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Simultaneous heart-kidney transplant in patients with borderline estimated glomerular filtration rate without dialysis dependency

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Abstract

Background: Appropriate patient selection for simultaneous heart-kidney transplantation (sHK) in patients with moderate renal dysfunction remains challenging.

Methods: From the United Network for Organ Sharing database (2003–2020), we identified 5678 adults with an estimated pre-transplant glomerular filtration rate (eGFR) between 30 and 45 mL/min/1.73 m^2 and no pre-transplant dialysis. Patients undergoing sHK ($n = 293$) were compared with those undergoing heart transplantation alone ($n = 5385$) using 1:3 propensity score matching.

Results: The sHK utilization rate increased from 1.8% in 2003 to 12.2% in 2020 ($p < .001$). After matching, 1 and 5-year survival was 87.7% (95% confidence interval [CI] 83.3–91.0) and 80.0% (95% CI 74.2–84.6) after sHK, and 87.3% (95% CI 85.2–89.1) and 71.8% (95% CI 68.4–74.9) after heart transplant alone ($p = .04$). In the subgroup analysis, sHK was associated with a 5-year survival benefit only in patients with 30 < eGFR ≤ 35 mL/min/1.73 m^2 ($p = .05$) but not in those with 35 < eGFR < 45 mL/min/1.73 m^2 ($p = .45$). Patients who underwent heart transplants alone also had a higher incidence of becoming chronic dialysis-dependent after transplant within 5-year follow-up (10.2%, 95% CI 8.0–12.6 vs. 3.8%, 95% CI 1.7–7.1, $p = .004$). The 5-year

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AUTHOR CONTRIBUTIONS

Qiudong Chen and Fardad Esmailian were involved in the study conceptualization and design. Qiudong Chen, Jad Malas, Kevin Gianaris, and Gabriel Esmailian conducted the data analysis and interpretation and drafted the manuscript. Dominic Emerson, Dominick Megna, Pedro Catarino, Lawrence Czer, Michael E. Bowdish, Joanna Chikwe, Jignesh Patel, Jon Kobashigawa, and Fardad Esmailian were involved in the data interpretation, manuscript writing/review, and critical revisions. All authors reviewed and edited the final manuscript and revisions.

CONFLICTS OF INTEREST STATEMENT

The authors of this manuscript have no conflicts of interest to disclose.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

incidence of subsequent kidney waitlisting and transplants after heart transplants alone was 5.6% and 1.9%, respectively.

Conclusion: Among propensity-matched patients without pre-transplant dialysis, compared to heart transplants alone, sHK had improved 5-year survival in those with 30 < eGFR ≤ 35 but not in those with 35 < eGFR < 45 mL/min/1.73 m^2. One-year survival was similar irrespective of eGFR. Receiving a kidney after a heart transplant alone is rare under the current allocation system.

Keywords

heart disease; organ allocation; patient survival; United Network for Organ Sharing

1 | INTRODUCTION

Concomitant kidney disease is frequently encountered in patients undergoing heart transplantation. This may be due to either preexisting intrinsic kidney disease or cardiorenal syndrome. Significant kidney disease predicts morbidity and mortality after heart transplantation,[1] and simultaneous heart-kidney transplants (sHK) may be indicated in selected patients. Although the use of sHK has increased significantly in the United States in the last two decades,[2] the appropriate patient selection remains challenging, leading to considerable variability in practice between regions and institutions.[3] Besides the difficulty of distinguishing potentially reversible kidney injury from intrinsic, advanced kidney disease, the decision for sHK is further complicated by the ethical dilemma of appropriate donor organ allocation, as sHK takes donor kidneys away from patients with end-stage kidney disease awaiting isolated kidney transplants.[4]

In a previous consensus document on sHK, multiple stakeholders in cardiothoracic and kidney transplantation recommended consideration for sHK when the estimated glomerular filtration rate (eGFR) is less than 30 mL/min/1.73 m^2, while eGFR greater than 45 mL/min/1.73 m^2 was thought to be an inappropriate indication for sHK.[5] What is less clear is the efficacy of sHK in patients with eGFR between 30 and 45 mL/min/1.73 m^2 and no pre-transplant dialysis dependency. In these patients, expert consensus recommended an individualized approach. Therefore, the utilization and outcomes of sHK in this patient population warrant special attention. We thus compared sHK to heart transplantation alone in patients with a pre-transplant eGFR between 30 and 45 mL/min/1.73 m^2 and no dialysis dependency before transplantation.

2 | MATERIALS AND METHODS

2.1 | Data source

This retrospective analysis was performed using the United Network for Organ Sharing (UNOS) Standard Transplant Analysis and Research files as of July 2022, which included data for organ donations, transplants, and new listings occurring through June 30, 2022. From the thoracic organ transplant file, we identified 5987 adult patients (>18 years) undergoing either heart transplantation alone or sHK with an estimated GFR of 30 and 45 mL/min/1.73 m^2 and no pre-transplant dialysis dependency between January 1, 2003 and December 31, 2020. Patients with any previous solid organ transplantations or those

undergoing multiorgan transplantation besides sHK (n = 309) were excluded, leaving 5385 patients in the heart transplant alone group and 293 patients in the sHK group. The kidney transplant file was merged to follow the kidney waitlist and transplant events after heart transplantation. Additionally, the thoracic follow-up file was used to identify the incidence of becoming chronic dialysis dependent after heart transplantation.

Recipient/donor characteristics and patient outcomes were defined according to the standard UNOS definitions.[6] Baseline recipient GFR was calculated using the recipient serum creatinine at the time of heart transplant and was estimated using the 2021 CKD-EPI equation. Those with UNOS status 1A before the 2018 allocation policy change and status 1 or 2 afterward were considered to have urgent status at transplant. Donor-to-recipient predicted heart mass (PHM) ratio was calculated with a previously developed formula using recipient and donor age, gender, height, and weight. This was used as a surrogate for donor-recipient size match.[7] Recipient functional status was classified using the Karnofsky Performance Scale Index. This study was approved by the Institutional Review Board at Cedars-Sinai Medical Center, with a waiver of informed consent (protocol ID: STUDY00001188, approval date February 19, 2021).

2.2 | Primary and secondary outcomes

The primary outcome was survival up to 5 years after heart transplantation. Secondary outcomes included in-hospital complications (treated acute rejection episodes, post-transplant dialysis, stroke, and permanent pacemaker implant), hospital length of stay, and short-term mortality at 30 and 90 days after transplantation. We also evaluated the incidence of becoming chronic dialysis-dependent, being waitlisted for a subsequent kidney transplant, and receiving a kidney transplant after a heart transplant. These non-fatal secondary outcomes were analyzed in time-to-event competing risk analyses with death as a competing risk. The median follow-up for the entire cohort was 5.1 years (interquartile range [IQR] 2.0–9.1 years).

2.3 | Statistical analysis

Baseline patient characteristics were reported as either mean ± standard deviation or median with IQR for continuous variables depending on overall distribution and proportions for categorical variables. Between-group comparisons were performed using Student's t-test or Wilcoxon rank-sum test for continuous variables depending on the variable distribution. Pearson's χ^2-test was performed for categorical variables. Missing data were handled with simple imputation (Supplemental Method), and the amount of missingness is outlined in Table S1.

To create more balanced groups of sHK transplants and heart transplants alone for comparison, we used an optimal fixed ratio (1:3) propensity matching algorithm without replacement. This ratio was chosen to achieve optimal covariate balance while maintaining sufficient sample size to ensure adequate statistical power. Covariates included in the matching algorithm were selected a priori based on clinical relevance and previous literature. These included both recipient variables (age, gender, race, body mass index, diabetes, status at transplant, prior sternotomy, creatinine, total bilirubin, eGFR, pre-transplant

mechanical circulatory support use [including extracorporeal membrane oxygenation, intra-aortic balloon pump, ventricular assist device, and total artificial heart], mechanical ventilation, inotropic use, pre-transplant location, pre-transplant functional status, and period of transplantation), and donor variables (age, gender, body mass index, and total ischemic time). The standardized mean difference (SMD) assessed the covariate balance before and after matching. An SMD of 10% or less was deemed the ideal balance, and an SMD of 20% or less was considered acceptable. In matched patients, in-hospital and short-term outcomes were compared using the paired *t*-test for continuous variables and McNemar's test for categorical variables to account for the paired nature of matched data.

Additionally, because the benefit of sHK may be different based on baseline eGFR, we also performed subgroup analyses in patients with $30 < \text{eGFR} \leq 35$ mL/min/1.73 m^2 and those with $35 < \text{eGFR} < 45$ mL/min/1.73 m^2. In each subgroup, a separate 1:3 propensity score matching was performed using the same methods and variables mentioned in the proceeding text. As a sensitivity analysis, we used multivariable Cox modeling with a robust sandwich variance estimator to evaluate the association between the transplant type (sHK vs. heart transplants alone) and 5-year mortality. Variables included in this model were similar to those used for the propensity score matching. Stratified Cox modeling was used to evaluate the effect of sHK among eGFR subgroups.

Survival curves were derived using the Kaplan–Meier method for the primary endpoint and compared between strata using the log-rank test. Right censoring was performed at 5-year follow-up. A competing risk analysis was performed to construct cumulative incidence curves for non-fatal secondary endpoints of becoming chronic dialysis-dependent, being waitlisted for a kidney transplant, and receiving a kidney transplant after a heart transplant. The Fine and Gray subdistributional hazard model was used to provide hazard ratios comparing non-fatal outcomes between strata. Of note, because the exact date of chronic dialysis initiation after a heart transplant is not available in the thoracic follow-up file, in the time-to-event analysis, we used the follow-up date where chronic dialysis dependency was first documented. All tests were two-tailed with an alpha level of .05. All statistical analyses were performed using SAS 9.3 (SAS Institute, Cary, North Carolina).

3 | RESULTS

3.1 | Patient population

Among the 5678 patients with eGFR between 30 and 45 mL/min/1.73 m^2 and no pre-transplant dialysis dependency, 5385 patients (94.8%) underwent heart transplantation alone, and 293 patients (5.2%) underwent sHK. The utilization of sHK in this patient population increased significantly from 1.8% (5/279) in 2003 to 12.2% (51/417) in 2020 ($p < .001$, Figure 1). Variation in sHK utilization according to the annual center volume of all heart transplants is shown in Figure S1.

There are noticeable differences in baseline recipient characteristics between the two groups (Table 1). Patients undergoing sHK were more frequently male (86.0% vs. 70.7%), Black (33.8% vs. 14.3%), and diabetic (42.7% vs. 34.0%), with a higher level of pre-transplant serum creatinine (2.0, IQR 1.8–2.2 vs. 1.7, IQR 1.6–1.9 mg/dL) and lower eGFR (35.8, IQR

32.5–39.6 vs. 39.5, IQR 35.7–42.4 mL/min/1.73 m^2) (all $p < .01$). sHK patients were also more frequently listed as status 1A, 1, or 2 at transplant (62.8% vs. 52.2%) and hospitalized before transplant (58.4% vs. 47.6%) with severe functional limitation (59.7% vs. 44.8%, all $p < .001$). Baseline heart donor characteristics are outlined in Table 1. Compared to patients undergoing heart transplants alone, sHK patients more frequently received hearts from male donors (80.6% vs. 70.3%, $p < .001$) with less gender mismatch (19.8% vs. 25.9%, $p = .02$). Other baseline donor characteristics, including age, left ventricular function, and total ischemic time, were similar (Table 1). Optimal fixed ratio (1:3) propensity score matching resulted in 293 patients undergoing sHK and 879 matched patients undergoing heart transplants alone, and all covariates were well-balanced between the matched groups (all SMD < 15%, Table 1).

3.2 | Post-transplant outcomes

In the unmatched cohort, sHK patients were less likely to experience treated acute rejection before hospital discharge (3.1% vs. 7.6%, $p = .004$) but had longer hospital length of stay (18, IQR 13–28 vs. 16, IQR 11–25 days, $p = .004$). Other in-hospital complications, 30-day, and 90-day mortality were similar (Table 2). Five-year survival was 80.0% (95% confidence interval [CI] 74.2–84.6) after sHK and 75.2% (95% CI 73.9–76.4) after heart transplants alone (Figure S2, $p = .12$). Compared to sHK patients, heart transplant alone patients had a numerically higher incidence of becoming chronic dialysis dependent, being waitlisted for a subsequent kidney transplant, and receiving a subsequent kidney transplant, although these differences did not reach statistical significance (Table 2). Comparison of these incidences between patients with 30 < eGFR ≤ 35 and 35 < eGFR < 45 mL/min/1.73 m^2 who underwent heart transplants alone are shown in Figure S3.

In 1:3 propensity-matched patients, sHK patients were similarly less likely to experience treated acute rejection before discharge and had longer hospital lengths of stay, with no differences in other in-hospital complications or 30-day and 90-day mortality (Table 2). One and 5-year survival was 87.7% (95% CI 83.3–91.0) and 80.0% (95% CI 74.2–84.6) after sHK, and 87.3% (95% CI 85.2–89.1) and 71.8% (95% CI 68.4–74.9) after heart transplant alone (Figure 2A, $p = .04$). The primary causes of death in matched patients are outlined in Table S2.

In the subgroup analysis of matched patients with 30 < eGFR ≤ 35 mL/min/1.73 m^2, 5-year survival was 68.4% (95% CI 63.1–73.1) after heart transplantation alone and 80.0% (95% CI 71.0–86.4) after sHK ($p = .05$, Figure 2B). Whereas in the subgroup analysis of matched patients with 35 < eGFR < 45 mL/min/1.73 m^2, 5-year survival after heart transplantation alone was 76.0% (95% CI 71.4–79.9) and 80.0% (95% CI 71.7–86.0) after sHK (Figure 2C, $p = .45$). One-year survival was similar irrespective of eGFR. In the sensitivity analysis using multivariable Cox modeling, sHK was similarly associated with reduced risk of 5-year mortality (adjusted hazard ratio [HR] .74, 95% CI .56–.99, $p = .04$). When stratified by eGFR subgroups, the adjusted HR was .67 (95% CI .45–.99, $p = .05$) in patients with 30 < eGFR ≤ 35 mL/min/1.73 m^2 and .78 (95% CI .53–1.14, $p = .19$) in those with 35 < eGFR < 45 mL/min/1.73 m^2.

Compared to matched sHK patients, heart transplant alone patients were significantly more likely to become chronic dialysis-dependent after transplant at 5 years (10.2%, 95% CI 8.0–12.6 vs. 3.8%, 95% CI 1.7–7.1, $p = .004$, Figure S4). The 5-year incidence of being waitlisted for a subsequent kidney transplant was 5.6% (95% CI 4.1–7.4) after heart transplants alone and 2.3% (95% CI .9–5.1) after sHK ($p = .06$, Figure 2). The 5-year incidence of receiving a subsequent kidney transplant was 1.9% (95% CI 1.1–3.2) after heart transplants alone and 0% after sHK ($p = .06$).

4 | DISCUSSION

Patient selection for sHK continues to be challenging, and there are limited reports of outcomes of sHK explicitly focusing on those with borderline eGFR and no dialysis dependency before transplant. In this context, our analysis of the national UNOS registry demonstrated several important findings. First, among heart transplant candidates with eGFR between 30 and 45 mL/min/1.73 m^2 and no pre-transplant dialysis dependency, sHK has been increasingly utilized, with 12% of these patients undergoing sHK as opposed to heart transplants alone in 2020. Second, in propensity-matched patients, sHK resulted in a 5-year survival benefit in patients with 30 < eGFR≤35 mL/min/1.73 m^2 but not in those with 35 < eGFR < 45 mL/min/1.73 m^2, although 1-year survival was similar irrespective of eGFR. Third, compared to sHK patients, there was a significantly higher incidence of post-transplant chronic dialysis dependency in matched patients undergoing heart transplants alone. Lastly, current incidences of subsequent kidney waitlisting or transplants after heart transplants alone were extremely low.

This 5-year survival benefit of sHK we observed among patients with 30 < eGFR≤35 mL/min/1.73 m^2 is likely due to both the reversal of kidney dysfunction and the protective effect of one transplanted organ on the other. The development of end-stage renal disease after heart transplantation is associated with poor survival.[8,9] A decreased incidence of rejection and cardiac allograft vasculopathy have also been observed when the heart is transplanted with another organ from the same donor.[10,11] However, when considering the true “opportunity cost” of sHK, one must also take into account the competing needs of kidney-alone transplant candidates, given the ongoing organ scarcity.[12] Multiorgan transplant candidates commonly receive priority for their nonprimary organ, and kidney allografts allocated for sHK have superior quality (as measured by the Kidney Donor Profile Index) than those allocated for isolated kidney transplants.[13] Additionally, an increased rate of early kidney graft loss and inferior kidney graft survival have been reported in patients undergoing sHK compared to isolated kidney transplants.[14,15] This may undermine organ-sharing equity and fail to maximize the collective benefit for all transplant candidates.

The increased utilization of sHK in our study population is consistent with the overall increase in sHK observed by previous studies.[16,17] This may be driven by the rise of mechanical assist devices and the prioritization of sicker patients with more concomitant kidney dysfunction on the waitlist, particularly after the 2018 revision of adult heart allocation policies. Notably, the increased tendency for sHK may also reflect the previous lack of national eligibility criteria for combined heart-kidney allocation. Individual centers may naturally favor more liberal sHK allocation, as underutilization of sHK may result

in an increased rate of kidney failure after heart transplants alone and inferior outcomes. In contrast, overutilization of sHK is a silent event that carries little penalties. A recent UNOS registry analysis demonstrated that the adjusted odds of sHK varied 57-fold between the highest and lowest sHK performing centers, and the median baseline eGFR in sHK recipients ranged from 19 to 59 mL/min/1.73 m^2.[3] This significant practice variation in patient selection led to the recent establishment and approval of national policies for combined heart-kidney allocation by the Organ Procurement and Transplantation Network. In this yet-to-be-implemented policy, eligibility for sHK included regularly administered dialysis in patients with end-stage kidney disease, or eGFR≤30 mL/min/1.73 m^2 in those with chronic kidney disease. In patients with sustained acute kidney injury, eligibility requirements were more stringent, including dialysis at least once every 7 days or GFR ≤ 25 mL/min/1.73 m^2 measured at least once every 7 days for 6 weeks.

A critical part of this newly approved national policy on combined heart-kidney allocation is the safety net for kidney-after-heart allocation. This gives priority listing status for kidney transplants for up to 1 year after heart transplants in patients who did not receive upfront sHK but has persistent kidney dysfunction (dialysis-dependent or eGFR < 20 mL/min/1.73 m^2). We observed that the chance of undergoing subsequent kidney transplants after heart transplants alone is currently negligible, and the new safety net policy may be imperative for patients who develop significant kidney dysfunction early after heart transplants alone. Moreover, we found that 1-year survival after heart transplants alone and sHK are similar, which may further support the rationale of the safety net policy to avoid the futile use of kidney allografts in those with the potential for kidney recovery. Existing literature comparing sHK to delayed kidney transplants after heart transplants have shown mixed results, although they are generally prone to significant selection bias because patients undergoing delayed kidney transplants after heart transplants have already survived long enough and passed kidney transplant evaluation.[16,18] Nevertheless, studies evaluating similar safety net policies for liver-kidney allocation have demonstrated improved organ allocation without compromising patient survival after their implementation,[19–21] and post-implementation assessments of the new combined heart-kidney allocation policy will be crucial to understand its implications and inform future policy adjustments.

4.1 | Limitations

This analysis of national outcomes of sHK among patients with borderline GFR (30–45 mL/min/1.73 m^2) and no pre-transplant dialysis dependency has several limitations. First and foremost, due to the limited data available in the UNOS registry, we had to rely on a single pre-transplant serum creatinine measurement to calculate eGFR. As a result, we could not assess the chronicity of kidney dysfunction or identify any underlying structural kidney abnormalities or the presence of proteinuria. The use of a single pre-transplant eGFR to quantify the extent of kidney dysfunction is also not reflective of the new OPTN heart-kidney allocation policy, where chronic kidney disease was defined as having an eGFR ≤60 mL/min/1.73 m^2 for greater than 90 consecutive days. This distinction must be considered when interpreting our findings. Second, we lacked data to reliably identify native kidney recovery after transplantation, a factor that may be particularly relevant among patients with borderline GFR. Third, although propensity score matching mitigated potential

selection bias, the statistical power was limited after matching due to reduced sample size, and unmeasured confounders could still exist. Fourth, the exact indication or justification for performing sHK could not be established in this registry analysis, and we could not account for the practice variation in patient selection between transplant centers. Fifth, because the exact date of post-transplant chronic dialysis initiation is unknown, we relied on the follow-up date where chronic dialysis dependency was first documented in our time-to-event analysis. This could have led to inaccurate estimations of the incidence of chronic dialysis use after heart transplantation. Sixth, missing data were addressed using simple imputation only, and we used the 2021 CKD-EPI equation to estimate GFR. In contrast, most previous studies used the Modification of Diet in Renal Disease Study equation. Lastly, because of the limited number of sHK patients who met our inclusion criteria, it is possible that the present study was not sufficiently powered to detect subtle differences in outcomes.

5 | CONCLUSION

Among heart transplant candidates with eGFR between 30 and 45 mL/min/1.73 m^2 and no pre-transplant dialysis dependency, sHK has been increasingly utilized. In propensity-matched patients undergoing either sHK or heart transplants alone, sHK resulted in a 5-year survival benefit among those with $30 < eGFR \leq 35$ mL/min/1.73 m^2 but not in those with $35 < eGFR < 45$ mL/min/1.73 m^2, although 1-year survival was similar irrespective of eGFR. Additionally, the current incidences of subsequent kidney waitlisting or transplants after heart transplants alone were extremely low. To maximize the societal utility of kidney allografts and avoid futile sHK in this population, a safety net policy that allows priority for subsequent kidney transplantation after heart transplants alone may be the most prudent.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available via the Organ Procurement and Transplantation Network. Details regarding data access can be found at https://optn.transplant.hrsa.gov/data/view-data-reports/request-data/data-request-instructions/.

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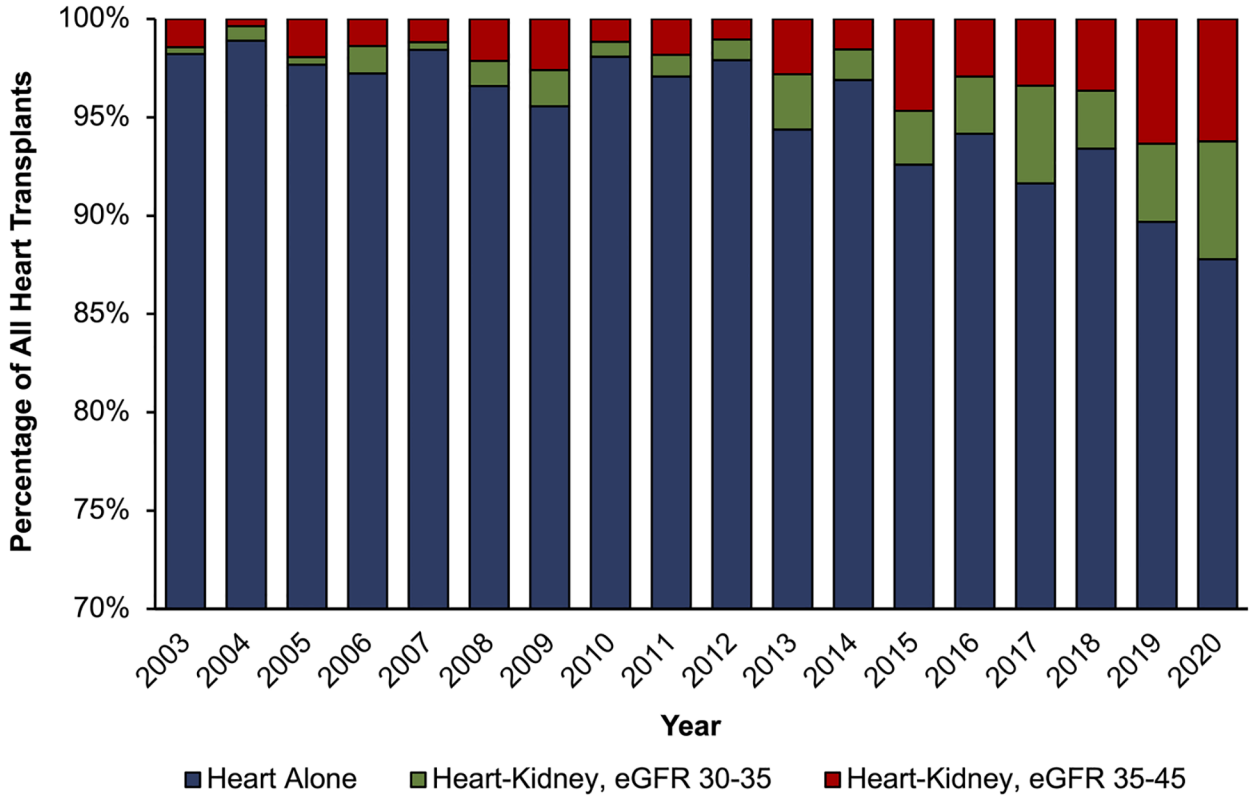

FIGURE 1.

Utilization trend of simultaneous heart-kidney transplant in recipients with estimated baseline glomerular filtration rate (GFR) between 30 and 45 mL/min/1.73 m^2 and no pre-transplant dialysis dependency.

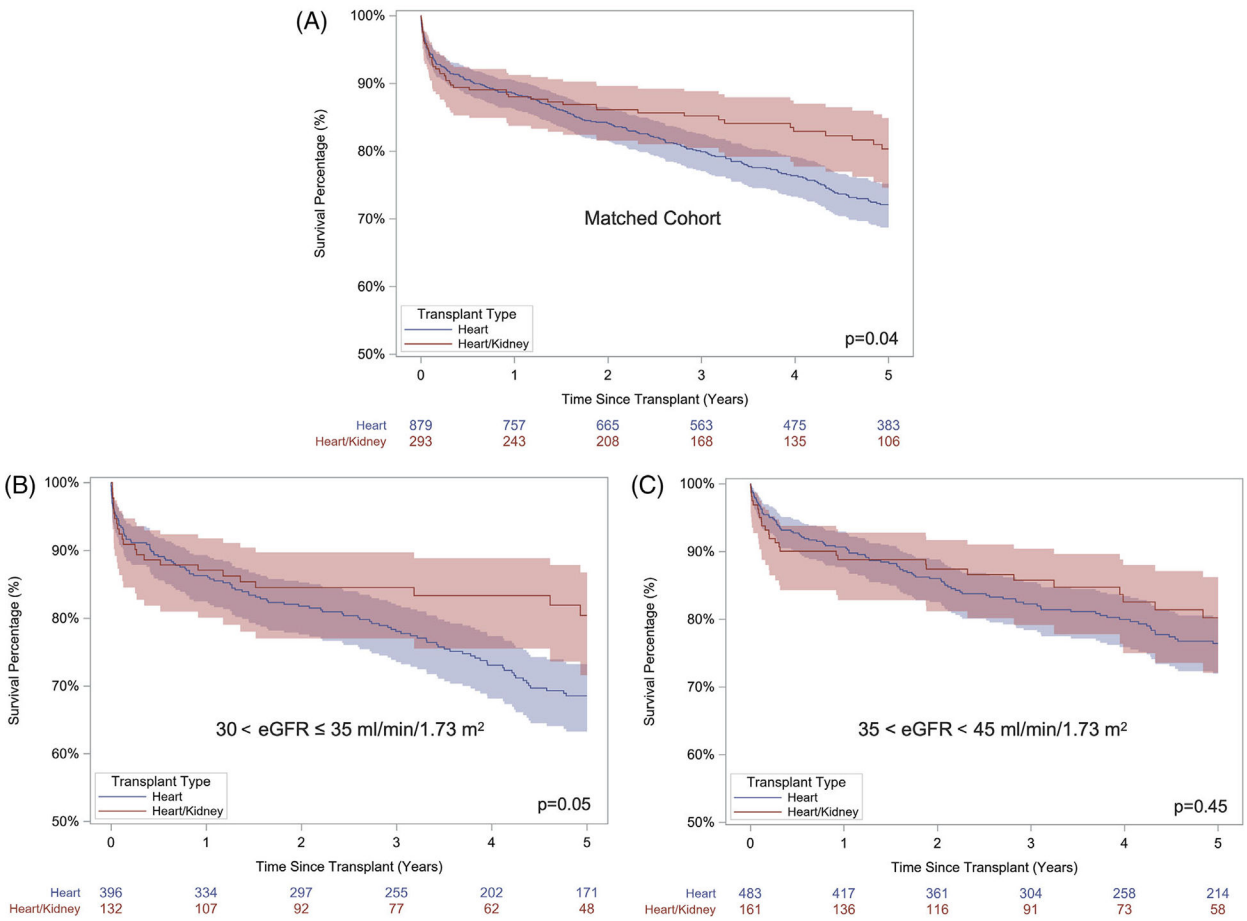

FIGURE 2.

Post-transplant survival with 95% confidence interval after simultaneous heart-kidney transplants and heart transplants alone in the 1:3 propensity-matched cohort (A), matched patients with 30 < eGFR ≤ 35 mL/min/1.73 m^2 (B), and matched patients with 35 < eGFR < 45 mL/min/1.73 m^2 (C). In patients with 30 < eGFR ≤ 35 mL/min/1.73 m^2 and 35 < eGFR < 45 mL/min/1.73 m^2, a separate 1:3 propensity score matching was performed in each subgroup to create well-balanced subgroups for comparison. eGFR, estimated glomerular filtration rate.

TABLE 1

Baseline recipient and donor characteristics in the overall cohort and 1:3 propensity-matched cohort.

	Overall cohort			1:3 Propensity matched cohort		
Variable	**Simultaneous heart-kidney transplants (*n* = 293)**	**Heart transplants alone (*n* = 5385)**	***p*-value**	**Simultaneous heart-kidney transplants (*n* = 293)**	**Heart transplants alone (*n* = 879)**	**SMD**
Recipient characteristics						
Age (years)	60 (52–65)	60 (53–65)	.82	60 (52–65)	60 (52–65)	−1.6%
Gender: male	86.0 (252)	70.7 (3806)	<.001	86.0 (252)	84.1 (739)	−4.5%
Body mass index (kg/m^2)	26.8 (24.0–39.0)	27.6 (24.4–31.2)	.04	26.8 (24.0–39.0)	27.0 (24.0–30.3)	1.4%
Race			<.001			
White	52.9 (155)	75.0 (4039)		52.9 (155)	57.9 (509)	−10.7%
Black	33.8 (99)	14.3 (772)		33.8 (99)	31.6 (278)	−5.2%
Hispanic	6.8 (20)	7.0 (377)		6.8 (20)	6.1 (54)	2.7%
Others	6.5 (19)	3.7 (197)		6.5 (19)	4.3 (38)	9.7%
Diabetes	42.7 (125)	34.0 (1830)	.002	42.7 (125)	41.5 (365)	−2.3%
Cerebrovascular disease	7.5 (22)	5.3 (287)	.12	7.5 (22)	7.3 (64)	−.9%
Prior sternotomy	39.6 (116)	39.4 (2120)	.94	39.6 (116)	39.1 (344)	.9%
Ischemic cardiomyopathy	36.5 (107)	41.9 (2255)	.07	36.5 (107)	38.9 (342)	−4.9%
Creatinine (mg/dL)	2.0 (1.8–2.2)	1.7 (1.6–1.9)	<.001	2.0 (1.8–2.2)	2.0 (1.8–2.2)	6.1%
Estimated GFR (mL/min/1.73m^2)	35.8 (32.5–39.6)	39.5 (35.7–42.4)	<.001	35.8 (32.5–39.6)	35.7 (32.6–39.4)	1.5%
Total bilirubin (mg/dL)	.7 (.5–1.2)	.8 (.5–1.2)	.04	.7 (.5–1.2)	.8 (.5–1.1)	.8%
Status 1A, 1, or 2 at transplant	62.8 (184)	52.2 (2810)	<.001	62.8 (184)	65.1 (572)	−4.6%
Days on heart waitlist	77 (22–261)	82 (23–250)	.86	77 (22–261)	74 (21–245)	−1.4%
Pre-transplant mechanical support						
ECMO	.7 (2)	1.0 (51)	.99	.7 (2)	.3 (3)	−3.8%
IABP	13.0 (38)	8.6 (462)	.01	13.0 (38)	12.5 (110)	−1.5%
VAD or TAH	38.6 (113)	34.2 (1842)	.13	38.6 (113)	36.6 (322)	−4.0%
Chronic steroids	5.8 (17)	6.7 (361)	.75	5.8 (17)	5.9 (52)	−.5%
Transfusions after listing	19.5 (57)	19.9 (1073)	.19	19.5 (57)	22.4 (197)	−7.4%
Mechanical ventilation	.3 (1)	1.7 (91)	.09	.3 (1)	.8 (7)	4.5%
Inotropic support	43.3 (127)	42.6 (2294)	.80	43.3 (127)	44.4 (390)	2.1%
Location before transplant			.002			

Variable	Overall cohort			1:3 Propensity matched cohort		
	Simultaneous heart-kidney transplants (*n* = 293)	**Heart transplants alone (*n* = 5385)**	***p*-value**	**Simultaneous heart-kidney transplants (*n* = 293)**	**Heart transplants alone (*n* = 879)**	**SMD**
Hospitalized, ICU	37.9 (111)	31.6 (1702)		37.9 (111)	38.3 (337)	1.0%
Hospitalized, non-ICU	20.5 (60)	16.0 (862)		20.5 (60)	18.4 (162)	5.3%
Home	41.6 (122)	52.4 (2821)		41.6 (122)	43.2 (380)	−3.2%
Functional status			<.001			
Mild limitation	8.9 (26)	12.4 (670)		8.9 (26)	9.3 (82)	−1.5%
Moderate limitation	24.6 (72)	29.8 (1606)		24.6 (72)	22.8 (200)	4.1%
Severe limitation	59.7 (175)	44.8 (2410)		59.7 (175)	61.4 (540)	3.5%
Unknown	6.8 (20)	13.0 (699)		6.8 (20)	6.5 (57)	1.5%
Transplant before 2010	15.7 (46)	33.7 (1812)	<.001	15.7 (46)	16.8 (148)	2.7%
Annual center volume of all heart transplants	30 (21–44)	29 (18–49)	.10	30 (21–44)	30 (19–49)	2.8%
Donor characteristics						
Age (years)	30 (24–39)	31 (22–42)	.96	30 (24–39)	30 (22–42)	−2.1%
Gender: male	80.6 (236)	70.3 (3787)	<.001	80.6 (236)	79.8 (701)	−1.9%
Body mass index (kg/m^2)	26.4 (23.8–29.3)	26.4 (23.3–30.5)	.71	26.4 (23.8–29.3)	25.9 (23.1–29.9)	2.2%
Race: white	62.8 (184)	66.3 (3571)	.22	62.8 (184)	64.1 (563)	2.6%
Diabetes	2.4 (7)	4.3 (229)	.12	2.4 (7)	3.2 (28)	−4.4%
Hypertension	12.6 (37)	15.4 (827)	.21	12.6 (37)	15.4 (135)	−7.9%
Gender mismatch	19.8 (58)	25.9 (1395)	.02	19.8 (58)	18.9 (166)	2.2%
Size mismatch (donor/recipient PHM ratio < .86)	14.3 (42)	14.0 (753)	.87	14.3 (42)	14.3 (42)	.0%
LVEF < 50%	3.1 (9)	3.1 (166)	.99	3.1 (9)	3.3 (29)	−1.3%
Total ischemic time (h)	3.2 (2.4–3.9)	3.3 (2.5–3.9)	.91	3.2 (2.4–3.9)	3.2 (2.5–3.8)	1.8%

Note: Values are expressed in % (*n*) or median (interquartile range).

Abbreviations: ECMO, extracorporeal membrane oxygenation; GFR, glomerular filtration rate; IABP, intra-aortic balloon pump; ICU, intensive care unit; LVEF, left ventricular ejection fraction; PHM, predicted heart mass; SMD, standardized mean difference; TAH, total artificial heart; VAD, ventricular assist device.

TABLE 2

Post-transplant outcomes in the overall cohort and 1:3 propensity-matched cohort

	Overall cohort			1:3 Propensity matched cohort		
Outcomes	**Simultaneous heart-kidney transplants (*n* = 293)**	**Heart transplants alone (*n* = 5385)**	***p*-value**	**Simultaneous heart-kidney transplants (*n* = 293)**	**Heart transplants alone (*n* = 879)**	***p*-value**
In-hospital outcomes						
Treated acute rejection	3.1 (9)	7.6 (410)	.004	3.1 (9)	7.7 (68)	.006
Dialysis	16.0 (47)	15.0 (809)	.41	16.0 (47)	17.4 (153)	.59
Permanent pacemaker	2.4 (7)	3.0 (161)	.30	2.4 (7)	2.3 (20)	.91
Stroke	3.4 (10)	3.2 (172)	.27	3.4 (10)	3.9 (34)	.72
Length of stay (days)	18 (13–28)	16 (11–25)	<.001	18 (13–28)	17 (12–26)	.03
Short-term outcomes						
30-day mortality	5.1 (15)	5.3 (286)	.89	5.1 (15)	5.1 (45)	.99
90-day mortality	8.5 (25)	8.3 (444)	.86	8.5 (25)	7.6 (67)	.61
Five-year outcomes (%, 95% CI)						
Survival	80.0 (74.2–84.6)	75.2 (73.9–76.4)	.12	80.0 (74.2–84.6)	71.8 (68.4–74.9)	.04
$30 < eGFR \leq 35$ mL/min/1.73 m^2	80.0 (71.0–86.4)	72.5 (69.6–75.1)	.12	80.0 (71.0–86.4)	68.4 (63.1–73.1)	.05
$35 < eGFR < 45$ mL/min/1.73 m^2	80.0 (71.7–86.0)	76.0 (74.5–77.2)	.29	80.0 (71.7–86.0)	76.0 (71.4–79.9)	.45
Chronic dialysis dependency	3.8 (1.7–7.1)	6.4 (5.7–7.1)	.11	3.8 (1.7–7.1)	10.2 (8.0–12.6)	.004
Subsequent kidney waitlist	2.3 (.9–5.1)	4.0 (3.5–4.6)	.19	2.3 (.9–5.1)	5.6 (4.1–7.4)	.06
Subsequent kidney transplant	0 (0–0)	1.4 (1.1–1.8)	.08	0 (0–0)	1.9 (1.1–3.2)	.06

Note: Values are expressed in % (*n*) or median (interquartile range) unless otherwise specified.
Abbreviations: CI, confidence interval; eGFR, estimated glomerular filtration rate.