Trends in Coronary Artery Disease Screening before Kidney Transplantation

Xingxing S. Cheng,1 Sai Liu,1 Jialin Han,1 Margaret R. Stedman,1 Glenn M. Chertow,1 Jane C. Tan,1 and William F. Fearon2

Key Points
- Coronary artery disease testing before kidney transplant has remained constant since the mid-2000s, despite a shift away from preoperative testing.
- Overall post-transplant death and myocardial infarction rates have fallen steadily from 2000 to 2015.

Abstract
Background Coronary artery disease (CAD) screening in asymptomatic kidney transplant candidates is widespread but not well supported by contemporary cardiology literature. In this study we describe temporal trends in CAD screening before kidney transplant in the United States.

Methods Using the United States Renal Data System, we examined Medicare-insured adults who received a first kidney transplant from 2000 through 2015. We stratified analysis on the basis of whether the patient’s comorbidity burden met guideline definitions of high risk for CAD. We examined temporal trends in nonurgent CAD tests within the year before transplant and the composite of death and nonfatal myocardial infarction in the 30 days after transplant.

Results Of 94,832 kidney transplant recipients, 37,139 (39%) underwent at least one nonurgent CAD test in the 1 year before transplant. From 2000 to 2015, the transplant program waitlist volume had increased as transplant volume stayed constant, whereas patients in the later eras had a slightly higher comorbidity burden (older, longer dialysis vintage, and a higher prevalence of diabetes mellitus and CAD). The likelihood of CAD test in the year before transplant increased from 2000 through 2003 and remained relatively stable thereafter. When stratified by CAD risk status, test rates decreased modestly in patients who were high risk but remained constant in patients who were low risk after 2008. Death or nonfatal myocardial infarction within 30 days after transplant decreased from 3% in 2000 to 2% in 2015. Nuclear perfusion scan was the most frequent modality of testing throughout the examined time periods.

Conclusions CAD testing rates before kidney transplantation have remained constant from 2000 through 2015, despite widespread changes in cardiology guidelines and practice.

KIDNEY360 3: 516–523, 2022. doi: https://doi.org/10.34067/KID.0005282021

Introduction
The evidence base for coronary artery disease (CAD) screening before kidney transplantation (KTx) has shifted dramatically over the last 20 years. In 1992, Manske et al. performed screening coronary angiography in 151 KTx candidates with insulin-dependent diabetes mellitus, 31 (21%) of whom had ≥75% diameter narrowing in a major epicardial artery (1). Of these 31 patients, 26 consented to be randomized to undergo revascularization (percutaneous or surgical) or medical treatment. Ten of 13 patients who were medically treated (77%) reaching a primary endpoint of unstable angina, myocardial infarction (MI), and/or cardiac death in a median 8 months, compared with two out of 13 (15%) in the revascularization group. On the basis of this trial, transplant programs around the world and in the United States adopted a more intensive approach toward CAD screening of asymptomatic KTx candidates, despite the caveats that (1) medical treatment administered during the trial was outdated (only calcium-channel blocker and aspirin), (2) the study consisted of patients with a severe diabetes phenotype not necessarily generalizable to other KTx candidates, and (3) the sample size was small, raising the possibility of a type I error. Indeed, the publication of numerous studies in the 2000s (2–4) that failed to demonstrate benefit of revascularization over medical management in patients with asymptomatic CAD (reviewed by Hart et al. in context to KTx [5]), and the recently published International Study of Comparative Health Effectiveness with Medical and Invasive Approaches—Chronic Kidney Disease trial
confirming these findings in patients with CKD and stable CAD (6), have further questioned the utility of widespread screening before KTx.

Whether these newer studies have resulted in any change in CAD screening practices for KTx candidates is unknown. The 2012 American College of Cardiology/American Heart Association (ACC/AHA) Clinical Practice Guidelines (7) are the most widely used guidelines in the United States (8). They recommend noninvasive cardiac testing in asymptomatic KTx candidates who meet three of the eight risk factors (age, dialysis duration, diabetes mellitus, hypertension, smoking, dyslipidemia, left ventricular hypertrophy, family history of premature CAD). To date, only one study examined temporal trends in utilization of cardiac studies in patients with advanced kidney disease: Herzog et al. showed that the unadjusted rate of stress tests in patients who were Medicare insured and dialysis dependent decreased from 27 in 2008 to 18 per 100 person-years in 2012 (9); presumably a portion was for KTx-related screening. However, the study was not specific to KTx candidates. Two other Medicare-based studies examined CAD testing specifically in KTx candidates (10,11) but did not examine temporal trends or testing modalities.

In the wake of the recent results from International Study of Comparative Health Effectiveness with Medical and Invasive Approaches—Chronic Kidney Disease and during the highly anticipated CARSK trial, a randomized controlled trial studying surveillance CAD testing versus none in waitlisted KTx candidates (12), clinical practice guidelines are due for an update. Understanding of patterns and trends of test utilization over time provides a firm basis on which to recommend and affect changes. With this in mind, we performed this study to describe temporal trends of CAD testing and early post-transplant outcomes in the year preceding KTx, including a descriptive analysis of the commonly used modalities.

**Methods**

**Dataset**

We used the US Renal Data System, which contains comprehensive information on virtually all patients with ESKD in the United States. It includes claims data from Medicare Parts A & B. Medicare Parts A & B cover all hospitalizations, emergency room visits, outpatient physician offices, and diagnostic testing. Our dataset is complete up to and including the year 2016.

**Cohort Definition**

We identified all adult patients who underwent a first KTx between January 1, 2000 and December 31, 2015. Of these, we required ≥1 year of uninterrupted Medicare Part A & B coverage before and after KTx as inclusion criteria.

**Outcome**

Our primary outcome was whether the patient had a nonurgent diagnostic test for CAD within 1 year before transplant. We aimed to include only nonurgent diagnostic studies undertaken for the purposes of pretransplant screening. We identified these studies on the basis of International Classification of Diseases (ICD) procedure codes (ICD-9 and ICD-10) and current procedural terminology codes with diagnosis-related group codes (see Supplemental Figure 1). Because claims codes are not accompanied by the indication, we chose to approximate the urgency of testing by the place of service. We defined as an urgent CAD test as follows:

- any noninvasive CAD test conducted on the day of or after an emergency department (ED) visit, or during the dates covered by a hospitalization;
- any coronary angiogram done on the day of, or after an ED visit; or
- any coronary angiogram done during hospitalization, with MI listed as a diagnosis (see Supplemental Figure 1 for the relevant diagnosis-related group codes).

In practice, coronary angiograms in patients with ESKD can entail a brief stay in the hospital, especially if the patient undergoes a percutaneous intervention during the procedure. Consequently, we deemed coronary angiograms occurring during hospitalizations for revascularizations done in the absence of ACS to be nonurgent. This methodology is consistent with prior approaches (10).

We also aimed to capture the occurrence of adverse events in all patients, as the proportion of patients transplanted each calendar year who experienced an adverse event within 30 days of KTx. We used a composite of death and nonfatal MI (Supplemental Figure 1) from the Patient files and Medicare Part A claims file, respectively.

**Covariates**

We obtained covariates specific to the transplant programs and individual patients. For transplant programs, we obtained covariates for every calendar year in the study: annual transplant volume, annual waitlist size (defined as the transplant program’s waitlist size on January 1 of that calendar year), and the competitiveness of the donor service area as estimated by the Herfindahl-Hirschman Index as previously applied to transplant programs (13). For patients, we obtained the following covariates: demographics (from the Patient file), socioeconomic factors including median neighborhood income on the basis of zip code of residence (from census data), and highest educational attainment (from the Transplant Candidate Registration file), transplant factors (from the Transplant and Transplant Recipient Registration files), dialysis modality (from the treatment history files), and claims-based comorbidities on the basis of one inpatient or two outpatient claims separated by ≥1 day within a 1-year lookback window from the date of transplant as described by Elixhauser et al. (14,15). Because CAD testing in the year before KTx was our main outcome of interest, we chose to define the look-back window for CAD as a 1-year window from 2 years before to 1 year before KTx. From age, comorbidities, and dialysis vintage, we were able to ascertain whether the patient met the criteria for testing under the 2012 ACC/AHA guidelines for testing before transplant (7).

**Analysis**

We used logistic regression to estimate the association of transplant era with the provision of diagnostic studies for CAD and posttransplant outcomes, with and without adjustment for covariates as outlined above.
Supplemental Analysis

To evaluate the trend in patients who were waitlisted, not just transplanted, we examined the proportion of patients on the kidney transplant waitlist on January 1 of each calendar year who underwent a nonurgent diagnostic test for CAD that calendar year.

Ethics

The Stanford University Institutional Review Board approved this study (protocol number IRB-51697) in adherence with the Declaration of Helsinki. The clinical and research activities being reported are consistent with the Principles of the Declaration of Istanbul on Organ Trafficking and Transplant Tourism. All data analysis was carried out in SAS Enterprise version 7.4 (Cary, NC).

Results

Our final cohort consisted of 94,832 KTx recipients of whom 37,139 (39%) underwent at least one nonurgent CAD test in the 1 year before KTx (Figure 1). A further 8923 CAD tests took place in these patients in the year before KTx, which were designated as “urgent,” that is, having taken place during inpatient stays or on the day of or after ED visits (Figure 1). The total number of total patients who met the primary outcome (37,139) was less than the sum of the number of patients with coronary angiogram (10,006) and with noninvasive testing (32,342), because 5209 patients had both types of tests (71% had a noninvasive test followed by coronary angiography, and 29% vice versa). Table 1 displays the baseline characteristics of the study cohort over time. Over the study period, the transplant program waitlist volume had increased (median 130 in 2000–2003 to 251 in 2012–2015), whereas transplant volume remained constant. Patients in the later eras were older (median age 51 in 2000–2003 and 56 in 2012–2015), and more likely to receive some college and above education (27% in 2000–2003 to 43% in 2012–2015). Dialysis vintage was longer (median 3.6 years in 2000–2003 to 4.5 years in 2012–2015) and the prevalence of diabetes mellitus (41% in 2000–2003 to 47% in 2012–2015) and CAD (17% in 2000–2003 to 21% in 2012–2015) was higher in later eras.

Figure 2 shows the temporal trend in CAD testing, along with important landmark regulatory changes and publications related to screening of patients who were asymptomatic for CAD. CAD testing increased from 2000 through 2003 and remained relatively stable thereafter. Age, male sex, White or other race, dialysis vintage, diabetes status, preexisting CAD, smoking, hypertension, and living donor transplant were all associated with CAD testing within 1 year before KTx (Table 2). When stratified by a patient’s CAD risk status (as defined by the 2012 ACC/AHA guidelines), CAD testing rates appeared to decrease slightly in patients with high CAD risk after 2008 but remained constant in patients with low CAD risk after 2008 (Figure 3). A similar trend exists in waitlisted patients over time (Supplemental Analysis, Supplemental Figure 1).

Figure 4 shows temporal changes in the distribution of modality for CAD tests. Where multiple tests were undertaken in the year before KTx, the first was used. The proportion of patients who underwent nonurgent coronary angiogram in the year before KTx remained stable throughout the study period at approximately 6%. Nuclear perfusion tests were by far the most commonly used CAD diagnostic test. Stress echocardiogram and coronary computed tomography angiography became more widely utilized after 2010, but still were only applied to a minority of patients.

Figure 5 shows the declining rate of 30-day event (death or nonfatal MI after KTx, from 3% in 2000 to 2% in 2015). Each type of adverse event decreased: death from 2% in 2000 to 1% in 2015, and MI from 2% in 2000 to 0.5% in 2015.

Discussions

In this descriptive study of Medicare-insured, first-time adult KTx recipients, we observed that overall

| Cohort Assembly | Primary Outcome |
|-----------------|-----------------|
| **First KTx recipients** | **Coronary Angiogram** |
| 1/1/2000–12/31/2015 | N=243,381 |
| Age >= 18 | N=231,867 |
| Continuous Medicare A/B enrollment for 1 year before and after KTx and not missing facility ID | N=94,832 |
| N=37139 | **Tests in 1 year before KTx** |
| N=16480 | Tests in 1 year before KTx |
| Exclude: | Exclude: |
| Urgent inpatient tests | 2764 |
| All inpatient tests | 1556 |
| ED-associated tests | 2788 |
| ED-associated tests | 1815 |
| Remaining tests | 10928 |
| Remaining tests | 36158 |
| Remaining patients | 10006 |
| Remaining patients | 32342 |
| Total patients | 37139 |

Figure 1. Cohort assembly and definition of nonurgent coronary artery disease (CAD) testing in the year before kidney transplant (KTx). ED, emergency department.
Coronary Artery Disease Screening before Kidney Transplantation, Cheng et al. 519

pretransplant CAD testing rates in KTx recipients appear to have peaked in the mid- to late 2000s and remained constant since, although there was a very slight shift of testing from patients who were higher risk to lower risk. A similar trend exists when we examined all patients who were waitlisted, not just transplanted, during this time period. In contrast, 30-day adverse events after KTx, to use KTx date as a landmark event to preemptive revascularization in patients who were asymptomatic. In contrast, a recent study on Medicare beneficiaries reports an overall reduction in CAD testing from 2008 to mid-2010s, especially a reduction in low-value CAD testing, defined as stress testing within 60 days before a low-risk surgery (16). The authors of the latter study attribute the reduction in low-value CAD testing to the frequent updating of clinical practice guidelines from cardiology societies and the American Board of Internal Medicine’s Choosing Wisely campaign published in 2012.

A few explanations are possible for the divergence between KTx practice and general practice. KTx candidates are a unique population with complex pathophysiology and high prevalence of CAD risk factors and warrant additional consideration. Indeed, the 2014 ACC/AHA Guideline on Perioperative Cardiovascular Evaluation and Management of Patients Undergoing Noncardiac Surgery specifically excluded kidney and liver transplant candidates from its scope (17). Concerns over “renalism,” or exclusion of patients with kidney disease from potentially useful revascularization in clinical practice (18) and from cardiovascular trials at large (19), may also lead to

### Table 1: Baseline characteristics

| Characteristics                  | All Years | 2000–2003 | 2004–2007 | 2008–2011 | 2012–2015 |
|----------------------------------|-----------|-----------|-----------|-----------|-----------|
| **Program characteristics**     |           |           |           |           |           |
| Number of program-years          | 4031      | 1014      | 1014      | 1000      | 1003      |
| Transplant volume each year      | 47 (20–93)| 44 (19–83)| 50 (21–95)| 47 (22–97)| 47 (19–97)|
| Waitlist volume on January 1 of each year | 188 (59–395) | 130 (50–273) | 169 (59–350) | 222 (77–467) | 251 (66–532) |
| Herfindahl–Hirshmann Index*      | 0.5 (0.3–0.7) | 0.5 (0.3–0.7) | 0.4 (0.3–0.6) | 0.5 (0.3–0.7) | 0.5 (0.3–0.9) |
| **Patient characteristics**     |           |           |           |           |           |
| Number of patients               | 94,832    | 20,597    | 24,515    | 24,729    | 24,991    |
| Age, yr                          | 54 (43–64)| 51 (40–61)| 54 (42–64)| 55 (44–65)| 56 (45–66)|
| Sex                              |           |           |           |           |           |
| Male                             | 57,921 (61%) | 12,312 (60%) | 15,107 (62%) | 15,154 (61%) | 15,348 (61%) |
| Female                           | 36,903 (39%) | 8285 (40%) | 9405 (38%) | 9572 (39%) | 9641 (39%) |
| Race                             |           |           |           |           |           |
| White                            | 57,229 (60%) | 12,587 (61%) | 14,791 (60%) | 14,765 (60%) | 15,086 (60%) |
| Black                            | 30,257 (32%) | 6478 (32%) | 7712 (32%) | 8035 (32%) | 8032 (32%) |
| Other                            | 7346 (8%) | 1532 (7%) | 1929 (8%) | 1873 (7%) |           |
| Education level^                 |           |           |           |           |           |
| Some college and above           | 32,993 (35%) | 5613 (27%) | 7503 (31%) | 8985 (36%) | 10,892 (43%) |
| High school and below            | 45,734 (48%) | 9400 (46%) | 11,932 (49%) | 12,146 (49%) | 12,256 (49%) |
| Unknown                          | 10,968 (12%) | 2142 (10%) | 3798 (15%) | 3295 (10%) | 669 (3%) |
| Living donor                     | 5137 (5%) | 1442 (7%) | 1282 (5%) | 1239 (5%) | 1174 (5%) |
| Dialysis vintage, yr             | 4 (2–5) | 4 (2–5) | 4 (2–6) | 4 (3–6) |           |
| Diabetes mellitus^               | 43,438 (46%) | 8372 (41%) | 11,054 (45%) | 12,120 (49%) | 11,892 (47%) |
| Smoking^                         | 7346 (8%) | 1532 (7%) | 1929 (8%) | 1873 (7%) |           |
| Hypertension^                    | 90,430 (95%) | 19,205 (93%) | 23,541 (96%) | 23,981 (97%) | 23,703 (95%) |
| Coronary artery disease^         | 20,672 (22%) | 3570 (17%) | 5704 (23%) | 6036 (24%) | 5362 (21%) |
| Meeting ACC/AHA 2012 definition of high-risk^ | 69,106 (73%) | 13,054 (63%) | 17,760 (72%) | 19,310 (78%) | 18,982 (76%) |

Continuous variables are expressed as median (quartile 1 to quartile 3) and categorical variables are expressed as n (%). ACC/AHA, American College of Cardiology/American Heart Association.

*Education level: 5% data missing.

Diabetes, smoking, hypertension: claims-based ascertainment, on the basis of a look-back window of 1 year before transplant.

Coronary artery disease (CAD): claims-based ascertainment, on the basis of a look-back window from 2 years before to 1 year before transplant.

Meeting ACC/AHA 2012 definition of high-risk: ≥3 of the risk factors including diabetes mellitus, known CAD, >1 year on dialysis, left ventricular hypertrophy, age ≥60 years, smoking, hypertension, or dyslipidemia.
skepticism in the applicability of cardiovascular trial results to KTx candidates. Such skepticism may partly account for the slow uptake of contemporary trial evidence by transplant providers. A third explanation is that the high extent to which regulatory scrutiny by regulatory agencies and insurers have made transplant programs particularly risk averse. A signal that programmatic risk aversion is driving CAD testing is the slight increase of tests in patients identified as low risk by the more recent and specifically transplant-related guidelines. Although there is no evidence to support CAD screening before KTx in patients without diabetes mellitus who are low risk, it is in these very patients that the CAD testing rate rose over the study period, suggesting the explanation may lie outside medical indications. Indeed, in a recent survey of US transplant providers, responses specifically identified regulatory constraints in governing program practice (8). The Centers for Medicare & Medicaid Services is revamping transplant program metrics, shifting emphasis away from short-term post-transplant outcomes and more toward increasing transplant access (20). These movements could potentially mitigate this trend of increasing CAD screening in low-risk candidates.

Our study also sheds light on contemporary practice patterns vis-à-vis modality selection. Invasive coronary angiography as a first-line screening test appears to be reserved for a minority of patients or be the preference in a minority of programs, with no major change over time. Nuclear perfusion scan remains the most common modality, despite evidence that its performance characteristics in KTx candidates are inferior to those of stress echocardiography (21). Despite the rise of coronary computed tomography angiography in the general Medicare-insured population (22), its use in KTx candidates remains quite limited, possibly due to concern of lower diagnostic performance in the setting of vascular calcification in ESKD or contrast nephropathy’s negative effect on residual kidney function. These findings suggest that clinical practice in modality selection is dictated heavily by local expertise and norms, rather than the most up-to-date evidence (11).

Our study also sheds light on contemporary practice pattern vis-à-vis modality selection. Invasive coronary angiography as a first-line screening test appears to be reserved for a minority of patients or be the preference in a minority of programs, with no major change over time. Nuclear perfusion scan remains the most common modality, despite evidence that its performance characteristics in KTx candidates are inferior to those of stress echocardiography (21). Despite the rise of coronary computed tomography angiography in the general Medicare-insured population (22), its use in KTx candidates remains quite limited, possibly due to concern of lower diagnostic performance in the setting of vascular calcification in ESKD or contrast nephropathy’s negative effect on residual kidney function. These findings suggest that clinical practice in modality selection is dictated heavily by local expertise and norms, rather than the most up-to-date evidence (11).

Our study has several strengths. We examined trends over a 16-year period and ascertained data on all KTx recipients who were Medicare beneficiaries, thereby including all transplant recipients above the age of 65 and the majority below. We used validated approaches to capture comorbidity and to track posttransplant events from administrative data. There are several important limitations. Based on the

**Table 2. Patient factors associated with nonurgent coronary artery disease testing in multivariate analysis**

| Characteristics                | Odds Ratio (95% Confidence Interval) | P Value |
|-------------------------------|-------------------------------------|---------|
| Age, yr                       | 1.03 (1.03 to 1.03)                | <0.0001 |
| Sex                           |                                     |         |
| Female                        | 1.00 (ref)                          | n/a     |
| Male                          | 1.06 (1.03 to 1.09)                | <0.0001 |
| Race                          |                                     |         |
| White                         | 1.12 (1.08 to 1.16)                | <0.0001 |
| Black                         | 1.00 (ref)                          | n/a     |
| Other                         | 1.10 (1.04 to 1.17)                | 0.001   |
| Education                     |                                     |         |
| High school or below          | 1.00 (ref)                          | n/a     |
| Some college or beyond        | 0.99 (0.96 to 1.02)                | 0.6     |
| Unknown                       | 0.98 (0.93 to 1.03)                | 0.4     |
| Dialysis vintage, yr          | 1.03 (1.03 to 1.04)                | <0.0001 |
| Diabetes mellitus             | 1.42 (1.38 to 1.46)                | <0.0001 |
| Coronary artery disease       | 1.40 (1.36 to 1.45)                | <0.0001 |
| Any smoking                   | 1.14 (1.08 to 1.20)                | <0.0001 |
| Hypertension                  | 1.98 (1.83 to 2.15)                | <0.0001 |
| Living donation               | 1.61 (1.55 to 1.67)                | <0.0001 |

ref, reference; n/a, not applicable.
requirement that patients were Medicare beneficiaries, we did not include a portion of preemptive KTx recipients. As a claims-based study, details on CAD testing and comorbidities are less granular. For instance, we are unable to identify the actual indication for testing. Nonetheless, use of a claims-based algorithm to exclude likely urgent testing is consistent with literature (10). Most importantly, we studied KTx recipients rather than candidates, and so have missed the KTx candidates who were subject to CAD screening but never reaped the rewards of transplantation or those who were excluded from waitlist by CAD screening practices. Because this is a study of temporal trends, we needed a landmark event (in this case, KTx date) to group the patients into temporal eras. Different methodologies would be needed to answer questions regarding how many patients are excluded by pre-KTx CAD screening and whether these exclusions are justified.

In summary, we describe in this study the stable rate of pretransplant CAD testing in KTx recipients from 2000 to 2015, despite publication of multiple landmark clinical trials suggesting that fewer diagnostic studies for CAD might be warranted. Due to the limitations posed by our study design, and because our main analysis focused on eventual KTx recipients, we cannot make claims about the utility of screening. However, given the persistently high prevalence of screening, consideration of screening de-escalation for KTx programs may enhance both the cost effectiveness of pretransplant care and promote more equitable access to KTx.

Disclosures
G.M. Chertow reports having consultancy agreements with Akebia, Amgen, Ardelyx, AstraZeneca, Baxter, Cricket, DiaMedica, Gilead, Miromatrix, Reata, Sanofi, Unicycive, and Vertex; reports
having an ownership interest in Ardelyx, CloudCath, Durect, DxNow, Eliaz Therapeutics, Outset, Physiowave, and PuraCath; reports receiving research funding from National Institute of Diabetes and Digestive and Kidney Diseases, and National Institute of Allergy and Infectious Diseases; reports being a scientific advisor or membership of the Board of Directors, Satellite Healthcare, and Co-Editor, *Brenner & Rector’s The Kidney* (Elsevier); and reports other interests/relationships with the Data and Safety Monitoring Board service: Angion, Bayer, National Institute of Diabetes and Digestive and Kidney Diseases, and ReCor. W.F. Fearon reports having consultancy agreements with CathWorks, and Siemens; reports having an ownership interest in HeartFlow; and reports receiving research funding from Abbott Vascular, Boston Scientific, and Medtronic. X.S. Cheng reports receiving honoraria from ClarityCo and Medscape Education. All remaining authors have nothing to disclose.

**Funding**

This work was supported by the American Heart Association grant 19CDA34490021 (X. Cheng), National Institute of Diabetes and Digestive and Kidney Diseases grant K23 DK123410-1 (X. Cheng), and the Sobrato Gift Fund (J. Tan).

**Author Contributions**

X. Cheng, G. Chertow, W. Fearon, and J. Tan conceptualized the study; X. Cheng, J. Han, and S. Liu were responsible for the data curation; X. Cheng, J. Han, S. Liu, and M. Stedman were responsible for the formal analysis; X. Cheng was responsible for the funding acquisition, investigation, and project administration; X. Cheng, J. Han, S. Liu, and M. Stedman were responsible for the methodology; X. Cheng and M. Stedman provided supervision; X. Cheng, G. Chertow, W. Fearon, and J. Tan were responsible for the visualization; X. Cheng, M. Stedman, G. Chertow, W. Fearon,

**Figure 4. | Modality of nonurgent CAD testing by year.** Where more than one test was done, the first test is shown. EKG, electrocardiogram; CCTA, coronary computed tomography angiography.

**Figure 5. | Incidence of 30-day adverse events (death, graft failure, or myocardial infarction) after kidney transplantation each calendar year, all study patients, unadjusted (dotted) and adjusted (black) for transplant program characteristics, patient demographics, transplant type, and comorbidities.**
and J. Tan wrote the original draft; and X. Cheng, G. Chertow, W. Fearon, and J. Tan reviewed and edited the manuscript.

Supplemental Material

This article contains the following supplemental material online at http://kidney360.asnjournals.org/lookup/suppl?doi=10.34067/KID.0005282021/-/DCSupplemental.

Supplemental Figure 1. Trend in CAD testing over time.

References

1. Manske CL, Wang Y, Rector T, Wilson RF, White CW: Coronary revascularisation in insulin-dependent diabetic patients with chronic renal failure. Lancet 340: 998–1002, 1992 https://doi.org/10.1016/0140-6736(92)93010-K

2. McFalls EO, Ward HB, Moritz TE, Goldman S, Krupski WC, Hauptman J, Tan reviewed and edited the manuscript.

3. Boden WE, O’Rourke RA, Teo KK, Hartigan PA, Maron DJ, Kostuk WJ, Knudtson M, Dada M, Caspenson P, Harris CL, Charytan DM: Comparative utilization and temporal trends in cardiac stress testing in patients with type 2 diabetes: The DIAD study: A randomized controlled trial. JAMA 301: 1547–1555, 2009 https://doi.org/10.1001/jama.2009.476

4. Young LH, Wackers FJ, Chyuan DA, Davey JA, Barrett EJ, Tailfier R, Heller GV, Iskandrian AE, Wittlin SD, Gau G, Blaustein AS, Booth DC, Bates ER, Sperutz JA, Berman DS, Mancini GB, Weintraub WS; COURAGE Trial Research Group: Optimal medical therapy with or without PCI for stable coronary disease. N Engl J Med 356: 1503–1516, 2007 https://doi.org/10.1056/NEJMoa070829

5. Hart A, Weir MR, Kasikis BC: Cardiovascular risk assessment in kidney transplantation. Kidney Int 87: 527–534, 2015 https://doi.org/10.1038/ki.2014.335

6. Bangalore S, Maron DJ, O’Brien SM, Fleg JL, Kretov EI, Briguori C, Kaul U, Reynolds HR, Mazurek T, Sidhu MS, Berger JS, Mathew RO, Bockeria O, Broderick S, Praco R, Herzog CA, Huang Z, Stone GW, Boden WE, Newman JD, Ali ZA, Mark DB, Sperutz JA, Alexander KP, Chaitman BR, Chertow GM, Hochman JS; ISCHEMIA-CKD Research Group: Management of coronary disease in patients with advanced kidney disease. N Engl J Med 382: 1608–1618, 2020 https://doi.org/10.1056/NEJMoa1915925

7. Lentine KL, Costa SP, Weir MR, Robb JF, Fleischer LA, Kasikis BL, Carithers RL, Rastogi M, Bolton K, Auerbach AD, Eagle KA; American Heart Association Council on the Kidney in Cardiovascular Disease and Council on Peripheral Vascular Disease: Cardiac disease evaluation and management among kidney and liver transplantation candidates: A scientific statement from the American Heart Association and the American College of Cardiology Foundation. J Am Coll Cardiol 60: 434–480, 2012 https://doi.org/10.1016/j.jacc.2012.05.008

8. Cheng X, Mathew RO, Parasuraman R, Tantisattamo E, Levea SL, Kapoor R, Dadhania DM, Rangaswami J: Coronary artery disease screening of asymptomatic kidney transplant candidates: A web-based survey of practice patterns in the United States. Kidney Med 2: 505–507, 2020 https://doi.org/10.1016/j.xkme.2020.04.006

9. Herzog CA, Natwick T, Li S, Charytan DM: Comparative utilization and temporal trends in cardiac stress testing in U.S. Medicare beneficiaries with and without chronic kidney disease. JACC Cardiovasc Imaging 12: 1420–1426, 2019 https://doi.org/10.1016/j.jcmg.2018.04.012

10. Lentine KL, Schnitzler MA, Brennan DC, Snyder JJ, Hauptman PJ, Abbott KC, Axelrod D, Salvaggio PR, Kasikis B: Cardiac evaluation before kidney transplantation: A practice patterns analysis in Medicare-insured dialysis patients. Clin J Am Soc Nephrol 3: 1115–1124, 2008 https://doi.org/10.2215/CJN.05351107

11. Shpigel AA, Saeed MJ, Novak E, Alhamad T, Rich MW, Brown DI: Center-related variation in cardiac stress testing in the 18 months prior to renal transplantation. JAMA Intern Med 179: 1135–1136, 2019 https://doi.org/10.1001/jamainternmed.2019.0423

12. Ying T, Gill J, Webster A, Kim SJ, Morton R, Klarenbach SW, Kelly P, Ramsay T, Knoll GA, Pilmore H, Hughes G, Herzog CA, Chadban S, Gill JS: Canadian-Australasian Randomised trial of screening kidney transplant candidates for coronary artery disease: A trial protocol for the CASRK study. Am J Heart 214: 175–183, 2019 https://doi.org/10.1016/j.ajh.2019.05.008

13. Adler JT, Yeh H, Markmann JF, Axelrod DA: Is donor service area market competition associated with organ procurement organization performance? Transplantation 100: 1349–1355, 2016 https://doi.org/10.1097/TP.0000000000000979

14. Elshausen A, Steiner C, Harris DR, Coffey RM: Comorbidity measures for use with administrative data. Med Care 36: 8–27, 1998 https://doi.org/10.1097/00005650-199801000-00004

15. Agency for Healthcare Research and Quality: Elshausen Comorbidity Software Refined for ICD-10-CM Healthcare Cost and Utilization Project (Hcup), 2020. Available at: www.hcup-us.ahrq.gov/toolssoftware/comorbidityicd10/comorbidity_icd10.jsp. Accessed March 1, 2021

16. Kini V, Viragh T, Magid D, Masoudi FA, Moghtaderi A, Black B: Trends in high- and low-value cardiovascular diagnostic testing in fee-for-service Medicare, 2000–2016. JAMA Netw Open 2: e1913070, 2019 https://doi.org/10.1001/jamanetworkopen.2019.13070

17. Fleisher LA, Fleischmann KE, Auerbach AD, Barnason SA, Beckman JA, Bozkurt B, Davila-Roman VG, Gerhard-Herman MD, Holll CA, Kane GC, Marine JE, Nelson MT, Spencer CC, Thompson A, Ting HH, Uretsky BF, Wijeysundera DN, American College of Cardiology, American Heart Association: 2014 ACC/AHA guideline on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery: A report of the American College of Cardiology/American Heart Association Task Force on practice guidelines. J Am Coll Cardiol 64: e77–e137, 2014 https://doi.org/10.1016/j.jacc.2014.07.944

18. Chertow GM, Normand S-LT, McNeil BJ: “Renalism”: Inappropriately low rates of coronary angiography in elderly individuals with renal insufficiency. J Am Soc Nephrol 15: 2462–2468, 2004 https://doi.org/10.1097/01.ASN.0000135969.33773.0B

19. Coca SG, Krumholz HM, Garg AX, Parikh CR: Underrepresentation of renal disease in randomized controlled trials of cardiovascular disease. JAMA 296: 1377–1384, 2006 https://doi.org/10.1001/jama.296.11.1377

20. Kasikis BL, Wey A, Salkowski N, Zaud D, Schauffhausen CR, Israhi AK, Snyder JJ: Seeking new answers to old questions about public reporting of transplant program performance in the United States. Am J Transplant 19: 317–323, 2019 https://doi.org/10.1111/ajt.15051

21. Wang LW, Fahim MA, Hayen A, Mitchell RL, Baines L, Lord S, Craig JC, Webster AC: Cardiac testing for coronary artery disease in potential kidney transplant recipients. JA mS o cN e p h r o l 15: 2462–2468, 2004 https://doi.org/10.1016/j.amjnephro.2019.05.008

22. Morris JR, Bellolio MF, Sangaralingham LR, Schilz SR, Shah ND, Goyal DG, Bell MR, Kopecky SL, Gilani WN, Hess EP: Comparative trends and downstream outcomes of coronary computed tomography angiography and cardiac stress testing in emergency department patients with chest pain: An administrative claims analysis. Acad Emerg Med 23: 1022–1030, 2016 https://doi.org/10.1111/acem.13005

Received: August 11, 2021 Accepted: December 9, 2021