

# Kidney transplantation and too-sick removal among waitlisted candidates with prior malignancy: a retrospective OPTN/UNOS cohort study, 2000–2026

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## Research Article

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# Abstract

## Background

Among candidates already listed for kidney transplantation, whether recorded prior malignancy is associated with the subsequent probability of transplantation remains uncertain.

## Methods

We conducted a retrospective registry cohort study of 921,534 adult kidney-alone registrations in the United States Organ Procurement and Transplantation Network Standard Transplant Analysis and Research file from January 1, 2000, through June 30, 2026. Region-stratified, patient-clustered piecewise cause-specific Cox models estimated relative associations. Standardized competing-risk curves compared registrations with and without recorded prior malignancy over 0–5 years.

## Results

Prior malignancy was recorded in 74,435 registrations (8.1%). Adjusted hazard ratios for kidney transplantation were 1.029 (95% CI, 1.013–1.045), 1.025 (95% CI, 1.003–1.047), and 1.068 (95% CI, 1.032–1.106) during 0–1, 1–3, and 3–5 years, respectively. The standardized 5-year kidney transplantation probability was 47.14% with recorded prior malignancy and 45.77% without it (risk difference, + 1.38 percentage points; 95% CI, + 0.98 to + 1.77). The living-donor kidney transplantation probability was higher (16.82% vs 14.77%), whereas the deceased-donor probability was slightly lower (30.33% vs 31.00%). Adjusted hazard ratios for too-sick removal ranged from 1.133 to 1.202.

## Conclusions

Among candidates already accepted to the kidney waitlist, recorded prior malignancy was associated with a modestly higher standardized 5-year probability of kidney transplantation. The small difference comprised a higher probability of living-donor transplantation alongside a slightly lower probability of deceased-donor transplantation. Too-sick removal was also more frequent.

## Background

Kidney transplantation offers a substantial survival advantage over continued dialysis for appropriately selected patients with kidney failure [1]. For a candidate with treated cancer, the decision to proceed must balance the anticipated benefit of transplantation against recurrence risk under immunosuppression and the competing hazards of remaining on dialysis. Current guidance favors cancer-specific assessment based on tumor type and stage, response to treatment, recurrence risk, and expected transplant benefit rather than a single waiting interval for all malignancies [2–3].

Implementation remains heterogeneous because the scope and sequence of candidate evaluation differ across transplant programs [4].

Evidence on postlisting outcomes among candidates with prior malignancy remains sparse. An early single-center study of 382 potential recipients described listing decisions, waitlist removal, death, and transplantation among 38 patients with a cancer history [5]. Subsequent registry research has largely focused on selected recipients who ultimately underwent transplantation, examining graft survival, patient survival, and posttransplant cancer outcomes [6]. Consequently, whether recorded prior malignancy is associated with the probability of receiving a kidney transplant or with adverse attrition after waitlisting has not been well characterized.

We therefore examined whether recorded prior malignancy was associated with the standardized 5-year probability of kidney-alone transplantation among adult United States waitlist registrations. Overall kidney transplantation, defined as deceased-donor kidney transplantation (DDKT) or living-donor kidney transplantation (LDKT), was the primary outcome. DDKT and LDKT were evaluated separately to characterize donor-source patterns, and too-sick removal was assessed as the principal adverse waitlist outcome.

## Methods

### Study Design and Data Source

We conducted a retrospective registry cohort study using the June 2026 Organ Procurement and Transplantation Network (OPTN) Standard Transplant Analysis and Research (STAR) kidney/pancreas file, obtained through OPTN Data Request DATA0017675 under the applicable Data Use Agreement. The analytic unit was a kidney-alone waitlist registration. Repeated registrations were retained and linked by patient identifier. The study window extended from January 1, 2000, through June 30, 2026. Reporting followed the Strengthening the Reporting of Observational Studies in Epidemiology statement [7].

### Study Population and Exposure

We included adult kidney-alone waitlist registrations in the United States from January 1, 2000, through June 30, 2026, with prior-malignancy status recorded as either present or absent at registration. Registrations with recorded prior malignancy constituted the exposed group, and those with recorded absence constituted the comparison group. We excluded erroneous registrations, records with invalid follow-up intervals, registrations without observable follow-up or a valid same-day terminal event, and records with unknown dialysis status. Valid terminal events occurring on the registration date were retained. All eligible registrations were included without a formal sample-size calculation. Detailed eligibility criteria, exposure coding, and cohort construction are provided in Fig. 1 and Additional file 1 (Supplementary Methods and Table S1A).

## Outcomes and Follow-up

The primary outcome was kidney-alone transplantation, defined as deceased-donor kidney transplantation (DDKT) or living-donor kidney transplantation (LDKT). DDKT and LDKT were also evaluated separately as donor-source components of the primary outcome. Other mutually exclusive waitlist outcomes were too-sick removal, waitlist death, and removal for other reasons. Candidates without a classified event were administratively censored.

Follow-up began on the registration date and ended at the first classified event, the administrative data cutoff of June 30, 2026, or 5 years after registration, whichever occurred first. Valid terminal events occurring on the registration date were retained according to the same-day event rule. Complete outcome definitions, registry coding, event-date selection, and classification priorities are provided in the Supplementary Methods.

## Covariates

Adjusted models included age at listing, sex, race and ethnicity, ABO blood group, diabetes, dialysis status and duration, panel-reactive antibody or calculated panel-reactive antibody at listing, primary kidney diagnosis, number of previous transplants, functional status, body mass index category, and listing era. Covariates were selected a priori on clinical grounds as potential confounders rather than according to univariable statistical significance.

Unknown or unreported covariate values were retained as explicit categories because exclusion would remove a large, era-dependent subset of registrations and the STAR file did not provide auxiliary variables sufficient for defensible imputation of the harmonized PRA/cPRA measure. PRA/cPRA was unknown for 22.5% of registrations overall, with missing values occurring in the pre-KAS and 2022-onward eras and being more frequent in the latter. We therefore quantified missingness by prior-malignancy status and listing era and repeated the primary adjusted analysis without PRA/cPRA as a sensitivity analysis. Detailed variable definitions and the handling of sparse categories are described in the Supplementary Methods.

## Statistical Analysis

Baseline characteristics were summarized as medians with interquartile ranges (IQRs) or counts with percentages. Between-group differences were assessed using standardized mean differences rather than significance tests. Available follow-up was summarized using the reverse Kaplan–Meier method.

Five mutually exclusive cause-specific event processes—DDKT, LDKT, too-sick removal, waitlist death, and other removal—were modeled over a common 0–5-year horizon. Cause-specific hazard ratios describe event-specific rates among registrations that remain free of all classified events [8].

For relative associations, separate cause-specific Cox models were fitted within 0–1, 1–3, and 3–5 years, allowing the associations of the exposure and covariates to vary across intervals. Kidney transplantation was additionally modeled as a combined DDKT-or-LDKT endpoint. All models were stratified by Organ Procurement and Transplantation Network region, included the full adjustment set, and used patient-clustered robust standard errors to account for repeated registrations.

For the primary absolute estimand, the 15 fitted cause-by-interval components (5 mutually exclusive causes across 3 follow-up intervals) were integrated to generate standardized cumulative incidence curves from registration through 5 years. Predictions for recorded prior malignancy present and absent were standardized to the same fixed target population, comprising all eligible registrations made on or before June 30, 2021, and therefore having the opportunity for 5 years of administrative follow-up. The primary contrast was the difference in the standardized 5-year probability of kidney transplantation between registrations with and without recorded prior malignancy. Its 95% confidence interval was estimated using 500 patient-level cluster-bootstrap replicates.

Sensitivity analyses restricted the cohort to each patient's first eligible registration, replaced region stratification with listing-center stratification, and repeated the primary adjusted models without PRA/cPRA. Data processing and figure generation used Python 3.12.13 (pandas 3.0.1, NumPy 2.3.5, and matplotlib 3.10.8). Model fitting, standardization, and bootstrapping used R 4.4.3 (survival 3.8-3, data.table 1.18.2.1, Matrix 1.7-2, and Rcpp 1.0.14).

Final vector artwork was rendered from aggregate outputs using ReportLab 4.4.9.

## Use of artificial intelligence

OpenAI Codex was used solely for language editing and refinement. The authors are fully responsible for the content and final manuscript.

## Results

### Cohort Characteristics

The final cohort comprised 921,534 registrations from 737,017 patients. Prior malignancy was recorded in 74,435 registrations (8.1%), and its absence was recorded in 847,099 (91.9%) (Fig. 1). The reverse Kaplan-Meier median available follow-up was 14.4 years (IQR, 6.5–20.3), with 2,099,198 person-years of observation. Candidates with prior malignancy were older at listing (median, 63 vs 52 years) and more often White; the standardized mean difference for age was 0.817 (Table 1).

Table 1  
Baseline characteristics by recorded prior-malignancy status

| Characteristic        | Level        | Overall (N = 921534) | No prior malignancy (N = 847099) | Prior malignancy (N = 74435) | SMD   |
|-----------------------|--------------|----------------------|----------------------------------|------------------------------|-------|
| Age at listing, years | Median (IQR) | 53.0 (43.0–62.0)     | 52.0 (42.0–61.0)                 | 63.0 (55.0–68.0)             | 0.817 |
| Sex                   | Female       | 358132 (38.9%)       | 330768 (39.0%)                   | 27364 (36.8%)                | 0.047 |
|                       | Male         | 563402 (61.1%)       | 516331 (61.0%)                   | 47071 (63.2%)                |       |
| Race and ethnicity    | White        | 406788 (44.1%)       | 358264 (42.3%)                   | 48524 (65.2%)                | 0.476 |
|                       | Black        | 267736 (29.1%)       | 252135 (29.8%)                   | 15601 (21.0%)                |       |
|                       | Hispanic     | 164191 (17.8%)       | 157848 (18.6%)                   | 6343 (8.5%)                  |       |
|                       | Asian        | 63290 (6.9%)         | 60430 (7.1%)                     | 2860 (3.8%)                  |       |
|                       | Other        | 17960 (1.9%)         | 17000 (2.0%)                     | 960 (1.3%)                   |       |
|                       | Unknown      | 1569 (0.2%)          | 1422 (0.2%)                      | 147 (0.2%)                   |       |
| ABO blood group       | A            | 299768 (32.5%)       | 273224 (32.3%)                   | 26544 (35.7%)                | 0.078 |
|                       | B            | 136323 (14.8%)       | 126415 (14.9%)                   | 9908 (13.3%)                 |       |
|                       | AB           | 35226 (3.8%)         | 32314 (3.8%)                     | 2912 (3.9%)                  |       |
|                       | O            | 450217 (48.9%)       | 415146 (49.0%)                   | 35071 (47.1%)                |       |
| Diabetes              | No           | 517963 (56.2%)       | 474452 (56.0%)                   | 43511 (58.5%)                | 0.055 |
|                       | Yes          | 401648 (43.6%)       | 370804 (43.8%)                   | 30844 (41.4%)                |       |

Values are median (interquartile range) or n (%). One multilevel standardized mean difference (SMD) is shown on the first row of each characteristic. KAS, Kidney Allocation System; PRA, panel reactive antibody; cPRA, calculated panel reactive antibody.

| Characteristic                                                                                                                                                                                                                                               | Level                               | Overall (N = 921534) | No prior malignancy (N = 847099) | Prior malignancy (N = 74435) | SMD   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|----------------------|----------------------------------|------------------------------|-------|
|                                                                                                                                                                                                                                                              | Unknown                             | 1923 (0.2%)          | 1843 (0.2%)                      | 80 (0.1%)                    |       |
| Dialysis status/vintage                                                                                                                                                                                                                                      | Preemptive                          | 224613 (24.4%)       | 201088 (23.7%)                   | 23525 (31.6%)                | 0.205 |
|                                                                                                                                                                                                                                                              | < 1 year                            | 242536 (26.3%)       | 226779 (26.8%)                   | 15757 (21.2%)                |       |
|                                                                                                                                                                                                                                                              | 1 to < 3 years                      | 234987 (25.5%)       | 218469 (25.8%)                   | 16518 (22.2%)                |       |
|                                                                                                                                                                                                                                                              | >=3 years                           | 149748 (16.2%)       | 137327 (16.2%)                   | 12421 (16.7%)                |       |
|                                                                                                                                                                                                                                                              | On dialysis, start date unavailable | 69650 (7.6%)         | 63436 (7.5%)                     | 6214 (8.3%)                  |       |
| PRA/cPRA at listing                                                                                                                                                                                                                                          | 0%                                  | 583348 (63.3%)       | 537917 (63.5%)                   | 45431 (61.0%)                | 0.066 |
|                                                                                                                                                                                                                                                              | 1–19%                               | 44257 (4.8%)         | 40958 (4.8%)                     | 3299 (4.4%)                  |       |
|                                                                                                                                                                                                                                                              | 20–79%                              | 53643 (5.8%)         | 49112 (5.8%)                     | 4531 (6.1%)                  |       |
|                                                                                                                                                                                                                                                              | 80–97%                              | 19143 (2.1%)         | 17566 (2.1%)                     | 1577 (2.1%)                  |       |
|                                                                                                                                                                                                                                                              | 98–100%                             | 13691 (1.5%)         | 12614 (1.5%)                     | 1077 (1.4%)                  |       |
|                                                                                                                                                                                                                                                              | Unknown                             | 207452 (22.5%)       | 188932 (22.3%)                   | 18520 (24.9%)                |       |
| Primary kidney diagnosis                                                                                                                                                                                                                                     | Glomerular disease                  | 149898 (16.3%)       | 140497 (16.6%)                   | 9401 (12.6%)                 | 0.292 |
|                                                                                                                                                                                                                                                              | Diabetes                            | 312625 (33.9%)       | 291972 (34.5%)                   | 20653 (27.7%)                |       |
|                                                                                                                                                                                                                                                              | Hypertension                        | 182849 (19.8%)       | 169385 (20.0%)                   | 13464 (18.1%)                |       |
|                                                                                                                                                                                                                                                              | Polycystic kidney disease           | 63871 (6.9%)         | 58710 (6.9%)                     | 5161 (6.9%)                  |       |
|                                                                                                                                                                                                                                                              | Urologic disease                    | 16384 (1.8%)         | 14930 (1.8%)                     | 1454 (2.0%)                  |       |
| Values are median (interquartile range) or n (%). One multilevel standardized mean difference (SMD) is shown on the first row of each characteristic. KAS, Kidney Allocation System; PRA, panel reactive antibody; cPRA, calculated panel reactive antibody. |                                     |                      |                                  |                              |       |

| Characteristic                                                                                                                                                                                                                                               | Level                     | Overall (N = 921534) | No prior malignancy (N = 847099) | Prior malignancy (N = 74435) | SMD   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------|----------------------------------|------------------------------|-------|
|                                                                                                                                                                                                                                                              | Other                     | 195901 (21.3%)       | 171600 (20.3%)                   | 24301 (32.6%)                |       |
|                                                                                                                                                                                                                                                              | Unknown                   | 6 (0.0%)             | 5 (0.0%)                         | 1 (0.0%)                     |       |
|                                                                                                                                                                                                                                                              |                           |                      |                                  |                              |       |
| Previous transplants                                                                                                                                                                                                                                         | 0                         | 812137 (88.1%)       | 749788 (88.5%)                   | 62349 (83.8%)                | 0.141 |
|                                                                                                                                                                                                                                                              | 1                         | 94217 (10.2%)        | 84126 (9.9%)                     | 10091 (13.6%)                |       |
|                                                                                                                                                                                                                                                              | >=2                       | 15180 (1.6%)         | 13185 (1.6%)                     | 1995 (2.7%)                  |       |
| Functional status                                                                                                                                                                                                                                            | Independent/high function | 603290 (65.5%)       | 556948 (65.7%)                   | 46342 (62.3%)                | 0.128 |
|                                                                                                                                                                                                                                                              | Moderate limitation       | 225650 (24.5%)       | 204544 (24.1%)                   | 21106 (28.4%)                |       |
|                                                                                                                                                                                                                                                              | Substantial limitation    | 48519 (5.3%)         | 44216 (5.2%)                     | 4303 (5.8%)                  |       |
|                                                                                                                                                                                                                                                              | Severe limitation         | 7876 (0.9%)          | 7097 (0.8%)                      | 779 (1.0%)                   |       |
|                                                                                                                                                                                                                                                              | Unknown                   | 36199 (3.9%)         | 34294 (4.0%)                     | 1905 (2.6%)                  |       |
| Body mass index, kg/m2                                                                                                                                                                                                                                       | < 18.5                    | 16327 (1.8%)         | 15164 (1.8%)                     | 1163 (1.6%)                  | 0.074 |
|                                                                                                                                                                                                                                                              | 18.5 to < 25              | 248892 (27.0%)       | 229292 (27.1%)                   | 19600 (26.3%)                |       |
|                                                                                                                                                                                                                                                              | 25 to < 30                | 301780 (32.7%)       | 276110 (32.6%)                   | 25670 (34.5%)                |       |
|                                                                                                                                                                                                                                                              | 30 to < 35                | 220410 (23.9%)       | 202046 (23.9%)                   | 18364 (24.7%)                |       |
|                                                                                                                                                                                                                                                              | >=35                      | 128738 (14.0%)       | 119328 (14.1%)                   | 9410 (12.6%)                 |       |
|                                                                                                                                                                                                                                                              | Unknown                   | 5387 (0.6%)          | 5159 (0.6%)                      | 228 (0.3%)                   |       |
| Listing era                                                                                                                                                                                                                                                  | Pre-KAS                   | 441060 (47.9%)       | 415909 (49.1%)                   | 25151 (33.8%)                | 0.322 |
| Values are median (interquartile range) or n (%). One multilevel standardized mean difference (SMD) is shown on the first row of each characteristic. KAS, Kidney Allocation System; PRA, panel reactive antibody; cPRA, calculated panel reactive antibody. |                           |                      |                                  |                              |       |

| Characteristic                                                                                                                                                                                                                                               | Level              | Overall (N = 921534) | No prior malignancy (N = 847099) | Prior malignancy (N = 74435) | SMD |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|----------------------|----------------------------------|------------------------------|-----|
|                                                                                                                                                                                                                                                              | Post-KAS/pre-COVID | 198281 (21.5%)       | 180240 (21.3%)                   | 18041 (24.2%)                |     |
|                                                                                                                                                                                                                                                              | COVID era          | 70919 (7.7%)         | 63528 (7.5%)                     | 7391 (9.9%)                  |     |
|                                                                                                                                                                                                                                                              | 2022 onward        | 211274 (22.9%)       | 187422 (22.1%)                   | 23852 (32.0%)                |     |
| Values are median (interquartile range) or n (%). One multilevel standardized mean difference (SMD) is shown on the first row of each characteristic. KAS, Kidney Allocation System; PRA, panel reactive antibody; cPRA, calculated panel reactive antibody. |                    |                      |                                  |                              |     |

## Five-Year Outcomes and Standardized Risks

Within 5 years of registration, 280,882 DDKTs, 126,318 LDKTs, 57,545 too-sick removals, 86,845 waitlist deaths, and 171,965 other removals occurred. A further 197,979 registrations remained event-free at 5 years or were censored earlier (Additional file 1: Table S2).

The fixed standardization population included 689,520 registrations. The standardized 5-year probability of kidney transplantation was 47.14% (95% CI, 46.76–47.52) under recorded prior malignancy and 45.77% (95% CI, 45.66–45.88) under recorded absence, yielding a risk difference of + 1.38 percentage points (95% CI, + 0.98 to + 1.77) (Table 2; Fig. 2). The corresponding risk differences were + 0.92 percentage points at 1 year and + 1.06 percentage points at 3 years.

Table 2  
Standardized cumulative incidence at 1, 3, and 5 years

| Outcome                                       | Year | No prior malignancy, % | Prior malignancy, %    | Risk difference, percentage points |
|-----------------------------------------------|------|------------------------|------------------------|------------------------------------|
| Kidney transplantation                        | 1    | 21.84                  | 22.76                  | + 0.92                             |
|                                               | 3    | 37.72                  | 38.78                  | + 1.06                             |
|                                               | 5    | 45.77 (45.66 to 45.88) | 47.14 (46.76 to 47.52) | + 1.38 (+ 0.98 to + 1.77)          |
| Deceased-donor kidney transplantation         | 1    | 12.01                  | 11.57                  | -0.44                              |
|                                               | 3    | 23.81                  | 22.97                  | -0.84                              |
|                                               | 5    | 31.00 (30.90 to 31.11) | 30.33 (29.98 to 30.67) | -0.68 (-1.04 to -0.31)             |
| Living-donor kidney transplantation           | 1    | 9.84                   | 11.20                  | + 1.36                             |
|                                               | 3    | 13.91                  | 15.81                  | + 1.90                             |
|                                               | 5    | 14.77 (14.69 to 14.85) | 16.82 (16.55 to 17.09) | + 2.05 (+ 1.78 to + 2.32)          |
| Removal because the candidate became too sick | 1    | 1.15                   | 1.38                   | + 0.22                             |
|                                               | 3    | 4.21                   | 4.80                   | + 0.59                             |
|                                               | 5    | 6.66 (6.60 to 6.73)    | 7.51 (7.33 to 7.70)    | + 0.85 (+ 0.66 to + 1.04)          |
| Waitlist death                                | 1    | 3.00                   | 2.86                   | -0.14                              |
|                                               | 3    | 8.13                   | 7.70                   | -0.43                              |
|                                               | 5    | 11.35 (11.26 to 11.43) | 10.86 (10.60 to 11.13) | -0.48 (-0.76 to -0.21)             |

Risk differences compare recorded prior malignancy minus recorded absence. All probabilities were generated from the same cause-specific competing-risk model system and standardized to 689,520 eligible registrations on or before June 30, 2021. The primary 5-year kidney-transplantation intervals used 500 patient-level cluster-bootstrap replicates and a fixed 50,000-registration prediction sample. Secondary 5-year intervals used 200 additional patient-level cluster-bootstrap replicates and the nested 100,000-registration prediction sample. Point estimates were calculated in the complete target population; 95% confidence intervals are shown in parentheses.

## Donor-Source Components and Too-Sick Removal

Adjusted hazard ratios for overall kidney transplantation were 1.029 (95% CI, 1.013–1.045) during 0–1 year, 1.025 (95% CI, 1.003–1.047) during 1–3 years, and 1.068 (95% CI, 1.032–1.106) during 3–5 years (Table 3).

Table 3  
Adjusted piecewise cause-specific associations with recorded prior malignancy

| Outcome                                       | Interval  | At risk at interval start, n | Events, n | Hazard ratio (95% CI)  | P value |
|-----------------------------------------------|-----------|------------------------------|-----------|------------------------|---------|
| Kidney transplantation                        | 0–1 year  | 921534                       | 218063    | 1.029<br>(1.013–1.045) | < 0.001 |
|                                               | 1–3 years | 578636                       | 130642    | 1.025<br>(1.003–1.047) | 0.025   |
|                                               | 3–5 years | 264800                       | 58495     | 1.068<br>(1.032–1.106) | < 0.001 |
| Deceased-donor kidney transplantation         | 0–1 year  | 921534                       | 131917    | 0.967<br>(0.948–0.986) | < 0.001 |
|                                               | 1–3 years | 578636                       | 96769     | 0.984<br>(0.960–1.009) | 0.211   |
|                                               | 3–5 years | 264800                       | 52196     | 1.051<br>(1.013–1.090) | 0.009   |
| Living-donor kidney transplantation           | 0–1 year  | 921534                       | 86146     | 1.155<br>(1.127–1.185) | < 0.001 |
|                                               | 1–3 years | 578636                       | 33873     | 1.176<br>(1.129–1.225) | < 0.001 |
|                                               | 3–5 years | 264800                       | 6299      | 1.230<br>(1.115–1.357) | < 0.001 |
| Removal because the candidate became too sick | 0–1 year  | 921534                       | 11726     | 1.202<br>(1.136–1.270) | < 0.001 |
|                                               | 1–3 years | 578636                       | 27342     | 1.140<br>(1.097–1.185) | < 0.001 |

Hazard ratios compare recorded prior malignancy with recorded absence. Models adjusted for age, sex, race and ethnicity, ABO blood group, diabetes, dialysis status/vintage, PRA/cPRA, primary kidney diagnosis, previous transplants, functional status, body mass index, and listing era; models were stratified by OPTN region and used patient-clustered robust standard errors. Kidney transplantation is the overall outcome; DDKT and LDKT are donor-source components and were not designated as separate primary outcomes. Too-sick removal is an adverse waitlist outcome. P values are unadjusted supporting measures. CI, confidence interval; OPTN, Organ Procurement and Transplantation Network.

| Outcome                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Interval  | At risk at interval start, n | Events, n | Hazard ratio (95% CI)  | P value |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|------------------------------|-----------|------------------------|---------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 3–5 years | 264800                       | 18477     | 1.133<br>(1.077–1.192) | < 0.001 |
| <p>Hazard ratios compare recorded prior malignancy with recorded absence. Models adjusted for age, sex, race and ethnicity, ABO blood group, diabetes, dialysis status/vintage, PRA/cPRA, primary kidney diagnosis, previous transplants, functional status, body mass index, and listing era; models were stratified by OPTN region and used patient-clustered robust standard errors. Kidney transplantation is the overall outcome; DDKT and LDKT are donor-source components and were not designated as separate primary outcomes. Too-sick removal is an adverse waitlist outcome. P values are unadjusted supporting measures. CI, confidence interval; OPTN, Organ Procurement and Transplantation Network.</p> |           |                              |           |                        |         |

The standardized 5-year DDKT probability was 30.33% with recorded prior malignancy (95% CI, 29.98–30.67) and 31.00% without it (95% CI, 30.90–31.11), with a risk difference of -0.68 percentage points (95% CI, -1.04 to -0.31). The corresponding LDKT probabilities were 16.82% (95% CI, 16.55–17.09) and 14.77% (95% CI, 14.69–14.85), with a risk difference of + 2.05 percentage points (95% CI, + 1.78 to + 2.32) (Table 2; Fig. 3). DDKT hazard ratios were 0.967 (95% CI, 0.948–0.986), 0.984 (95% CI, 0.960–1.009), and 1.051 (95% CI, 1.013–1.090) across the 3 intervals. The corresponding LDKT hazard ratios were 1.155 (95% CI, 1.127–1.185), 1.176 (95% CI, 1.129–1.225), and 1.230 (95% CI, 1.115–1.357). For too-sick removal, hazard ratios were 1.202 (95% CI, 1.136–1.270), 1.140 (95% CI, 1.097–1.185), and 1.133 (95% CI, 1.077–1.192); the standardized 5-year probabilities were 7.51% (95% CI, 7.33–7.70) and 6.66% (95% CI, 6.60–6.73), with a risk difference of + 0.85 percentage points (95% CI, + 0.66 to + 1.04). Adjusted associations for waitlist death and other removal are reported in Additional file 1: Table S3.

## Sensitivity Analyses of Cause-Specific Associations

Restricting the cohort to each patient's first registration yielded kidney transplantation hazard ratios of 1.01, 1.02, and 1.07 across the 3 intervals. With listing-center stratification, the corresponding estimates were 1.01, 1.00, and 1.05. Too-sick-removal hazard ratios remained above 1.13 in every interval in both sensitivity analyses (Additional file 1: Table S4). Omitting PRA/cPRA from the adjustment set yielded kidney-transplantation hazard ratios of 1.030, 1.026, and 1.069; the standardized 5-year kidney-transplantation risk difference was + 1.42 percentage points (Additional file 1: Table S6).

## Discussion

In this national cohort of adult kidney-alone waitlist registrations, recorded prior malignancy was associated with a 1.38-percentage-point higher standardized 5-year probability of kidney transplantation. The small absolute difference comprised opposing donor-source components: LDKT was 2.05 percentage points higher, while DDKT was 0.68 percentage points lower. Recorded prior malignancy was also associated with a persistently higher cause-specific rate of too-sick removal and a 0.85-percentage-

point higher 5-year probability of that outcome. Thus, a modest difference in overall transplantation probability coexisted with differences in donor pathway and health-related attrition.

These findings apply only to candidates who had completed sufficient clinical and oncologic evaluation to enter the kidney waitlist. Fischereder and Jauch showed that selection begins before listing: among potential recipients with a cancer history, some did not complete evaluation, were removed, or died before transplantation [5]. Evaluation practices also vary across transplant programs [4]. Studies limited to recipients with prior malignancy necessarily describe patients who successfully passed both prelisting assessment and subsequent waitlist selection [6, 9]. Our results therefore characterize outcomes among selected waitlisted candidates and cannot be extrapolated to patients who were never referred, evaluated, or listed.

Previous studies addressed adjacent but different questions. Mosconi et al. described cancer occurrence and waitlist outcomes in a single-center cohort [10], whereas Boissier et al. examined waiting intervals and long-term oncologic outcomes among recipients with previous urologic malignancies [9]. Becker et al. compared donor source and post-transplant outcomes in a matched recipient cohort [11]. These studies either included relatively small waitlist populations or conditioned on eventual transplantation. None estimated the adjusted probability of receiving a kidney after listing while retaining death, clinical deterioration, and other removals as competing events. By integrating these mutually exclusive outcomes within a common target population, the present study provides an absolute 5-year estimate that complements the time-specific cause-specific hazard ratios [8, 12].

The donor-source analysis showed that the modestly higher overall transplantation probability reflected a higher probability of LDKT, which numerically exceeded the small reduction in DDKT probability. Becker et al. similarly observed a higher proportion of living donors among recipients with prior malignancy, although their matched cohort was small and the difference was not statistically significant [11]. Other candidate studies have shown that access to LDKT varies by race and ethnicity and by the size and supportiveness of a candidate's social network [13–14]. Randomized trials have also demonstrated that home-based education and family- or social-worker-supported interventions can increase donor inquiries, evaluations, and pursuit of LDKT [15–16]. These findings provide plausible context for variation in the living-donor pathway but do not explain the association observed in our study. The STAR file lacks information on potential donor availability, the timing and outcome of donor evaluation, patient preferences, household resources, and center counseling. The higher LDKT probability should therefore be interpreted as a difference in donor-source pattern rather than an effect attributable to prior malignancy itself.

DDKT showed a different pattern, with a 0.68-percentage-point lower standardized 5-year probability among registrations with recorded prior malignancy. Unlike LDKT, DDKT is determined largely by allocation priority, dialysis-time credit, sensitization, organ availability, and continued transplant eligibility [17]. National policy changes, including implementation of the Kidney Allocation System, have altered deceased-donor transplantation patterns [18], while geographic organ availability and center-level offer-

acceptance practices remain heterogeneous [19–20]. Center performance oversight may also influence waitlist removal and transplantation practices [21]. The hazard ratio above 1 during years 3–5 should be interpreted cautiously because it applies only to candidates who remained free of transplantation, death, and removal during the earlier intervals. It therefore does not indicate a delayed improvement or compensatory increase in deceased-donor access. For the 5-year question, the standardized cumulative DDKT probability provides the more clinically interpretable summary.

Too-sick removal showed a more consistent association with recorded prior malignancy than that reported in the closest national study. Schold et al. analyzed 315,796 kidney transplant candidates and combined removals due to clinical deterioration with other waitlist removals; although prior malignancy was associated with a higher unadjusted removal rate, the adjusted hazard ratio was 1.03 (95% CI, 0.98–1.08) [21]. In the present study, the outcome was restricted to removal because the candidate had become too sick to undergo transplantation, and the adjusted hazard ratios remained between 1.13 and 1.20 across all follow-up intervals. Differences in outcome definition, study period, covariate adjustment, handling of repeated registrations, and center practices may explain the differing estimates. Delisting practices vary substantially across transplant centers [22], while frailty and comorbidity have been associated with waitlist mortality, lower transplantation probability, and delisting [23–25]. However, removal because a candidate became too sick does not identify the underlying medical cause. The observed excess therefore cannot be attributed specifically to cancer recurrence and may also reflect treatment-related sequelae, cardiovascular disease, infection, frailty, functional decline, or other clinical deterioration.

For candidates who have already entered the waitlist, counseling should address both the probability of receiving a transplant and the risk of losing medical suitability while waiting. The modestly higher overall transplantation probability observed in this study does not negate the persistently higher risk of too-sick removal, because candidates may follow several mutually exclusive waitlist pathways. Donor source should also be considered separately, as the overall transplantation estimate comprised a higher probability of LDKT and a slightly lower probability of DDKT. Previous studies have reported heterogeneous post-transplant oncologic outcomes: the Collaborative Transplant Study observed increased risks of recurrent and de novo cancers among recipients with pretransplant cancer [26], whereas ANZDATA found that recurrent and second primary cancers were infrequent and were not associated with additional mortality among recipients who developed cancer [27]. More recent registry evidence also suggests an increased risk of subsequent malignancy [28]. Together with the potential harm of prolonged waiting [29], these findings support individualized assessment of recurrence risk and the consequences of remaining without transplantation [30]. The present study cannot determine an optimal cancer-free interval, surveillance strategy, or preferred donor pathway.

Several limitations should be considered. Prior malignancy was captured as a binary registry field without information on cancer type, stage, treatment, recurrence, or remission duration, and its accuracy could not be independently verified. The substantial baseline differences between exposure groups, particularly in age, leave the possibility of residual confounding despite multivariable adjustment and

standardization. Because the cohort included only candidates who had entered the waitlist, selection during referral and prelisting evaluation could not be assessed. The registry also lacked information on potential living donors, socioeconomic resources, longitudinal frailty, and the clinical reasons for loss of transplant suitability. In addition, allocation policy, cancer care, coding practices, and center management changed over the 26-year study period. PRA/cPRA was unavailable for 22.5% of registrations and its missingness was strongly era dependent. Treating unknown values as a category may not remove residual confounding if missingness also reflects center practice or outcome risk. The similar estimates obtained after omitting PRA/cPRA indicate limited sensitivity to inclusion of this covariate, but do not establish robustness to missing-data bias. The direction and magnitude of any resulting residual confounding cannot be determined from this analysis.

## Conclusions

Among adult candidates already listed for kidney transplantation in the United States, recorded prior malignancy was associated with a modestly higher standardized 5-year probability of kidney transplantation. This difference reflected a higher probability of LDKT and a slightly lower probability of DDKT, while too-sick removal was more frequent. These findings indicate distinct waitlist trajectories among selected candidates but do not imply that prior malignancy improves transplant access or causes subsequent clinical deterioration.

## Abbreviations

ANZDATA

Australia and New Zealand Dialysis and Transplant Registry

BMI

body mass index

CI

confidence interval

CIF

cumulative incidence function

COVID-19

coronavirus disease 2019

cPRA

calculated panel-reactive antibody

DDKT

deceased-donor kidney transplantation

HR

hazard ratio

IQR

interquartile range

KAS

Kidney Allocation System  
LDKT  
living-donor kidney transplantation  
OPTN  
Organ Procurement and Transplantation Network  
PRA  
panel-reactive antibody  
SE  
standard error  
SMD  
standardized mean difference  
STAR  
Standard Transplant Analysis and Research  
STROBE  
Strengthening the Reporting of Observational Studies in Epidemiology  
UNOS  
United Network for Organ Sharing.

## Declarations

### **Ethics approval and consent to participate**

The Medical Ethics Committee of the Chinese PLA General Hospital determined that this study was exempt from ethics review (reference no. S2026-823). This secondary analysis used deidentified OPTN registry data and involved no participant recruitment or direct contact. Data access and use were governed separately by the applicable OPTN Data Use Agreement.

### **Consent for publication**

Not applicable. The manuscript contains no identifiable individual information or images.

## Competing interests

The authors declare that they have no competing interests.

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# Author Contribution

All authors reviewed and approved the final manuscript. Conceptualization: QY, HL. Data curation: QY, YL, XW. Formal analysis: YL, FG, HZ. Investigation: HZ, YL, XW, ZL, FG. Methodology: YL, FG, QY, HL. Software: YL, FG, HZ. Validation: HZ, YL, FG, QY, HL. Visualization: HZ, YL, FG. Resources: QY, HL, QC. Project administration: QY, HL, QC. Supervision: QY, HL. Funding acquisition: QY, HL. Writing - original draft: HZ, YL, XW, ZL, FG. Writing - review and editing: QY, HL, QC, YF, BJ, JT, BG, QA.

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# Data Availability

The individual-level data analyzed in this study were obtained from the June 2026 National OPTN STAR kidney/pancreas file through OPTN Data Request DATA0017675 under the applicable Data Use Agreement. The STAR data are not publicly downloadable and cannot be redistributed by the authors. Qualified researchers may request the corresponding release directly from OPTN through its data-request service , subject to OPTN approval and applicable restrictions.

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Figures

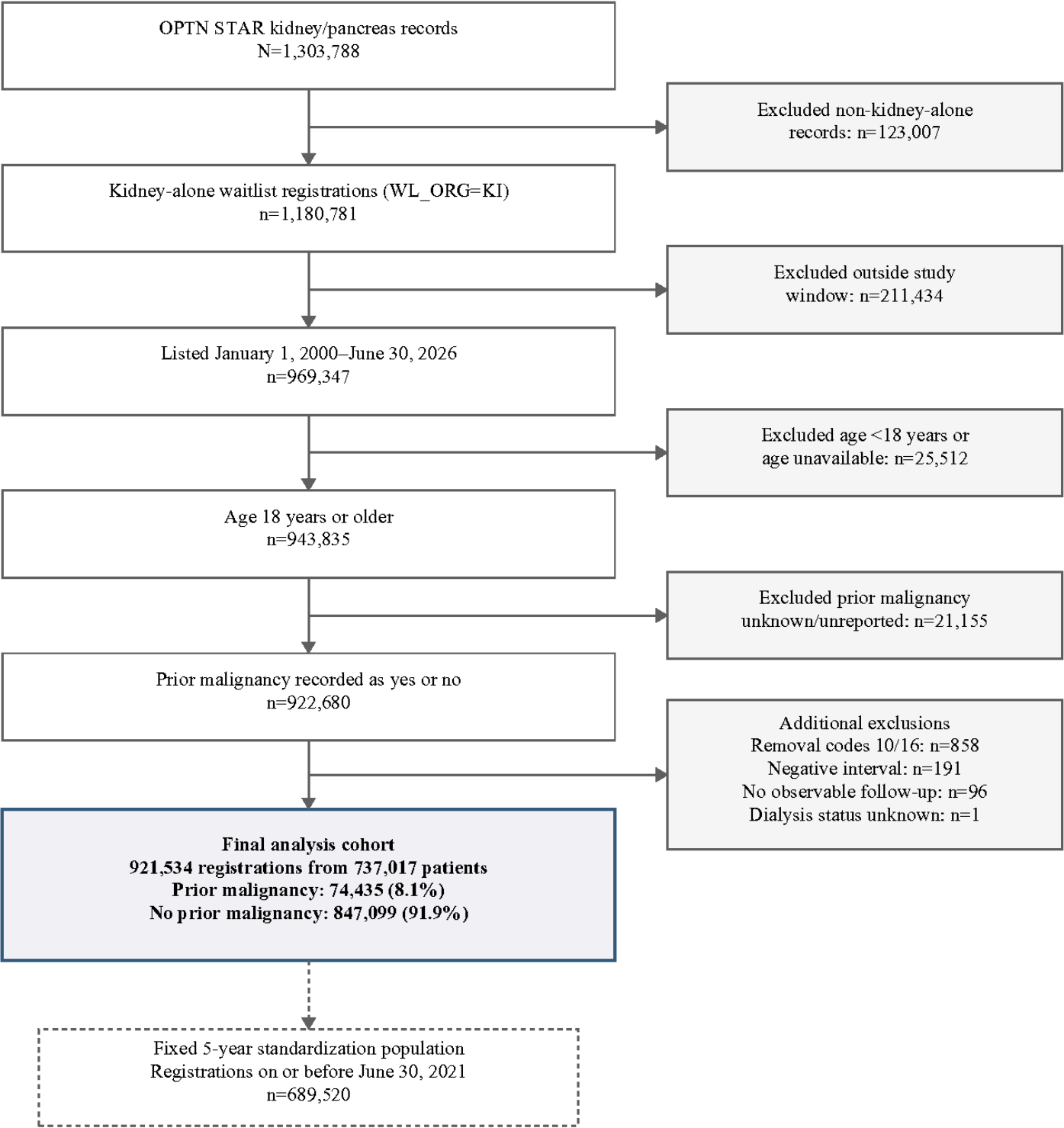


Figure 1

Cohort selection. The fixed 5-year standardization population was an analytic subset of the final analysis cohort and included all eligible registrations on or before June 30, 2021. OPTN, Organ Procurement and Transplantation Network; STAR, Standard Transplant Analysis and Research.

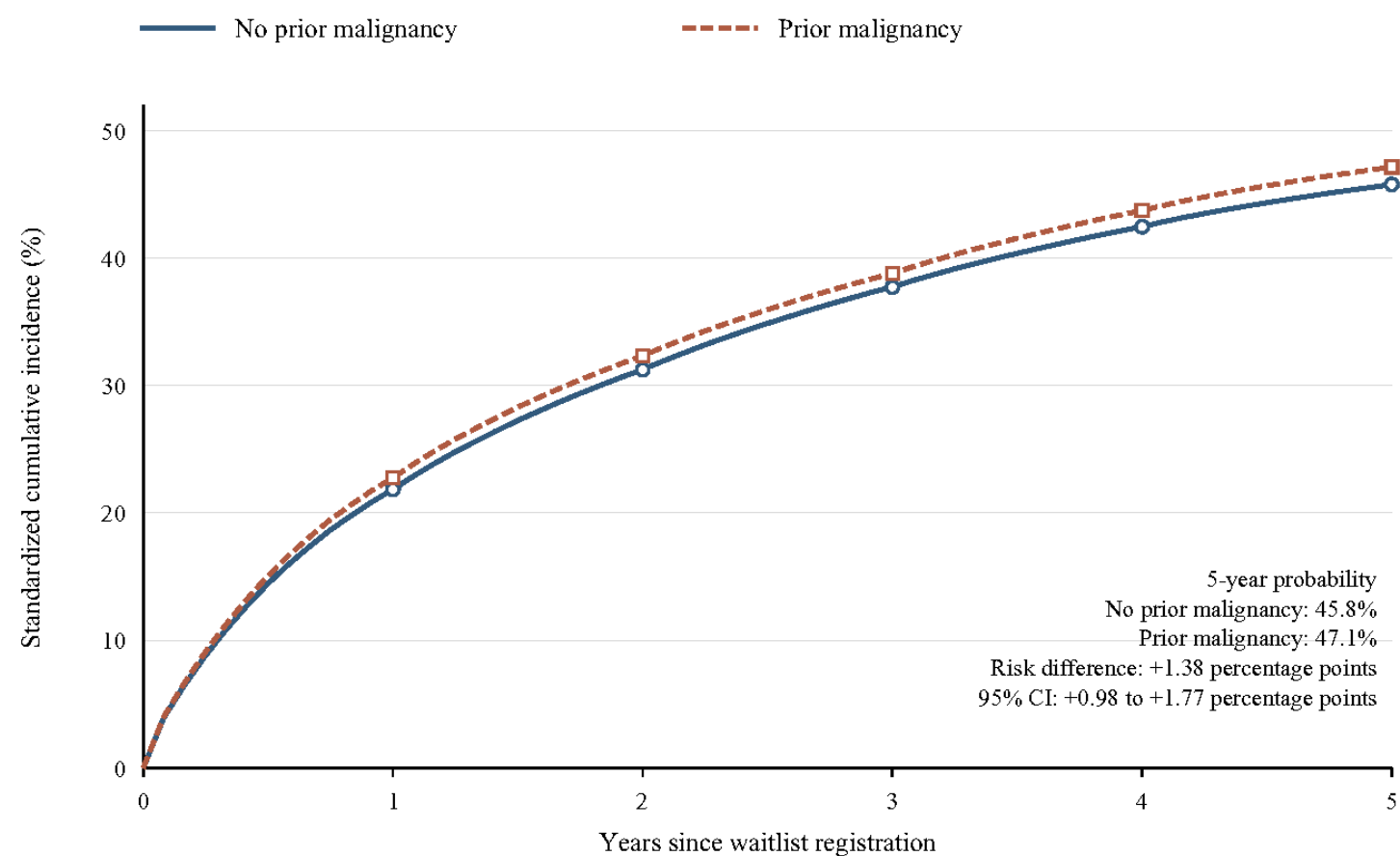


**Figure 2**

Standardized cumulative incidence of kidney transplantation over 0-5 years. Kidney transplantation included deceased-donor and living-donor kidney-alone transplantation. Curves show marginal predictions for recorded prior malignancy absent versus present, standardized to the same fixed population of 689,520 registrations. Colors, line types, and point shapes distinguish exposure groups.

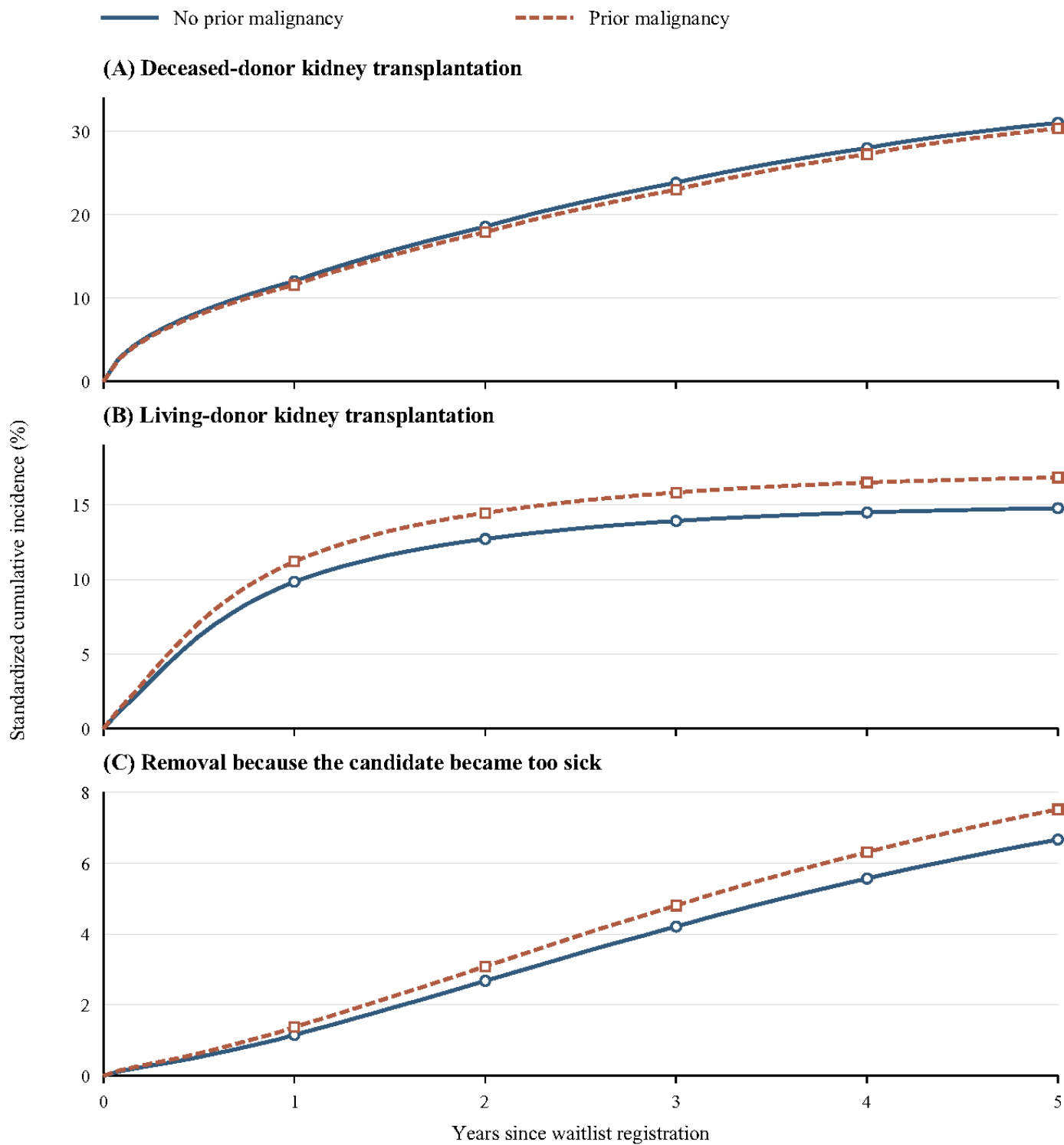


**Figure 3**

Standardized cumulative incidence of component waitlist outcomes. Panels show (A) deceased-donor kidney transplantation, (B) living-donor kidney transplantation, and (C) removal because the candidate became too sick. Deceased-donor and living-donor kidney transplantation were component analyses of the primary kidney-transplantation outcome; too-sick removal was the key secondary outcome. Curves were standardized to the same fixed population used in Figure 2.

## Supplementary Files

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