the overestimation of event rates that may occur with Kaplan-Meier analyses when event rates are high and/or there is an extended follow-up period, which is particularly relevant when using large (≥5 years) time frames to assess the full post-transplant trajectory.10,19 Nevertheless, a limitation of common competing risk analyses (Figure 2e) is that they do not generally consider events that occur after graft failure. For example, the competing risk CIF (Figure 4) shows that of patients aged 65 to 74 years at transplant, around 16% had experienced graft failure after 10 years. Combining this with the multistate model CIF (Figure 8) makes it clear, however, that patients in that age group who had experienced graft failure were almost all deceased by that time. Both figures convey useful information, and they are complementary. For nonmedical audiences, however, the multistate model CIF may be more intuitive and offers a more direct answer to the question: “What is likely to happen in the years after transplant?” As such, multistate models may be an effective way to convey risks and improve shared-decision making between caregivers and patients. Furthermore, when used for descriptive purposes, that is obtaining the crude (unadjusted) post-transplant trajectory for different groups of patients, multistate model implementation in R is accessible (excellent online documentation in the form of vignettes29) and not computationally demanding.

Some caveats are worth pointing out. Multistate models do not obviate the need for traditional and competing risk survival analyses. If the research question is focused on cumulative probability, i.e., “How many patients would have experienced graft failure by 5 years?” it is not helpful to treat graft failure as a transient state, and a competing risk analysis will suffice. In addition, whereas it is simple to construct multistate models that extend to events that happened a long time after transplant, the results must be cautiously interpreted. With very long follow-up, there is only a small minority of patients still contributing data. On the other hand, the fact that the SRTR registry covers all kidney transplants performed in the US means that certain late events, such as retransplantation, are reliably captured. Lastly, all of the analyses reported in this paper are unadjusted and therefore descriptive. The outcomes of older patients are not only a reflection of increased age per se but also of comorbid conditions and donor risks. Questions relating to the independent effect of age on the post-transplant trajectory are interesting in their own right and can be addressed using a multistate multivariable regression framework.15 The current study, however, has focused on making the case that even the reporting of crude transplant outcomes may benefit from a multistate model approach. Compared with standard survival analyses, multistate models are more accurate and add relevant information, and are straightforward to interpret and visualize.

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In summary, multistate models can describe the entire post-transplant trajectory in a single analysis, do not suffer from the potential overestimation of event rates that may occur with Kaplan-Meier analyses, and readily incorporate outcomes, such as events after graft failure, that are not always reported. This appears particularly relevant to obtain accurate estimates of the expected post-transplant course for older recipients. Multistate models may be a useful adjunct to traditional survival analyses when reporting unadjusted outcomes after kidney transplantation, particularly when using time frames longer than 5 years post-transplant.

DISCLOSURE
All the authors declared no competing interests.

ACKNOWLEDGMENTS
TV is the recipient of a Belgian American Educational Foundation grant.

Data Availability Statement
The R code of the data analysis is available on www.github.com/tvhove/STRTR-MSM. Combined with a recent version of the SAF files (which must be obtained from SRTR), it can be used to reproduce the analyses and plots in this study and its supporting information.

SUPPLEMENTARY MATERIAL
Supplementary File (PDF)
Figure S1. Distribution of kidney transplant recipient age at the time of graft failure, by era.
Figure S2. Distribution of kidney transplant recipient age at the time of death, by era.
Figure S3. Flowchart of patient selection.
Figure S4. Time of last recorded follow up, by age group.
Figure S5. Stacked cumulative incidence function of competing risk estimates, including a state for "lost to follow-up."
Figure S6. Mortality and probability of retransplant after graft failure, stratified by age at graft failure and whether patient was ever relisted.
Figure S7. Post-transplant course (4 possible states) by patient age group and donor type (living vs. deceased).
Table S1. Number of patients at risk of graft failure or death at different time points.
Table S2. Difference between the proportion of all patients who had a confirmed death date by 1 and 2 years after graft failure and the multistate model estimated mortality at the same time points.
Table S3. Proportion of patients relisted and retransplanted after graft failure, by age at the time of graft failure.

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