ORIGINAL ARTICLE

# Evaluation of Potential Renal Transplant Recipients With Computed Tomography Angiography

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**Objectives:** To determine the safety, clinical yield, and cost of computed tomography angiography (CTA) use in the workup of potential renal transplant recipients.

**Design:** Single-site, retrospective review of medical, surgical, and radiologic records.

**Setting:** Large university tertiary care center.

**Patients:** Potential recipients of transplants from living donors.

**Interventions:** Computed tomography with and without 100 mL of iodixanol intravenous contrast enhancement as part of the preoperative workup.

**Main Outcome Measures:** Mean pre- and post-CTA estimated glomerular filtration rate and number of patients requiring emergent dialysis after CTA, number of patients who had their treatment changed by CTA findings, patient predictors of significant CTAs, and cost per significant CTA.

**Results:** From July 20, 2006, through December 10, 2010, a total of 179 transplant candidates underwent CTA. Forty-two patients were predialysis at the time of CTA. Mean (SD) serum creatinine levels in this group were unchanged after CTA (5.06 [2.13] mg/dL vs 5.00 [2.28] mg/dL [to convert to micromoles per liter, multiply by 88.4], $P=.49$), and no patients required subsequent emergent dialysis. Forty-one patients (22.9%) had their treatment changed by CTA findings. Multivariate logistic regression analysis revealed 3 patient history and physical criteria that predicted significant CTA findings: chronic infection (odds ratio, 10.91; 95% CI, 2.72-43.69; $P<.001$), patient weight less than 69 kg (3.11; 1.49-6.51; $P<.001$), and ventral torso surgical scarring (4.13; 1.57-10.84; $P<.001$). Diagnostic cost per significant CTA study was $2660, with an estimated reduced cost of $1480 per significant study with screening using 1 of the 3 predictors.

**Conclusion:** Diagnostic CTA is a safe and cost-effective procedure for both operative planning and screening for potentially prohibitive abdominal disease.

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Preretransplantation screening plays an important role in risk stratification and leads to interventions that improve patient outcomes. The evaluation typically includes a complete history, physical examination, laboratory testing, and radiologic imaging. Current standard of care in the imaging workup of a transplantation candidate includes a chest radiograph, up-to-date colonoscopies, and/or mammograms in accordance with preventative health guidelines.[1,2] When indicated by physical examination findings, history, and/or laboratory test results, more advanced imaging is used.[1,2]

*See Invited Critique at end of article*

Imaging studies[3,4] with vascular mapping, including computed tomography angiography (CTA), can aid in preoperative planning and provide a screening tool for tumors that may decrease long-term patient survival. Computed tomography angiography has been studied for preoperative planning and evaluation in a number of abdominal operations.[5-20] Until now, the widespread use of CTA in the workup of the potential renal transplant recipient has been limited because of concerns of contrast-induced nephropathy, especially in predialysis patients. Questions surrounding its utility and cost-benefit analyses have not been sufficiently answered.

Several instances were noted at our institution whereby candidates who were cleared through the standard process demonstrated intraoperative or postoperative intra-abdominal findings that precluded transplantation, complicated the transplantation procedure, and/or shortened postoperative allograft survival. Although missed on patient history and physical examination, such findings may

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have been screened using CTA preoperatively. Although recipients of renal transplants from deceased donors have uncertain variations in transplant scheduling, making up-to-date CTA impractical, recipients of transplants from living donors may undergo imaging weeks or days before a scheduled operation date. Therefore, in 2006, our institution began performing CTA during the preoperative workup for all recipients of renal transplants from living donors, regardless of dialysis status.

We present our experience with CTA in the candidate evaluation through an institutional review board–approved, single-institution, retrospective cohort analysis. The aims of this study were to determine (1) the effect of CTA findings on patient care; (2) demographics, history, and physical examination findings that predict significant CTA; (3) the cost per significant CTA study; and (4) the risk of clinically significant CTA contrast nephropathy in predialysis transplant recipients.

## METHODS

### STUDY SITE

This study was a single-site, retrospective review of operative, imaging, and admission records in potential recipients of kidney transplants from living donors at a large tertiary care center. This research was approved by and in accordance with the hospital's institutional review board. The institution evaluates more than 450 new candidates for transplantation each year and performs more than 250 kidney transplants per year. Approximately 60 to 65 transplantations per year are via laparoscopic nephrectomy from living donors.

### STANDARD TRANSPLANTATION PROCEDURE

Institutional standard renal allograft placement is in the right iliac fossa with anastomoses to the right external iliac vessels due to a more optimal anatomical orientation. Deviations from this practice are based on a patient's surgical history, findings from the lower-extremity pulse examination and abdominal examination, intraoperative decisions, and, in the case of this study, recent abdominal imaging results. To review the abdominal studies, a review is performed in which the surgeon, radiologist, and transplantation coordinator review the CTA to determine findings that need to be addressed before transplantation and anastomotic location.

### IMAGING

From 2006 to 2010, all potential transplant recipients underwent outpatient CTA as part of their pretransplantation workup. There were no exclusion criteria. Timing of the CTA was based, in part, on the dialysis status of the recipient. Patients who were predialysis underwent CTA approximately 2 weeks before the expected surgery date, whereas patients currently undergoing dialysis had their imaging performed during their initial transplantation workup.

All patients underwent precontrast and postcontrast oral hydration as tolerated or allowed by their current renal function. *N*-acetylcysteine and sodium bicarbonate were not administered. The CTA was performed on a 64-row Multi-Detector computed tomographic scanner after administration of 100 mL of iodixanol 320 (Visipaque; GE Healthcare) intravenous contrast enhancement. Nonenhanced, arterial, and 2-minute delayed-phase thin-section (0.625-mm collimation) imaging was performed with 2-mm, axial, multiplanar reformation; maximum intensity projection; and volume-rendered angiographic reconstructions. Patients underwent scanning of both the abdomen and pelvis, enabling evaluation of the lung bases, a limited view of the heart, and complete visualization of the abdomen and pelvic contents. Nonenhanced scanning was included to allow visualization of calcifications within the aortoiliac system, which may be hidden by a strong intraluminal contrast signal.

A proportion of candidates were not yet undergoing dialysis at the time of their CTA. For this group, pre- and post-CTA creatinine levels were measured for safety and analysis. All post-CTA creatinine measurements occurred before transplantation. The paired *t* test with 2-tailed distribution was used to compare creatinine levels before and after imaging. These patients were also followed up to determine the incidence of emergent dialysis that was believed to be secondary to the iodinated contrast.

All preoperative patient records were reviewed in 3 electronic/scanned medical record databases: PowerChart (Cerner), TeleResults (TeleResults), and Horizon Patient Portfolio (McKesson).

Pretransplantation medical and surgical history was recorded, including but not limited to cause of the kidney disease (if known), prior transplantation(s), heart disease (eg, valvular, cardiomyopathy, and congestive heart failure), arterial disease (eg, coronary, carotid, peripheral, and cerebral), venous disease (eg, deep vein thrombosis and pulmonary embolism), endocrine disorders (eg, diabetes and thyroid dysfunction), cancer, and chronic infection (eg, hepatitis B/C, human immunodeficiency virus, and tuberculosis). Social history records included smoking, drinking, and intravenous drug abuse. Finally, demographics, history of family cancer, and positive physical examination findings were included. Pertinent physical examination signs included diminished peripheral pulses, edema, presence of incisional scarring, heart auscultation abnormalities, and palpation of abdominal masses. All of these history and physical examination findings were organized into categorical and ordinal variables for later statistical analysis.

### CTA ANALYSIS

The CTAs were analyzed by board-certified radiologists who specialized in abdominal imaging. The CTA reports were reviewed with regard to atherosclerotic disease, vessel patency, venous disease, masses, prior transplant presence, lung base, and cardiac abnormalities.

Patients' post-CTA records were reviewed in the same 3 databases. Operative reports, discharge summaries, imaging studies, laboratory results, and consultations were reviewed to determine if and how the CTA affected patient care. Post-CTA analysis was performed nonmasked to the patient's history and physical examination findings, so the effect of the CTA findings could be isolated. The CTA results that were predetermined by the patient's history and physical examination findings were not analyzed.

Significant treatment changes due to the CTA were classified into 1 of the following 3 categories: preclusion of transplantation for the duration of follow-up, modification of standard transplant anastomotic site, and ancillary therapeutic procedures or long-term specialist follow-up. The CTA findings may have initiated additional imaging. Additional diagnostic imaging alone, however, was not considered a patient management change. Decision flowcharts for determining the role of the CTA in each of the 3 categories can be found in eFigures 1, 2, and 3 (http://www.archsurg.com).

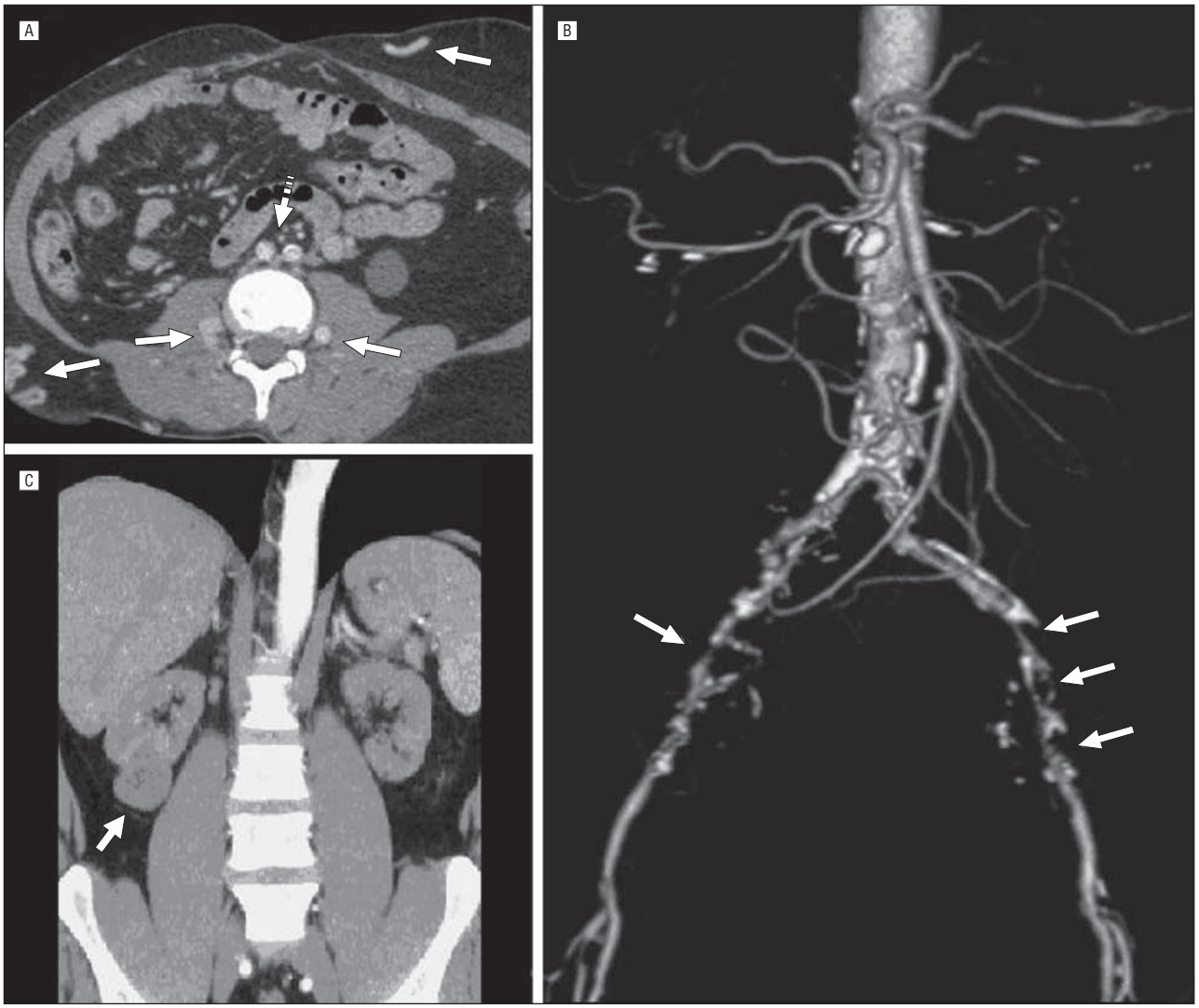


**Figure 1.** Representative computed tomography angiography (CTA) findings (digitally processed images). A, Axial computed tomographic image shows the presence of iliac arteries and occluded iliac veins (dashed arrow) with multiple collaterals (solid arrows). B, Severe bilateral iliac artery atherosclerosis (arrows). C, Renal cell carcinoma in lower pole of atrophic kidney (arrow).

### COST ANALYSIS

The costs of all CTA-based diagnostic procedures and imaging were calculated with *Current Procedural Terminology* codes and national mean Medicare reimbursement rates. This total was divided by the number of patients with significant CTA findings to estimate the mean diagnostic cost to change the treatment of one patient after CTA. The resulting mean costs were compared with the published literature for the costs of renal transplantation.

### PREDICTORS OF SIGNIFICANT CTA STUDIES

The aggregate cohort demographic, history, and physical examination findings were analyzed to determine possible screening characteristics present in those patients who had significant CTA studies. Predictors were selected by assessment of unadjusted associations with significant CTA findings. Potential predictor selection criteria included an odds ratio (OR) greater than 1 for categorical data, OR significance of $P \leq .20$ ($\chi^2$ test) to analyze possible combined effects, and predictor prevalence of at least 5% in the cohort.

Likelihood ratio tests from multivariate logistic regression modeling were then performed with predictor coefficient significance cutoffs of $P \leq .05$. Multivariate modeling was conducted with XLStat software (Microsoft, Inc). To estimate the effect of using this screening, a simplified combinatorial of the significant predictors was then applied to the cohort to estimate the effect of screening for history and physical examination findings on the yield, sensitivity, and cost of significant CTA studies.

## RESULTS

### PATIENT DEMOGRAPHICS, HISTORY, AND PHYSICAL EXAMINATION

From July 20, 2006, through December 10, 2010, a total of 179 patients underwent pretransplantation CTA. The cohort had a mean (SD) age of 51 (15) years and included 106 men and 73 women. One hundred fifteen of the 179 patients (64.2%) had hypertension and/or diabetes mellitus as the cause of their renal failure, and 101 patients (56.4%) were in stage V kidney failure (eTable 1).

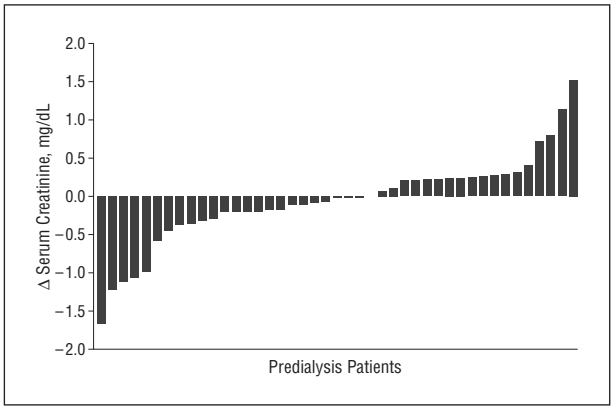


**Figure 2.** Distribution of serum creatinine changes in 43 predialysis patients before and after computed tomography angiography.

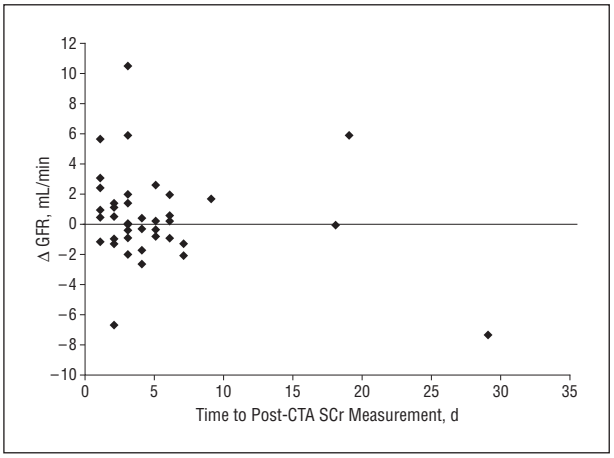


**Figure 3.** Temporal distribution of serum creatinine (SCr) changes. No relationship was found between time to SCr measurement after computed tomography angiography (CTA) and the magnitude of SCr change. GFR indicates glomerular filtration rate.

## CTA REPORTS

All CTA scans were of diagnostic quality. Example findings are shown in **Figure 1**. Sixty-five patients (36.3%) in the cohort were found to have moderate to severe aortoiliac disease. Thiry-six scans (20.1%) demonstrated external iliac artery atherosclerosis, with 8 (4.5%) showing significant stenosis of this vessel. The CTA scans identified 46 suspicious or indeterminate masses or hypertrophy and found prior renal transplants in 27 patients (15.1%) (eTable 2).

## TRANSPLANTATION OUTCOMES

The records of each patient in the cohort were followed up for 6 months. A total of 152 patients (84.9%) who underwent scanning received renal transplants. Of these 152 transplants, 126 (82.9%%) were from a living donor. Median time to transplantation after CTA was 45 days (range, 1-968 days). Ninety-two of the 152 grafts (60.5%) underwent anastomosis to the institution standard right external iliac vessels.

## PREDIALYSIS COHORT

Forty-three patients (24.0%) were predialysis at the time of CTA and had pre- and post-CTA serum creatinine (SCr) measured to assess worsening renal insufficiency. Mean time after CTA for SCr measurements was 4.8 days (range, 1-29 days). The mean (SD) pre- and post-CTA SCr levels were 5.06 (2.13) mg/dL and 5.00 (2.28) mg/dL, respectively ($P = .49$) (to convert to micromoles per liter, multiply by 88.4). The SCr level changes ranged from –1.67 mg/dL to +1.52 mg/dL. Eighteen patients had increases in their SCr levels, 24 patients had decreases in their SCr levels, and 1 patient had unchanged SCr levels. The distribution of changes in SCr levels is presented in **Figure 2**. Time to post-CTA SCr measurement had no relationship to SCr change (**Figure 3**). None of the 43 patients required dialysis as a result of the CTA.

## SIGNIFICANT CTA STUDIES

Overall, 41 of 179 patients (22.9%) had their care altered by CTA findings. Five patients had their transplant precluded, 22 had nonstandard anastomotic locations, and 20 had ancillary therapeutic procedures or long-term specialist follow-up because of their CTA findings. Six patients had treatment changes in more than 1 category. The CTA findings that precluded transplantation included masses in 4 patients (adnexal, pancreatic, prostatic, and adrenal) and evidence of cirrhosis in 1 patient. The most common anastomotic change due to the CTA was switching from right to left external iliac vessels (eTable 3). Examples of therapeutic procedures performed due to CTA findings include 6 nephrectomies for renal cell carcinoma (RCC) and 2 abdominal aortic aneurysm repairs (eTable 4).

## COST ANALYSIS

The estimated cost of all diagnostic procedures and imaging in the study was $108 617.96 (**Table 1**). This cost includes 1 native nephrectomy for a renal mass with negative pathologic test results. Six remaining nephrectomies that tested positive for RCC were therapeutic and diagnostic. For these cases, the biopsy portion of the nephrectomy procedure was considered a diagnostic study, whereas the nephrectomy and anesthesia were not included in the cost. Dividing the total by the number of significant CTA studies yields a cost per significant study of approximately $2649.22.

## PREIMAGING PREDICTORS OF SIGNIFICANT CTA STUDIES

Using the selection criteria previously described, the following 6 potential predictors were included in the multivariate analysis: greater than 4 years of total dialysis duration (OR, 2.26; $P = .17$), diabetes mellitus type 1 (1.98; $P = .17$), carotid artery disease (2.88; $P = .10$), chronic infection (10.91; $P < .001$), ventral torso surgical scarring (4.13; $P = .002$), and weight less than 69 kg (3.11; $P = .002$). Ventral torso surgical scarring includes incisional scars on the chest and/or abdomen.

Single-step logistic regression yielded the following significant predictors of CTA treatment change: chronic

**Table 1. Estimated Costs of Diagnostic Procedures Performed Because of CTA[a]**

| Procedure | *CPT* Code(s) | Quantity | Cost, $ | Total, $ |
|---|---|---|---|---|
| CTA of the abdomen and pelvis | | 180 | | 91 891.80 |
| | 74178 | | 438.48 | |
| | 76376 | | 72.03 | |
| MRI of the abdomen, contrast | 74183 | 6 | 645.89 | 3875.34 |
| MRI of the abdomen, no contrast | 74181 | 5 | 415.53 | 2077.65 |
| MRI of the pelvis, contrast | 72197 | 2 | 646.23 | 1292.46 |
| MRI of the pelvis, no contrast | 72195 | 3 | 416.55 | 1249.65 |
| MRCP, contrast | | 1 | | 717.92 |
| | 74183 | | 645.89 | |
| | 76376 | | 72.03 | |
| Diagnostic aortogram | | 1 | | 441.22 |
| | 75630 | | 251.77 | |
| | 01916[b] | | 189.45 | |
| Transvaginal ultrasonography | 76830 | 5 | 125.71 | 628.55 |
| Abdominal ultrasonography, limited | 76775 | 5 | 112.12 | 560.60 |
| Chest CT, no contrast | 71250 | 1 | 244.97 | 244.97 |
| Chest CT, contrast | 71270 | 1 | 383.25 | 383.25 |
| Full-body PET | 78816[c] | 1 | 1041.99 | 1041.99 |
| FNA of the prostate | | 1 | | 421.64 |
| | 55700 | | 233.42 | |
| | 88172 | | 50.62 | |
| | 88173 | | 137.60 | |
| Hysteroscopy with polypectomy and biopsy[d] | | 1 | | 36.12 |
| | 58558 | | 270.11 | |
| | 88305 | | 106.01 | |
| Renal biopsy, performed at time of nephrectomy | | 7 | | 1836.03 |
| | 50200 -51[e] | | 74.07 | |
| | 88172 | | 50.62 | |
| | 88173 | | 137.60 | |
| Unilateral laparoscopic nephrectomy | | 1 | | 1678.56 |
| | 50546 | | 1241.16 | |
| | 00862[f] | | 421.00 | |
| RLE arteriogram | 75658 | 1 | 240.21 | 240.21 |
| | **Total, $** | | | **108 617.96** |
| No. of significant CTAs | | | | 41 |
| Estimated diagnostic cost per significant CTA, $ | | | | 2649.22 |

Abbreviations: *CPT*, *Current Procedural Terminology*; CT, computed tomography; CTA, computed tomography angiography; FNA, fine needle aspiration; MRCP, magnetic resonance cholangiopancreatography; MRI, magnetic resonance imaging; PET, positron emission tomography; RLE, right lower extremity.

[a] Unless otherwise noted, costs are estimated from 2011 Medicare national average facility reimbursement rates. Available online from the 2011 AMA CPT Relative Value Search at https://ocm.ama-assn.org/OCM/CPTRelativeValueSearch.do. One laparoscopic nephrectomy was included in the total diagnostic procedures when the pathologic test result was negative for renal cell carcinoma as suspected.

[b] 01916 is the anesthesia code for conscious sedation for a vascular diagnostic procedure. The cost shown is calculated from 01916 reimbursement for 60 minutes of operating time (obtained from the operative record) and the 2011 national average anesthesia conversion factor (21.05).

[c] Full-body PET cost was estimated from a national Medicare reimbursement average from the following source: GE Healthcare. *Reimbursement Information for Positron Emission Tomography*. Waukesha, WI: GE Healthcare; 2011.

[d] This procedure does not have any anesthesia costs because it was performed at the same time as the living renal transplantation.

[e] -51 designates a nonprimary procedure. Each renal biopsy was a secondary procedure to a laparoscopic nephrectomy (both by one surgeon) and is therefore only reimbursed 50% of the normal rate.

[f] 00862 is the anesthesia code for generalized anesthesia and monitoring required for a major kidney operation. The cost shown is calculated from 00862 reimbursement for 195 minutes of operating time (obtained from operative record) and the conversion factor for Baltimore, Maryland.

infection, torso surgical scarring, and weight less than 69 kg (**Table 2**). Variance inflation factors were all less than 2, indicating no evidence of multicollinearity in the model. Applying these analyses in a combinatorial pattern to the cohort estimates a reduced cost and an increased yield but a lower sensitivity for significant CTA studies (**Table 3**).

## COMMENT

This study examines the risks and benefits of CTA use in the pretransplantation population. The benefits of CTA derive from its ability to serve as an anatomical guide for transplantation surgeons to avoid atherosclerotic arterial or thrombosed venous vasculature and to elucidate other diseases that may affect graft survival or decrease patient survival with or without a functioning graft. The primary concern is the reported incidence of contrast-induced nephropathy, particularly in the patient with known renal insufficiency.

### BENEFITS OF CTA SCREENING

Atherosclerotic vascular calcification is prevalent in patients with end-stage renal disease (ESRD).[21-27] Previous transplantations complicate this phenomenon by occu-

pying abdominal space and accelerating atherosclerosis.[28,29] Calcification itself makes vessels less amenable to anastomosis, and the atherosclerotic process can lead to luminal stenosis, compromising graft perfusion. Scanning the vasculature in the 3 phases of precontrast, arterial, and delayed sequencing allows for optimal evaluation of vascular calcification, stenosis or aneurysmal disease, and venous patency, respectively.[30]

In this study, 24 of 152 patients (15.8%) who underwent transplantation had the site of anastomosis influenced by CTA findings. This statistic is limited to those patients with grafts transplanted to institutionally nonstandard sites. In addition, per standard protocol, transplantation surgeons at the institution reviewed the scans preoperatively, but their impressions were not consistently documented. Thus, this study most likely underestimates the true effect of CTA on surgical site planning.

Another advantage of CTA is the contrast enhancement of potential tumors that could compromise posttransplantation survival. Renal cell carcinoma is a recognized risk in the ESRD population, with an approximately 40-fold greater prevalence than in the general population.[31-37] Renal cell carcinoma has been shown to significantly increase the risk of death and health care costs in nonscreened renal transplant recipients.[38] In this cohort, 11 suspicious renal masses were identified by CTA. After surgical removal, 6 were subsequently identified as RCC. The overall 3.4% CTA-demonstrated incidence of RCC agrees with other studies of the prevalence of this cancer in patients with ESRD. Important non-RCC, adnexal, adrenal, hepatobiliary, abdominal wall, and prostatic diseases were also found on scanning. Similar to the renal masses, these ancillary findings resulted in additional procedures and imaging necessary before proceeding to transplantation. In 5 patients, these findings eventually led to the patient being deemed ineligible for transplantation because of either lack of follow-up for the CTA findings or CTA findings were severe enough to preclude transplantation.

**Table 2. Significant Computed Tomography Angiography Prediction: Logistic Modeling Results**

| Parameter | OR (95% CI) | *P* Value |
|---|---|---|
| Weight <69 kg | 3.44 (1.51-7.80) | .003 |
| Chronic infection | 11.87 (2.71-51.89) | .001 |
| Total dialysis duration >4 y | 2.01 (0.50-8.02) | .32 |
| Carotid artery disease | 3.40 (0.78-14.74) | .10 |
| Torso surgical scarring | 3.74 (1.29-10.86) | .02 |
| Diabetes mellitus type 1 | 1.65 (0.54-5.07) | .38 |

Abbreviation: OR, odds ratio.

## RISKS OF CTA SCREENING

A major risk that limits widespread use of CTA in the pretransplantation workup is a concern of contrast-induced nephropathy (CIN), which is proposed to accelerate the need for dialysis and has been associated with an increased overall mortality risk in patients undergoing coronary angiography.[39-41] Baseline renal insufficiency is associated with an increased risk of CIN in multiple studies.[42-44] However, the proposed high risk of CIN in renal-impaired patients undergoing CTA remains uncertain for several reasons. First, the exact definition and incidence of clinically significant CIN vary from study to study.[45-48] Second, many studies on CIN focus on conventional coronary angiography procedures, which routinely use more than twice the volume (>200 mL) of standard concentration iodinated contrast required for CTA.[39-41] Moreover, the patient populations undergoing these procedures have differing risk factors that confound ascribing coronary angiography contrast morbidity risks to those undergoing CTA for transplantation. Finally, most studies investigating CIN risk do not use controls, which accounts for variations in SCr levels that frequently occur during hospital stays.[49,50] In a review of literature by Katzberg and Newhouse,[50] the total incidence of CIN requiring immediate intervention was 0 per 1175 patients after CTA, regardless of their current disease status.

In this study, we sought to reduce the risk of CIN by using moderate-dose nonionic iodinated contrast and by encouraging oral hydration. Preprocedure and postprocedure hydration, whether oral and/or intravenous, has been reported to significantly reduce the incidence of CIN in patients undergoing coronary angiography.[50-54] In addition, CTA was reserved until approximately 2 weeks before the surgery date for the predialysis group. However, even with longer-term CTA-to-surgery times, there was no incidence of contrast-induced emergent dialysis. Moreover, pre- to post-CTA laboratory measures of renal function were unchanged in the predialysis cohort. We contend that based on current available evidence from our cohort and the literature, the benefits in surgical planning and screening that CTA provides overshadow any concerns about CIN.

**Table 3. Results Screening for Significant CTA Predictors**

| No. of Predictors | No. of Patients | No. of Significant CTAs | Adjusted Yield[a] | Sensitivity[b] | Adjusted Total Cost, $[c] | Cost per Single CTA, $[d] |
|---|---|---|---|---|---|---|
| ≥0 | 179 | 41 | 0.23 | 1.00 | 108 958 | 2658 |
| ≥1 | 73 | 31 | 0.43 | 0.76 | 45 829 | 1478 |
| ≥2 | 16 | 10 | 0.63 | 0.24 | 11 787 | 1179 |

Abbreviation: CTA, computed tomography angiography.
[a] Adjusted yield is the number of significant CTAs divided by the number of patients having these predictors.
[b] Sensitivity is the number of significant CTAs divided by the total number of significant CTAs (n = 41).
[c] Total diagnostic cost for all patients having these predictors.
[d] Cost per significant CTA is the adjusted total cost divided by the number of significant CTAs.

## ECONOMICS OF CTA SCREENING

In today's health care environment, cost becomes an important factor to consider in the addition of any screening test. In our study, each significant CTA finding cost approximately $3000 in diagnostic procedures and/or imaging. Total cohort diagnostic cost was approximately $110 000. A recent estimate of kidney transplantation total cost (including workup, donor and/or recipient operations, medications, and subsequent health care resource use) was approximately $80 000 for either a living or deceased donor.[55] Thus, if only 2 of the 41 patients (4.9%) in our cohort with treatment changes successfully avoided transplantation complications, including graft loss by the CTA findings, the costs would arguably be justified (approximately $150 000 vs $110 000). Moreover, with the cost increase estimate for undiagnosed RCC previously cited,[34] the gross savings in health care costs for the 6 RCCs alone are approximately $90 000 for 2 years, nearly the diagnostic costs for the entire cohort. Although the actual effect of the CTA on graft survival cannot be discretely calculated from this study, we contend that it is a cost-effective investment in the pretransplantation workup.

## PREDICTING SIGNIFICANT CTA STUDIES

To further cut costs and effectively use imaging resources in pretransplantation patients, we cannot underappreciate history and physical examination. In our cohort, history and physical examination findings that predicted higher yields of significant CTA studies included history of chronic infection, relatively low weight (<69 kg), and ventral torso surgical scarring on physical examination. If a patient had even 1 of these findings, there was a 42.5% chance that the patient would have a significant CTA. Applying these screens to the cohort (Table 3) demonstrates the additional value the patient history and physical examination provide in selective use of CTA. However, more studies will need to be performed on comparable cohorts to cross-validate this model. In addition, the yield of significant CTAs without using predictors (22.9%) may be justifiable for its routine use in screening all potential transplant recipients.

There are 3 other major imaging modalities for imaging aortoiliac vasculature: ultrasonography, magnetic resonance angiography, and conventional digital subtraction angiography. Compared with ultrasonography, CTA is preferable because it is faster, is not as limited by patient body habitus, allows for better 3-dimensional vascular mapping, and requires less operator training. Moreover, the number and types of ultrasonographic testing required to mimic the screening a CTA can provide make the 2 modalities economically comparable. The advantages of CTA over magnetic resonance imaging include faster acquisition time, less cost, and better differentiation between vessel intima and calcified atherosclerotic plaque. Finally, CTA is preferable to conventional digital subtraction angiography because it requires less contrast, causes less patient discomfort, and allows for evaluation of calcifications within the vessels without washout from the contrast as previously mentioned.[56]

## STUDY LIMITATIONS

This study has several important limitations. As in the aforementioned CIN studies, we lacked a negative control to which transplantation outcomes could be compared because our center currently uses CTA as standard of care for all potential renal transplant recipients of living donor organs. Comparing outcomes among institutions or with a historical cohort would introduce confounding variables to accurately determine risk. Another limitation is that history and physical examination findings in the pretransplantation workup can vary, depending on the patient's knowledge and the physical examination findings. In addition, as previously mentioned, there was no separate cohort to validate the predictors of significant CTAs. The final limitation of this study is the lack of standardization in SCr measurement periods after the CTA. However, given that there was no correlation between time to post-CTA SCr and SCr change and no patients progressed to require dialysis after CTA, we contend that the procedure produced no clinically relevant nephropathy in the predialysis patient group.

## CONCLUSION

Patients with ESRD are at an increased risk for tumors and vascular disease processes. Posttransplantation immunosuppression exacerbates these conditions and may lead to significant patient morbidity, graft loss, and mortality. This cohort supports CTA as a component of the preoperative assessment for recipients of living donor organs as safe, as well as having an important role in screening patients with ESRD before transplantation. Furthermore, CTA-based surgical planning potentially decreases operative and graft ischemia times, which, when combined, improve overall transplant recipient outcomes.

Current guidelines for pretransplantation imaging advocate aortoiliac angiography in patients with symptomatic disease.[1] This practice stems from a 1993 study[57] from Norway that found that only 2% of patients who underwent routine angiography had atherosclerotic findings severe enough to warrant surgical intervention. The authors concluded that this low yield did not justify the inherent risks of angiography. We propose this guideline is outdated because of the low volume of contrast required in CTA procedures compared with traditional angiography. Moreover, existing guidelines do not take into account the value of modern CTA resolution in planning graft placement or the ancillary findings that can influence patient outcomes. The effect of CTA on patient treatment in our study was remarkable: almost 1 in 4 patients who underwent CTA demonstrated findings that altered their care. The procedure is relatively safe, is cost-effective, and has the potential to increase graft and patient survival.

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# Considerations Regarding Technology and Transplant Evaluations

Determining the most efficient, cost-effective evaluation of the potential kidney transplant recipient has become increasingly difficult. A variety of external forces have mandated that transplant centers reconsider their standard protocols. The disparity between the waiting list and organ availability is well known and continues to widen. This disparity, along with the increasing incidence of renal failure and aging of the population, means that potential recipients are older and have more intercurrent illnesses. The use of 1- and 3-year survival data as *the* measure of transplant center success has ensured that pretransplantation risk factors are more aggressively sought. Decreasing reimbursement and smaller margins have encouraged transplant programs to search for ways to improve efficiency of the evaluation process while simultaneously addressing stringent outcomes oversight.

Smith and coauthors[1] have convincingly demonstrated that incorporating computed tomography angiography into their routine evaluation of potential recipients of living donor transplants is cost-effective, especially considering that nearly 1 in 4 patients had a meaningful alteration in treatment based (presumably *solely*) on the computed tomography angiography findings. The ability to accurately determine the severity and anatomical distribution of vascular disease is particularly valuable to the transplant surgeon. The unexpected finding of severe vascular disease at the transplant operation is all too common because patients with end-stage renal disease typically do not present with classic signs and symptoms during the pretransplantation evaluation phase. Several strategies to identify arterial and venous compromise have been described but, as the authors note, are limited in usefulness. In this regard, computed tomography angiography may well be the best modality currently available and has the additional advantage of being able to identify clinically silent tumors, with low risk of complications.

Balancing outcomes and cost-effectiveness is a necessary component of modern surgical care. This article is a timely example of the types of considerations and treatment strategies that surgical teams need to apply to meet the expectations of patients, payers, and regulators.

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