





Assessment of the Utility of Kidney Histology as a Basis for Discarding Organs in the United States: A Comparison of International Transplant Practices and Outcomes

Peter P. Reese ^{1,2,3} Olivier Aubert ^{1,4} Maarten Naesens,⁵ Edmund Huang,⁶ Vishnu Potluri,^{2,3} Dirk Kuypers,⁵ Antoine Bouqueneau,⁷ Gillian Divard,¹ Marc Raynaud,¹ Yassine Bouatou,¹ Ashley Vo,⁶ Denis Glotz,^{1,8} Christophe Legendre,^{1,4} Carmen Lefaucheur ^{1,8} Stanley Jordan,⁶ Jean-Philippe Empana,¹ Xavier Jouven,^{1,9} and Alexandre Loupy ^{1,4}

Due to the number of contributing authors, the affiliations are listed at the end of this article.

ABSTRACT

Background Many kidneys donated for transplant in the United States are discarded because of abnormal histology. Whether histology adds incremental value beyond usual donor attributes in assessing allograft quality is unknown.

Methods This population-based study included patients who received a deceased donor kidney that had been biopsied before implantation according to a prespecified protocol in France and Belgium, where preimplantation biopsy findings are generally not used for decision making in the allocation process. We also studied kidneys that had been acquired from deceased United States donors for transplantation that were biopsied during allocation and discarded because of low organ quality. Using donor and recipient characteristics, we fit multivariable Cox models for death-censored graft failure and examined whether predictive accuracy (C index) improved after adding donor histology. We matched the discarded United States kidneys to similar kidneys transplanted in Europe and calculated predicted allograft survival.

Results In the development cohort of 1629 kidney recipients at two French centers, adding donor histology to the model did not significantly improve prediction of long-term allograft failure. Analyses using an external validation cohort from two Belgian centers confirmed the lack of improved accuracy from adding histology. About 45% of 1103 United States kidneys discarded because of histologic findings could be accurately matched to very similar kidneys that had been transplanted in France; these discarded kidneys would be expected to have allograft survival of 93.1% at 1 year, 80.7% at 5 years, and 68.9% at 10 years.

Conclusions In this multicenter study, donor kidney histology assessment during allocation did not provide substantial incremental value in ascertaining organ quality. Many kidneys discarded on the basis of biopsy findings would likely benefit United States patients who are wait listed.

JASN 32: 397–409, 2021. doi: <https://doi.org/10.1681/ASN.2020040464>

Nearly 95,000 patients are waiting for a kidney transplant in the United States, but only 14,725 deceased donor transplants were performed in the year 2018.¹ Despite the scarcity of organs, thousands of deceased donor kidneys are discarded each year in the United States.^{2–4} The White House introduced in 2019 the Advancing American Kidney Health initiative, and advocacy groups, such as the National Kidney Foundation, have invested major efforts in reducing organ discard and setting

Received April 17, 2020. Accepted September 28, 2020.

J.-P.E., X.J., and A.L. contributed equally to this work.

P.P.R. and O.A. share co-first authorship.

Published online ahead of print. Publication date available at www.jasn.org.

Correspondence: Dr. Alexandre Loupy, Paris Translational Research Center for Organ Transplantation, 56 Rue Leblanc, Paris 75015, France. Email: alexandre.loupy@inserm.fr

Copyright © 2021 by the American Society of Nephrology

aggressive goals to improve access to kidney transplantation in the United States.^{2,5} These initiatives treat the need to increase the number of kidneys for transplant as a major public health priority.

One of the leading reasons for kidney discard by United States centers is the use of biopsies in the decision-making process due to concern about renal pathology findings, such as glomerulosclerosis, fibrosis, and arteriosclerosis, often found in older donors or those with comorbidities.⁶ In a study spanning the years 2000–2015, biopsy findings were cited for 38.2% of United States kidney discards.⁴ However, growing evidence suggests that many discarded kidneys could instead be transplanted and provide substantial health benefits to patients with ESKD.^{7,8}

Unfortunately, biopsies performed during allocation may not provide accurate guidance about how these kidneys would function after transplant because the biopsy tissue may be interpreted under time pressure by pathologists without specific expertise in renal pathology.⁹ Yet, convincing transplant professionals to forego allocation biopsies may be difficult without showing that judgments about organ quality will not be improved by taking into account information about renal histology.

Prior studies suggest that the reproducibility of procurement biopsy findings is poor, there is wide geographic variation in the United States about which kidneys get a biopsy, and transplant centers collectively have no systematic approach to integrating the biopsy results into decision making.^{9,10} Kasiske *et al.*⁶ examined biopsy reports from discarded kidneys in which the contralateral kidney was transplanted and reported that glomerulosclerosis >20% was the main pathologic feature predictive of discard. When repeat biopsies were performed on the same kidneys, there were often substantial differences in the results.⁶ In contrast, Cockfield *et al.*¹¹ examined 730 implantation biopsies and proposed that vascular abnormalities, including arteriolar hyalinosis but not glomerulosclerosis, were most predictive of graft failure outcomes. Other groups have developed prognostic scoring systems, such as the Maryland Aggregate Pathology Index, that rely on detailed measurements from multiple anatomic compartments of the kidney.^{12,13} Taken together, these results and others reveal substantial debate about whether and what features of renal biopsy ought to influence allograft acceptance decisions.^{14,15}

Our group recently demonstrated that United States transplant centers commonly discard kidneys that would have been transplanted in Europe, particularly kidneys from older donors and those with comorbidities.⁷ In addition, that study showed that the kidneys discarded in France came from much older donors than those in the United States (61.58 versus 52.15 years) and had a higher kidney donor risk index (KDRI) than kidneys discarded in the United States (2.03 versus 1.83). One key difference in allocation between countries is that approximately half of United States deceased donor kidneys undergo allocation biopsy, and centers often cite those results as the rationale for refusing that kidney.⁴ In contrast,

Significance Statement

Many kidneys donated for transplantation are discarded because of abnormal histology, but it is unknown whether preimplantation kidney biopsies that are routinely performed in the United States add incremental value beyond usual donor attributes in predicting allograft survival. The investigators analyzed detailed data from transplant centers in France and Belgium, where pretransplant biopsies are prospectively performed as standard practice but do not guide decision making for organ allocation. They found that transplant histology did not improve the prediction of allograft failure beyond a robust baseline set of donor and recipient characteristics. They also studied donor kidneys from deceased United States donors—specifically, organs discarded because of abnormal histology—and matched them with similar kidneys transplanted in Europe. The matched kidneys had acceptable allograft survival, illustrating lost transplant opportunities in the United States.

kidneys are rarely biopsied in the process of allocating kidneys in France, Belgium, and other European transplant systems.¹⁶ Some European centers routinely perform preimplantation allograft biopsies in kidneys after organ acceptance, so that biopsy results do not interfere with the decision-making process of organ acceptance. This standard practice of preimplantation kidney biopsy that is unrelated to organ acceptance decisions provides a robust and unprecedented opportunity to examine the range of pathologic abnormalities and the clinical relevance of histologic lesions to post-transplant outcomes.

The primary aim of this study was to determine whether pretransplant biopsy results improve the prediction of allograft survival over routinely collected donor characteristics. The second aim was to estimate post-transplant outcomes for United States kidneys that were biopsied and discarded by matching those kidneys to very similar allografts that were transplanted at centers in Europe.

METHODS

Study Population

European Cohorts

The derivation cohort consisted of 1629 patients over 18 years of age who were prospectively enrolled at the time of kidney transplantation from a deceased donor at Necker Hospital ($n=920$) and Saint-Louis Hospital ($n=709$) in France between January 1, 2004 and January 1, 2014.

We excluded patients receiving kidneys from living donors ($n=494$) as well as deceased donor kidneys with biopsy performed but inadequate for full pathologic interpretation according to the international Banff classification ($n=214$). All data were anonymized and prospectively entered at transplantation; at 3 months, 6 months, and 1 year post-transplant; and at each transplant anniversary using a standardized protocol to ensure harmonization across the two study centers. Data from the derivation cohort were submitted for an annual audit to ensure data quality. Data were retrieved from the database on

January 1, 2019. All patients provided written informed consent at the time of transplantation.

An external validation was conducted using a cohort of 1107 recipients of deceased donor kidney transplants at the University Hospitals of Leuven ($n=951$) and Liege ($n=156$), Belgium, between January 1, 2004 and December 31, 2013 with preimplantation biopsy evaluation. Datasets from the validation centers were collected as part of routine clinical practice, entered in the centers' databases in compliance with local and national regulatory requirements, and sent anonymized to the Paris Transplant Group. Data were retrieved from the database March 1, 2019.

In France, the transplantation allocation system followed the rules of the French National Agency for Organ Procurement (Agence de la Biomédecine; <https://www.agence-biomedecine.fr>). Centers from Belgium followed the rules of the Eurotransplant allocation system (<https://www.eurotransplant.org/cms/>).

Kidneys Discarded in the US on the Basis of Histology Results

This cohort consisted of deceased donor kidneys that were recovered for transplantation, biopsied as part of the kidney allocation process, and then discarded because of low organ quality due by "biopsy findings" between 2015 and 2016 ($n=1103$). Data were obtained from the Organ Procurement and Transplantation Network (OPTN).¹⁷ The OPTN data system includes data on all donors, wait-listed candidates, and transplant recipients in the United States, as submitted by the members of OPTN. The Health Resources and Services Administration of the US Department of Health and Human Services oversees the activities of the OPTN contractor. Donor data are collected and entered into the dataset by organ procurement organizations and then reported to OPTN.

Outcomes

The primary outcome was the additional predictive value of kidney histology over routinely collected donor characteristics to predict allograft failure as measured by change in the Harrell concordance index (C index) in models with and without histologic characteristics. The secondary outcome was predicted post-transplant outcomes for United States kidneys that were biopsied and discarded by matching those kidneys to very similar allografts that were transplanted at centers in Europe.

Procedures and Clinical Protocols

The following parameters were collected in the derivation cohort: (1) donor characteristics, including age at donation, sex, body mass index, renal function, donor history of hypertension, donor history of diabetes, donor cause of death, donor serum creatinine at donation, donor hepatitis C virus (HCV) serostatus, donation after circulatory death status, and extended criteria donor status (defined conventionally as age ≥ 60 years or age 50–59 years plus two or more of the following: hypertension, death from stroke, or terminal creatinine

>1.5 mg/dl); (2) recipient characteristics at the time of transplantation, including age, sex, and prior transplant; (3) HLA mismatch (A, B, DR); and (4) the presence of circulating anti-HLA donor-specific antibodies (DSAs) at the time of transplantation assessed for all patients at the Jean Dausset Histocompatibility Laboratory.

Kidney Allograft Biopsy Protocol Performed at the Time of Transplantation

All deceased donor kidneys underwent preimplantation biopsies (referred to as "day 0") according to a prespecified protocol in the derivation cohort. These biopsies were performed by surgeons using a 16-gauge device in the operating suite after a definitive decision was made to accept the kidney for transplantation. The tissue was immediately fixed in an alcohol-formalin-acetic acid solution and subsequently embedded in paraffin. The biopsy sections ($4\ \mu\text{m}$) were stained with periodic acid–Schiff, Masson trichrome, and hematoxylin and eosin. Using the international Banff criteria, trained renal pathologists graded the graft biopsies using the following criteria: glomeruli number, number of sclerotic glomeruli, arteriosclerosis (vascular fibrous intimal thickening—cv Banff score), arterial hyalinosis (ah Banff score), and interstitial fibrosis and tubular atrophy (IFTA). For each criterion, single Banff scores (not ranges) were provided.¹⁸

KDRI Calculation

The KDRI score was calculated on the basis of the following donor parameters: age, height, weight, history of hypertension, history of diabetes, cause of death (cerebral stroke), serum creatinine at donation, HCV serostatus, and donation after circulatory death status.¹⁹ Notably, race/ethnicity for organ donors is not recorded in accordance with national French bioethics regulations. As a result, we entered "non-Black" for all French donors when calculating KDRI. The KDRI score for any kidney allograft estimates the risk of failure compared with a kidney from a reference donor defined as 40 years old, non-Black, and 170-cm tall weighing 80 kg with a creatinine level of 1 mg/dl, as well as negative history of hypertension, diabetes, and hepatitis C.

Statistical Analyses

Continuous variables were described using means and SDs or median and the interquartile range. We compared means and proportions between groups using the t test, ANOVA, or the chi-squared test (or the Fisher exact test if appropriate).

Predictive Models for Allograft Survival at the Time of Transplantation

The goal of this analysis was to determine whether day 0 deceased donor biopsy findings improve the prediction of allograft survival among kidney transplant recipients at two French centers. The analysis was performed from the time of transplantation with kidney graft loss as the event of interest, defined as the patient's return to dialysis or

retransplantation. For patients who died with a functioning graft, graft survival was censored at death.²⁰ Cox proportional hazards models were applied to quantify the hazard ratios (HRs) and the 95% confidence intervals (95% CIs) for kidney graft loss. The associations of donor and recipient baseline characteristics, transplant parameters, and immunologic factors with graft loss were first assessed in univariate regression analyses. All variables identified in these analyses with a *P* value of 0.10 were then entered in the initial multivariable model. A process of backward selection was then used to select variables for the final multivariable model. Internal validation of the final multivariable model was confirmed using a bootstrap procedure, which involved generating 1000 datasets derived from resampling the original dataset and permitted the estimation of the biased corrected 95% CI and the accelerated bootstrap HR.²¹

The discrimination ability of the final multivariable model was compared with the model with the addition of the day 0 biopsy results using the C index. We performed complete case analyses.

External Validation

The same analysis was independently replicated among kidney transplant recipients at two Belgian centers in order to assess whether the results obtained in France manifested similarly in Belgium. In this external validation cohort, the same donor and recipient baseline characteristic, transplant parameters, immunologic factors, and day 0 histologic factors were investigated.

Procedures for Matching United States Discarded Kidneys to Kidneys Transplanted in Europe

Using OPTN/United Network for Organ Sharing data, we identified donor kidneys that were classified as discarded due to “biopsy findings” in the United States from the years 2015 to 2016. We used 1:1 optimal matching without replacement to generate highly similar matched pairs of kidneys discarded in the United States to kidneys transplanted in France.²² We used an iterative approach to reduce the distance between matched pairs. First, a propensity score model was generated using KDRI and biopsy findings of glomerulosclerosis, arteriosclerosis, and IFTA. Next, a Mahalanobis distance matrix was constructed using both the propensity score and the covariates included in the propensity score model, and the caliper was set at 20% of standardized difference of the logit of propensity score.²³ We then applied penalties to the distance matrix to prioritize the algorithm for finding optimal matches in the following order: KDRI, glomerulosclerosis, IFTA, and arteriosclerosis. Finally, we used near-exact matching for glomerulosclerosis and near-fine balance for IFTA and arteriosclerosis.²⁴ A postmatch standardized difference <0.1 was considered satisfactory balance between covariates.^{25,26} R package “designmatch” was used to perform optimal matching, and covariate balance was assessed using R package “cobalt.”^{27,28}

All analyses were performed using R (version 3.2.1; R Foundation for Statistical Computing, Vienna, Austria) and Stata (Version 14.0; College Station, TX). Values of *P*<0.05 were considered significant, and all tests were two tailed (Supplemental Material).

RESULTS

Donor and Recipient Characteristics in the Derivation Cohort

In the derivation cohort, the mean donor age was 52.60 ± 16.68 years. A total of 958 (58.81%) donors were men, and 911 (55.92%) had died of cerebrovascular causes. A total of 473 (29.80%) donors presented with hypertension, and 126 (8.02%) donors had diabetes mellitus. The mean KDRI was 1.54 ± 0.64 . A total of 224 (13.75%) biopsies displayed >20% glomerulosclerosis, 92 (5.65%) presented with a score of IFTA (IFTA Banff score) greater than or equal to two, 546 (33.52%) had an arteriosclerosis score (cv Banff score) greater than or equal to two, and 322 (19.83%) had an arteriolar hyalinosis score (ah Banff score) greater than or equal to two. Among the 1629 kidney transplant recipients from the derivation cohort, the mean recipient age was 51.40 ± 13.21 years, and 966 (59.30%) were men. A total of 283 (17.37%) had received a prior kidney transplant. The median follow-up after transplantation was 6.79 years (interquartile range, 4.38–9.43). Table 1 presents the donor and recipient characteristics and the protocol day 0 biopsy results of the derivation cohort.

Value of Day 0 Allograft Histology in Predicting Kidney Allograft Loss in the Derivation Cohorts

The associations of donor and recipient characteristics, transplant characteristics, and immunologic parameters with graft loss were assessed in univariate Cox models (Table 2). From these parameters selected on the basis of univariate analysis, we identified after multivariable analysis the following significant independent predictors of graft loss (Table 2): KDRI (log transformation; HR, 2.56; 95% CI, 1.92 to 3.43; *P*<0.001) and the presence of day 0 circulating DSA (HR, 1.89; 95% CI, 1.48 to 2.43; *P*<0.001). We confirmed the validity and the robustness of the final multivariable model by performing bootstrapping resampling procedure with 1000 samples (bias-corrected 95% CIs and bias-corrected and -accelerated bootstrap HRs). After bias-correction through bootstrapping, the 95% CI of the HR was 1.98 to 3.30 for the KDRI, and 1.47 to 2.41 for the anti-HLA DSA on day 0.

The association of day 0 biopsy results was assessed in univariate analysis (Supplemental Table 1A). After adjustment, only IFTA remained independently associated with kidney allograft loss (HR, 1.51; 95% CI, 1.00 to 2.26; *P*=0.048) (Supplemental Table 1B).

The discrimination capacity of the final multivariable model and the model with the addition of the day 0 biopsy

Table 1. Baseline characteristics of derivation and validation cohorts

Characteristics	n	French Transplanted Kidneys (Derivation), n=1629	n	Belgian Transplanted Kidneys (Validation), n=1107	P Value
Donor characteristics					
Age, yr, mean (SD)	1629	52.60 (16.68)	1096	48.09 (14.28)	<0.001
Donor men, no. (%)	1629	958 (58.81)	1100	607 (55.18)	0.06
Height, cm, mean (SD)	1628	170.15 (10.31)	1090	172.46 (8.79)	<0.001
Weight, kg, mean (SD)	1628	73.81 (15.57)	1091	75.63 (13.35)	0.002
BMI, kg/m ² , mean (SD)	1628	25.42 (4.75)	1089	25.39 (4.16)	0.88
Hypertension, no. (%)	1587	473 (29.80)	1082	232 (21.44)	<0.001
Diabetes mellitus, no. (%)	1571	126 (8.02)	1107	4 (0.36)	<0.001
Donor serum creatinine ≥1.5 mg/dl, no. (%)	1613	212 (13.14)	932	144 (15.45)	0.96
Death from cerebrovascular disease, no. (%)	1629	911 (55.92)	1107	579 (52.30)	0.06
Expanded criteria donor, no. (%)	1626	687 (42.25)	1107	282 (25.47)	<0.001
KDRI, ^a mean (SD)	1540	1.54 (0.64)	888	1.32 (0.40)	<0.001
Histologic factors on day 0					
Percentage of glomerulosclerosis	1629		1107		
0–5		818 (50.21)		722 (65.22)	
6–10		278 (17.07)		172 (15.54)	
11–15		180 (11.05)		68 (6.14)	
16–20		129 (7.92)		51 (4.61)	
>20		224 (13.75)		94 (8.49)	<0.001
IFTA	1629		1107		
Low score: 0 or 1		1537 (94.35)		1082 (97.74)	
High score: ≥2		92 (5.65)		25 (2.26)	<0.001
Arteriosclerosis	1629		1107		
Low score: 0 or 1		1083 (66.48)		1082 (97.74)	
High score: ≥2		546 (33.52)		25 (2.26)	<0.001
Arteriolar hyalinosis	1624		1103		
Low score: 0 or 1		1302 (80.17)		1044 (94.65)	
High score: ≥2		322 (19.83)		59 (5.35)	<0.001
Recipient characteristics					
Recipient age, yr, mean (SD)	1629	51.40 (13.21)	1107	54.49 (12.79)	<0.001
Recipient men, no (%)	1629	966 (59.30)	1106	683 (61.75)	0.20
Prior kidney transplant, no. (%)	1629	283 (17.37)	1107	154 (13.91)	0.02
Immunologic factors					
No. of HLA A/B/DR mismatches	1628	4.01 (1.25)	1107	2.53 (1.27)	0.68
Anti-HLA DSA on day 0, no. (%)	1629	343 (21.06)	1107	0	<0.001

Bold indicates $P < 0.05$. BMI, body mass index.

^aThe KDRI score was calculated on the basis of the following donor parameters: age, height, weight, history of hypertension, history of diabetes, cause of death (cerebral stroke), serum creatinine at donation, HCV serostatus, and donation after circulatory death status.

results (in which all of the histologic Banff scores for glomerulosclerosis, IFTA, arteriosclerosis, and arteriolar hyalinosis were added) were assessed using the C index. The C index for the model without histology was 0.635 (95% CI, 0.60 to 0.66) compared with 0.646 (95% CI, 0.62 to 0.68) for the model with the addition of the day 0 biopsy results ($P = 0.10$).

Value of Day 0 Allograft Histology in Predicting Kidney Allograft Loss in the External Validation Cohorts

Table 1 shows recipient characteristics and allograft histology for the external validation cohort from Belgium. Supplemental Table 2 shows the univariate Cox model. Only KDRI (log transformation; HR, 3.23; 95% CI, 1.80 to

5.81; $P < 0.001$) remained independently associated with allograft loss in the multivariable analysis. As in the primary analyses, the discrimination capacity of the final multivariable model and the model with the addition of the day 0 biopsy results (in which all of the histologic Banff scores for glomerulosclerosis, IFTA, arteriosclerosis, and arteriolar hyalinosis were added) were assessed using the C index. The C index for the model without histology was 0.610 (95% CI, 0.56 to 0.67) compared with 0.617 (95% CI, 0.56 to 0.67) for the model with the addition of the day 0 biopsy results ($P = 0.62$).

Taken together, these results confirmed the primary analysis that showed no incremental value of day 0 biopsy in predicting long-term kidney allograft outcomes.

Table 2. Determinants of kidney allograft loss in the derivation cohort: Univariate and multivariable analyses

Characteristics	No. of Patients	No. of Events	HR	95% CI	P Value
Univariate analysis					
Baseline recipient characteristics					
Age, per 1-yr increment	1629	335	1.01	(1.00 to 1.02)	0.009
Sex					
Women	663	136	1		
Men	966	199	1.01	(0.81 to 1.26)	0.92
Prior kidney transplant					
No	1346	262	1		
Yes	283	73	1.36	(1.05 to 1.77)	0.02
Baseline donor characteristics					
Age, per 1-yr increment	1629	335	1.02	(1.01 to 1.03)	<0.001
Sex					
Women	671	148	1		
Men	958	187	0.86	(0.69 to 1.07)	0.18
Death of CV disease					
No	718	116	1		
Yes	911	219	1.61	(1.29 to 2.02)	<0.001
Hypertension					
No	1114	200	1		
Yes	473	124	1.71	(1.37 to 2.14)	<0.001
Diabetes mellitus					
No	1445	295	1		
Yes	126	26	1.16	(0.77 to 1.73)	0.48
Creatinine, mg/dl					
<1.5	1401	277	1		
≥1.5	212	53	1.41	(1.05 to 1.89)	0.02
ECD					
No	939	162	1		
Yes	687	171	1.72	(1.39 to 2.13)	<0.001
KDRI, ^a log transformation	1540	312	2.44	(1.83 to 3.25)	<0.001
Baseline immunologic factors					
No. of HLA A/B/DR mismatches	1628	335	1.02	(0.94 to 1.11)	0.67
Anti-HLA DSA on day 0					
No	1286	241	1		
Yes	343	94	1.79	(1.41 to 2.77)	<0.001
Multivariable analysis, <i>n</i> =1540 analyzed in the full model					
KDRI, ^a log transformation	1540	312	2.56	(1.92 to 3.43)	<0.001
Anti-HLA DSA on day 0					
No	1206	222	1		
Yes	334	90	1.89	(1.48 to 2.43)	<0.001

Bold indicates $P<0.05$. CV, cardiovascular; ECD, expanded criteria donor; HLA, human leukocyte antigen; DSA, donor specific antibody.

^aThe KDRI score was calculated on the basis of the following donor parameters: age, height, weight, history of hypertension, history of diabetes, cause of death (cerebral stroke), serum creatinine at donation, HCV serostatus, and donation after circulatory death status.

Matching Kidneys Discarded in the United States Due to Abnormal Histopathology to Similar Kidneys Transplanted in Europe

Table 3 shows the characteristics of 1103 donor kidneys that were discarded due to “biopsy findings” in the United States over 2 years. Prior to matching, the mean donor age for the discarded kidneys in the United States was slightly older than donors of French transplanted kidneys (55.43 ± 10.96 versus 52.60 ± 16.68 years; $P<0.001$). The donors of the United States discarded kidneys were more likely to have hypertension (73.78% versus 29.80%; $P<0.001$) and diabetes (29.62% versus 8.01%; $P<0.001$) than donors of French transplanted

kidneys. Day 0 biopsies from kidneys discarded in the United States revealed more glomerulosclerosis, more IFTA (IFTA Banff score), and more arteriosclerosis (cv Banff score) compared with the French transplanted kidneys ($P<0.001$ for all comparisons).

Overall, a total of 493 (45%) United States kidneys discarded due to histology were matched to kidneys transplanted in France. Figure 1 and Supplemental Tables 3 and 4 show that the matched kidneys were highly similar in terms of KDRI and histology, including glomerulosclerosis, arteriosclerosis, and IFTA. After matching, the standardized differences were <0.1 for the four variables in the match. While the mean KDRI was

Table 3. Baseline characteristics of kidneys transplanted in the French derivation cohort and kidneys discarded in the United States due to biopsy findings

Characteristics	Kidneys Transplanted in the French Derivation Cohort, <i>n</i> =1629		Kidneys Discarded in the United States Cohort, <i>n</i> =1103		<i>P</i> Value
	<i>n</i>	Value	<i>n</i>	Value	
Donor's characteristics					
Donor age, yr, mean (SD)	1629	52.60 (16.68)	1103	55.43 (10.96)	<0.001
Donor men, no. (%)	1629	958 (58.81)	1103	577 (52.31)	0.001
Height, cm, mean (SD)	1628	170.15 (10.31)	1103	169.12 (10.54)	0.003
Weight, kg, mean (SD)	1628	73.81 (15.57)	1103	85.51 (22.37)	<0.001
BMI, kg/m ² , mean (SD)	1628	25.42 (4.75)	1103	29.88 (7.35)	<0.001
Hypertension, no. (%)	1587	473 (29.80)	1087	802 (73.78)	<0.001
Diabetes mellitus, no. (%)	1571	126 (8.02)	1087	322 (29.62)	<0.001
Donor serum creatinine ≥1.5 mg/dl, no. (%)	1613	212 (13.14)	1103	571 (51.77)	<0.001
Death from cerebrovascular disease, no. (%)	1629	911 (55.92)	1103	926 (83.95)	<0.001
Expanded criteria donor, no. (%)	1626	687 (42.25)	1103	659 (59.75)	<0.001
KDRI, mean (SD)	1540	1.54 (0.64)	1085	1.885 (0.471)	<0.001
Day 0 biopsy					
Percentage of glomerulosclerosis	1629		1103		
0–5		818 (50.21)		190 (17.23)	
6–10		278 (17.07)		161 (14.60)	
11–15		180 (11.05)		145 (13.15)	
16–20		129 (7.92)		124 (11.24)	
>20		224 (13.75)		483 (43.79)	<0.001
IFTA	1629		1103		
Low score: 0 or 1		1537 (94.35)		416 (37.72)	
High score: ≥2		92 (5.65)		687 (62.28)	<0.001
Arteriosclerosis	1629		1103		
Low score: 0 or 1		1083 (66.48)		433 (39.26)	
High score: ≥2		546 (33.52)		670 (60.74)	<0.001

Bold indicates $P < 0.05$. BMI, body mass index.

1.88 in each group after matching, there were differences between groups in the distributions of individual KDRI components of donor age, height, weight, history of hypertension, history of diabetes, cause of death (cerebral stroke), serum creatinine at donation, HCV serostatus, and donation after circulatory death status.

Figure 2 depicts kidney allograft survival for the matched and unmatched kidneys. Overall, allograft survival rates for French kidneys matched to United States discarded kidneys were 93.1%, 80.7%, and 68.9% at 1, 5, and 10 years post-transplant, respectively (Figure 2A). We next compared the allograft survival of transplanted kidneys matched to United States discarded kidneys to overall expanded criteria donor French kidneys and found similar allograft survival rates of 93.4%, 80.9%, and 69.9% ($P = 0.69$), respectively (Figure 2B).

Supplemental and Sensitivity Analyses

The associations of donor and recipient characteristics, transplant characteristics, and immunologic parameters with all-cause graft loss were assessed in univariate and multivariable Cox models (Supplemental Table 5). Following the same variable selection process as in the primary analysis, we identified the following significant independent predictors of nondeath-censored graft loss: recipient age (HR, 1.02; 95% CI, 1.01 to

1.03; $P < 0.001$), KDRI (log transformation; HR, 2.62; 95% CI, 1.93 to 3.56; $P < 0.001$), prior kidney transplant (HR, 1.49; 95% CI, 1.20 to 1.86; $P < 0.001$), and the presence of day 0 circulating DSA (HR, 1.55; 95% CI, 1.26 to 1.89; $P < 0.001$). The discrimination capacity of the final multivariable model and the model with the addition of the day 0 biopsy results (in which all of the histologic Banff scores for glomerulosclerosis, IFTA, arteriosclerosis, and arteriolar hyalinosis were added) were assessed using the C index. In this supplemental analysis, the addition of biopsy data again was not associated with a statistically significant improvement in predictive accuracy, with a C index for the model without histology of 0.659 (95% CI, 0.64 to 0.68) compared with a C index of 0.667 (95% CI, 0.64 to 0.69) for the model with the addition of the day 0 biopsy ($P = 0.07$ for the comparison of C statistics between models).

To confirm the robustness of the primary results, we matched kidneys using biopsy findings and the donor's age instead of KDRI. Using 1:1 optimal matching, we matched 496 (45%) United States discarded kidneys to kidneys transplanted in France (Supplemental Table 6). The baseline characteristics of the matched and unmatched kidneys are summarized in Supplemental Table 7. There were no statistically significant differences in the histology between the two groups in terms of

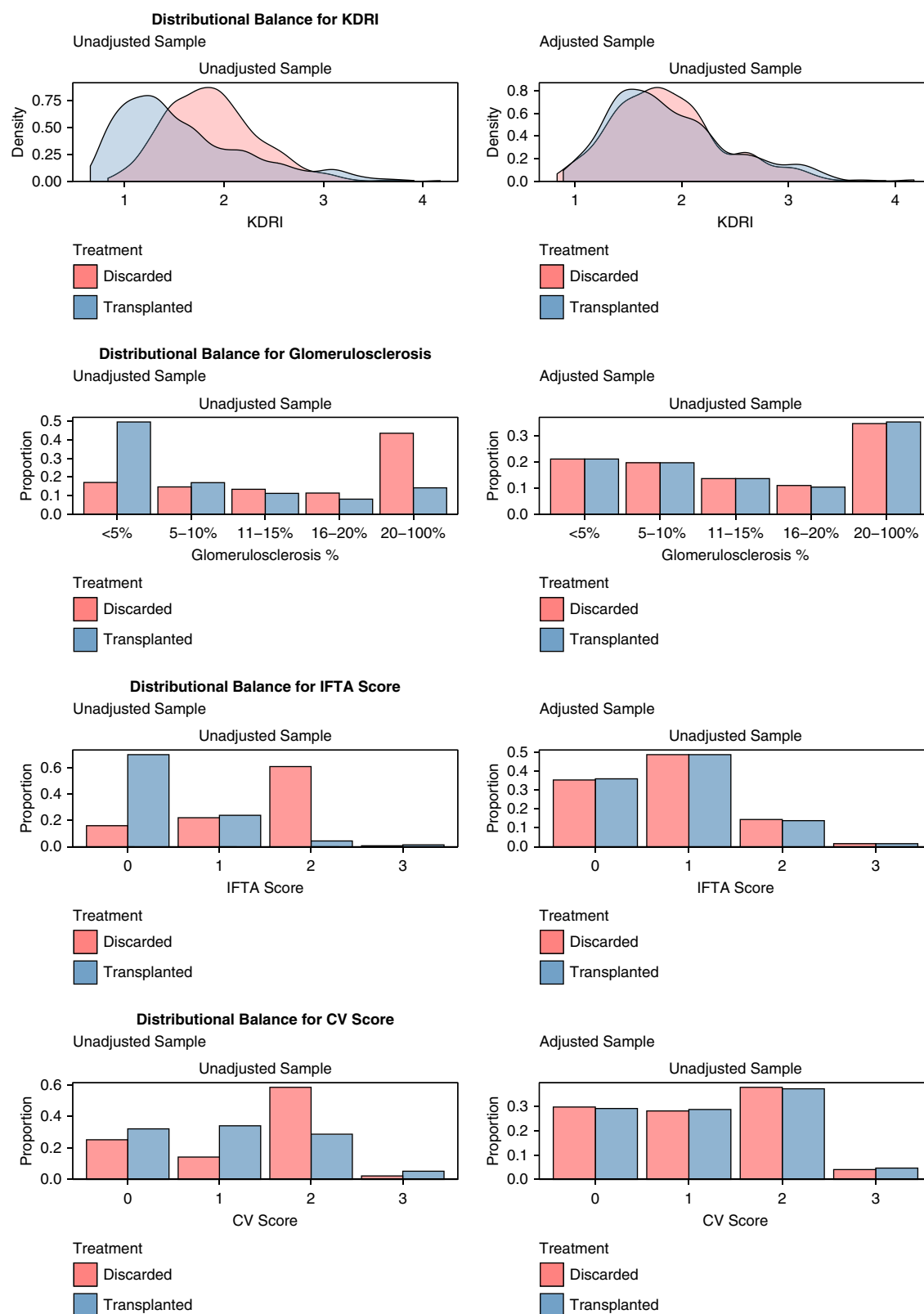


Figure 1. After matching, the kidneys were highly similar in terms of KDRI and histological features of glomerulosclerosis, interstitial fibrosis/tubular atrophy (IFTA), and arteriosclerosis (CV). The figure shows the distributional balance of the KDRI score and kidney histology before and after matching kidneys discarded in the United States to similar kidneys transplanted in the French derivation cohort. Overall, a total of 493 (45%) United States kidneys discarded due to histology were matched to kidneys transplanted in France.

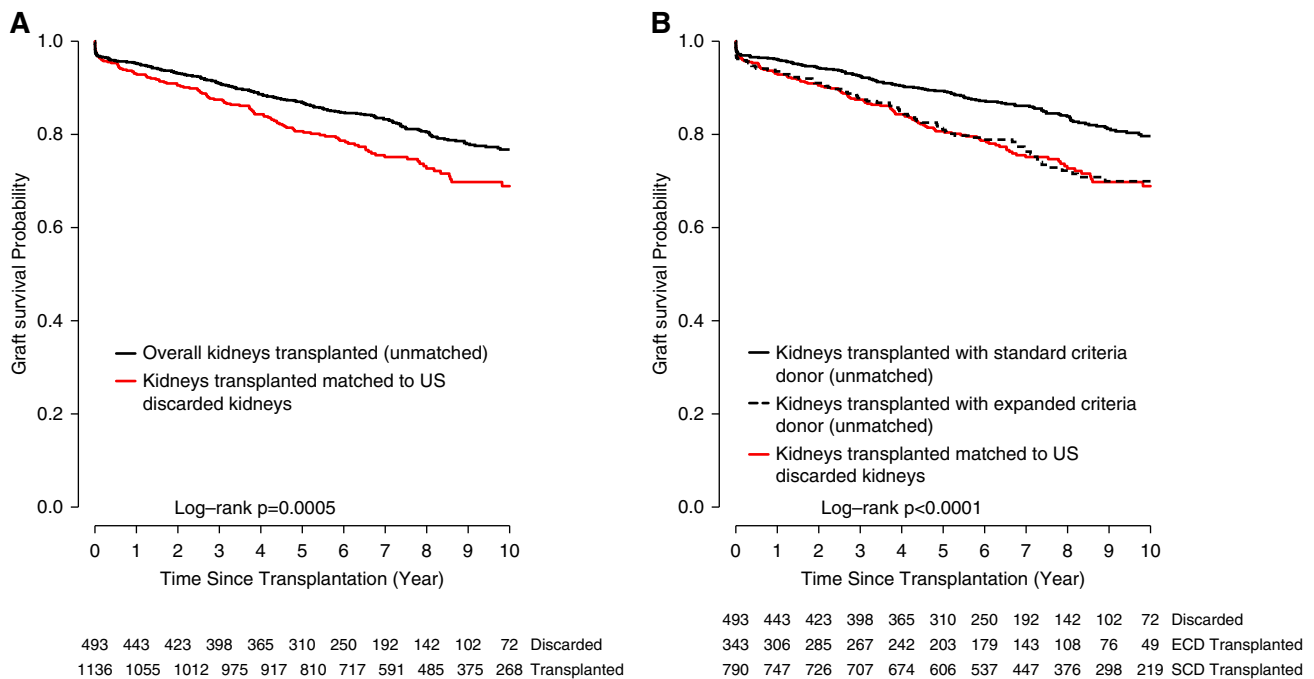


Figure 2. Kidneys transplanted in France matched to discarded US kidneys had survival similar to French expanded criteria donor kidneys. The figure shows Kaplan–Meier curves of allograft survival rates for kidneys transplanted in France matched and unmatched to United States discarded kidneys. (A) The allograft survival probability of the kidneys transplanted matched to United States discarded kidneys (red curve) to the rest of the population (unmatched kidneys; black curve). (B) The allograft survival probability of the matched kidneys (red curve) to the rest of the population according to the expanded criteria donor (ECD) status (kidneys transplanted with standard criteria donor [SCD], solid black curve; kidneys transplanted with ECD, dashed black curve). Among the recipients of the matched kidneys transplanted in France, 284 (57.61%) were men, 58 (11.76%) had diabetes, 39 (7.94%) were pre-emptive transplantations, 75 (15.21) had a prior kidney transplant, 107 (21.70%) had a DSA at the time of transplantation, the mean cold ischemia time was 18.99 ± 7.64 hours, and 163 (33.75%) had delayed graft function.

glomerulosclerosis score, IFTA Banff score, ah Banff score, and cv Banff score (Supplemental Figure 1). Supplemental Figure 2 depicts kidney allograft survival for the matched kidneys and unmatched kidneys. Allograft survival rates for kidneys transplanted matched to United States discarded kidneys were 93.7%, 80.8%, and 71.2% at 1, 5, and 10 years post-transplant, respectively (Supplemental Figure 2A). We then compared the allograft survival of French transplanted kidneys matched to United States discarded kidneys to overall expanded criteria donor kidneys and found similar allograft survival ($P>0.99$) (Supplemental Figure 2B).

DISCUSSION

Kidneys donated for transplantation often provide tremendous benefit to patients with end organ disease by extending survival and improving quality of life compared with dialysis.²⁹ As many countries have expanded the pool of allografts by accepting donors who are older with more comorbidities, major questions have emerged about whether pathologic examination of donated kidneys helps to better characterize organ quality or instead, drives serious inefficiencies in organ

allocation.³⁰ In this large multinational study, we demonstrate that kidney biopsies performed for decision making in the allocation process did not improve the prediction of allograft survival beyond routinely available clinical attributes of deceased donors and recipients. Next, we provide evidence that many kidneys discarded in the United States due to biopsy findings likely could have been transplanted and improved the lives of patients who are waitlisted. Specifically, we matched 45% of those discarded kidneys to kidneys with very similar pathologic findings transplanted in France and found that approximately 70% of these matched kidneys were functioning at 10 years. These analyses raise substantial doubts about the value of using procurement biopsies to guide kidney acceptance decisions and reveal a straightforward opportunity to utilize many kidneys currently being discarded in the United States.

These robust findings about the prognostic value of renal histology should challenge clinical practice at many transplant centers because approximately half of deceased donor kidneys in the United States undergo allocation biopsy. Our results are bolstered by long-standing concerns about the quality of the samples and the interpretation of biopsies obtained during allocation.⁴ Allocation biopsies are often wedge biopsies,

prepared by frozen section, and/or interpreted by pathologists without specialized kidney histology training. Additionally, biopsies may be vulnerable to sampling “error” if not representative of the whole organ. Despite these concerns, the act of biopsy has a strong relationship with kidney discard. Marrero *et al.*³¹ examined United States deceased donor kidneys from 2000 to 2012 and found that a biopsy—regardless of pathologic results—was independently associated with more than two times the odds of discard.

On the other hand, the pretransplant biopsies from European centers that were examined in our study are less susceptible to these quality concerns. The biopsies from the development and validation cohorts were obtained in a standardized fashion at academic transplant centers and then, processed and reviewed by the dedicated renal pathologists at those centers as part of usual care and without the time pressure of biopsies obtained and interpreted during organ allocation. Even in this setting of standardized kidney biopsies read by experts, however, day 0 donor biopsies added no predictive accuracy in the European derivation and validation cohorts. We also note that although some studies have asserted that wedge biopsies systematically overestimate the degree of kidney glomerulosclerosis, such overestimation would actually lead our study to underestimate the predicted graft survival of the matched European kidneys and reinforce our conclusions that viable kidneys are being discarded.^{15,32}

Our results suggest a viable pathway to bring transplantation to more patients in the United States through better stewardship of the resource of donated kidneys. Using advanced matching methods, we found that 45% of United States kidneys discarded for abnormal histology in the United States were highly similar in terms of the KDRI quality score and histology to kidneys actually transplanted in France. The ability to find matches for 45% of the discarded kidneys supports our clinical intuition that not every procured kidney would provide acceptable transplant outcomes. Some kidneys—for a variety of reasons related to function or disease—warrant discard. Not surprisingly, the overall pool of kidneys discarded in the United States was more likely than French transplanted kidneys to have higher-risk features, such as advanced donor age and diabetes, in addition to higher histopathologic grades of chronic injury. Yet, the recipients of kidneys matched on KDRI and histology that were transplanted in France enjoyed allograft survival that would likely be acceptable to some of the 95,000 patients on the United States kidney waiting list. In particular, well-informed individuals who are older or have diabetes (a large percentage of United States patients who are wait listed) might derive substantial benefits from accepting kidneys with histologic abnormalities compared with enduring the elevated risks of death or health deterioration caused by chronic dialysis.^{33–36} A reduction in allocation biopsies may benefit transplant systems in other ways, such as reducing cold ischemia time and costs that are driven by awaiting histologic results.³⁷

Transplant professionals may ask why existing tools to assess donated kidneys are so limited in their ability to forecast post-transplant outcomes. Indeed, the C statistics of KDRI and of all our models show only modest predictive accuracy. In addition to the low quality of allograft biopsies, other barriers may include excessive reliance on low-granularity cross-sectional data obtained from the donor. The field of kidney transplantation is in serious need of better tools to predict allograft outcomes. We propose that meaningful improvement in characterizing the quality of donor kidneys may require novel sources of data—such as more extensive and longitudinal information about donor health and kidney function, advanced imaging methods, or deep molecular and genetic phenotyping—all of which might be accomplished during the donor’s terminal hospitalization.³⁸

This study’s strengths include highly detailed data about kidney transplant recipients from European centers where preimplantation biopsies are prospectively performed but do not guide the decision-making process for allocating kidneys. We leveraged a comprehensive database of discarded kidneys in the United States. Although prior investigators have highlighted the limitations of usual care procurement biopsies in predicting allograft outcomes, our study advances the field by revealing the plausible counterfactual outcomes if similar kidneys were actually transplanted in European centers and showing the size of the lost opportunity to the large population of patients who are wait listed.^{9,15,39,40} We also acknowledge limitations. First, because of differences in the health care systems, the allograft survival in a European transplant population may be different from the survival that United States centers could achieve if they accepted similar kidneys.^{41,42} Second, the allograft outcomes achieved at academic European transplant centers may not be generalizable to less-experienced centers elsewhere. Third, it is possible that some discarded kidneys had additional adverse characteristics—such as donor infections—that would have caused kidney discard regardless of histopathology. On the other hand, organ procurement organizations specifically reported discarding these kidneys because of biopsy findings, so it is likely that biopsy findings were a central feature of the discard decision. Additionally, we matched on KDRI; prior studies suggest that KDRI is a very robust predictor of kidney discard, even if KDRI’s predictive accuracy for allograft survival is only modest.^{7,31} Fourth, our study is observational and may be subject to unmeasured confounding. A randomized trial of the use of biopsies in organ acceptance—such as the Pre-Implantation Trial of Histopathology In Renal Allografts (PITHIA) trial in the United Kingdom—could overcome this problem, although trials typically also have limitations related to generalizability, and our high-quality observational data will complement any trial findings.⁴³ Fifth, although external validation in the Belgian cohort provides additional evidence against the incremental predictive value of biopsies, the Belgian cohort has some limitations; namely, this cohort did not have the same diversity in histologic findings as the

French cohort, and the Belgian centers only rarely transplanted patients with pretransplant DSA. Finally, it is possible that we were unable to detect a small incremental predictive benefit related to kidney pathology due to our sample size. However, transplant clinicians and organ procurement organizations know well that biopsies create expense, create logistical difficulties with allocation, and prolong cold ischemia time. As a result, biopsies need to add substantial value to justify all of these disadvantages.

In a large, well-phenotyped, multinational cohort, kidney biopsy results from deceased donor kidneys did not improve prediction of allograft survival beyond usual donor attributes. We also determined that about half of kidneys discarded due to biopsy findings could have instead been transplanted with acceptable 10-year outcomes. These results add to a growing body of evidence that a ready opportunity exists for United States centers to increase the number of kidney transplants by adopting evidence-based standards for organ acceptance.^{7,44} This report provides a strong rationale for organ procurement organizations to reduce the routine practice of obtaining biopsies of deceased donor kidneys. Likewise, transplant center staff should view these biopsy results as limited in their ability to contribute meaningful information in their overall assessment of kidney quality.

DISCLOSURES

C. Lefaucheur reports consultancy agreements with CSL Behring and Hansa Biopharm; research funding from CSL Behring and MSDAvenir; and other interests/relationships as European Society for Organ Transplant member, Principal Investigator (PI) of the of the Horizon 2020 European Commission project, and Société Francophone de Transplantation member. C. Legendre reports consultancy agreements with CSL Behring and Hansa Medical; honoraria from Alexion, Astellas, Novartis, and Sandoz; scientific advisor or membership for Hansa Medical; and speakers bureau for Hansa Medical. P. Reese reports consultancy agreements with Collaborative Healthcare Research & Data Analytics (COHRDATA); epidemiology consultation on pharmacoeconomics analyses related to therapies for patients on dialysis; research funding as coprincipal investigator for studies of medication adherence (to any statin) funded by CVS Caremark and the National Institutes of Health and as coprincipal investigator for investigator-initiated demonstration trials funded by AbbVie and Merck involving transplantation of HCV-infected organs; honoraria from talks at academic centers or academic consortia; scientific advisor or membership as Associate Editor for *American Journal of Kidney Diseases* and in the United Network for Organ Sharing, including the role of past Chair and current member of the Ethics Committee; and other interests/relationships include legal consultation. All remaining authors have nothing to disclose.

FUNDING

This work was supported in part by French national research agency Institut National de la Santé et de la Recherche Médicale Action Thématique Incitative sur Program (ATIP) Avenir and Fondation Bettencourt Schueller. The work of V. Potluri was supported by National Kidney Foundation Satellite Dialysis Clinical Investigator Grant. This work was supported in part by Health Resources and Services Administration contract 234-2005-37011C. V. Potluri

reports grants from National Kidney Foundation, during the conduct of the study.

ACKNOWLEDGMENTS

The interpretation and reporting of these data are the responsibility of the author(s) and in no way should be seen as an official policy of or interpretation by the Agence de la Biomedicine (which maintains the CRISTAL database) or the French government. The content is the responsibility of the authors alone and does not necessarily reflect the views or policies of the Department of Health and Human Services, nor does mention of trade names, commercial products, or organizations imply endorsement by the US Government. Preliminary results were presented at the 2019 Annual Meeting of the American Society of Nephrology in Washington, DC.

O. Aubert, A. Loupy, and P. Reese designed the study; O. Aubert, G. Divard, E. Huang, A. Loupy, V. Potluri, M. Raynaud, and P. Reese analyzed the data; O. Aubert, Y. Bouatou, A. Bouquegneau, G. Divard, J.-P. Empana, D. Glotz, E. Huang, S. Jordan, X. Jouven, D. Kuypers, C. Lefaucheur, C. Legendre, A. Loupy, M. Naesens, V. Potluri, M. Raynaud, P. Reese, and A. Vo interpreted the data; O. Aubert, A. Loupy, V. Potluri, and P. Reese wrote the manuscript; and O. Aubert, Y. Bouatou, A. Bouquegneau, G. Divard, J.-P. Empana, D. Glotz, E. Huang, S. Jordan, X. Jouven, D. Kuypers, C. Lefaucheur, C. Legendre, A. Loupy, M. Naesens, V. Potluri, M. Raynaud, P. Reese, and A. Vo edited the manuscript.

SUPPLEMENTAL MATERIAL

This article contains the following supplemental material online at <http://jasn.asnjournals.org/lookup/suppl/doi:10.1681/ASN.2020040464/-/DCSupplemental>.

Supplemental Figure 1. Distributional balance of the donor's age and biopsy characteristics before and after matching French transplanted kidneys with kidneys discarded in the United States due to biopsy findings.

Supplemental Figure 2. Kaplan–Meier curves of allograft survival rates for kidneys transplanted in France and kidneys transplanted matched to United States discarded kidneys using donor's age instead of KDRI for matching.

Supplemental Material. Methods, interpretation of statistical analyses, and kidney donor risk index calculation.

Supplemental Table 1. Association of day 0 biopsy results with kidney allograft loss.

Supplemental Table 2. Factors associated with kidney allograft loss in univariate analysis in the validation cohort.

Supplemental Table 3. Baseline characteristics of the United States discarded kidneys matched to transplanted French kidneys on the basis of histology and KDRI and the unmatched United States and French kidneys.

Supplemental Table 4. Distribution of KDRI and biopsy characteristics in the pre- and postmatch cohorts.

Supplemental Table 5. Determinants of nondeath-censored kidney allograft loss in the derivation cohort: univariate and multivariable analyses.

Supplemental Table 6. Distribution of donor age and biopsy characteristics in the pre- and postmatch cohorts.

Supplemental Table 7. Baseline characteristics of the United States discarded kidneys matched with transplanted French kidneys on the basis of histology and the donor's age and the unmatched transplanted French kidneys.

REFERENCES

1. Organ Procurement and Transplantation Network: National Data: Overall by Organ. Available at: <https://optn.transplant.hrsa.gov/data/view-data-reports/national-data/#>. Accessed December 6, 2019

2. Cooper M, Formica R, Friedewald J, Hirose R, O'Connor K, Mohan S, et al.: Report of National Kidney Foundation Consensus Conference to decrease kidney discards. *Clin Transplant* 33: e13419, 2019
3. Reese PP, Harhay MN, Abt PL, Levine MH, Halpern SD: New solutions to reduce discard of kidneys donated for transplantation. *J Am Soc Nephrol* 27: 973–980, 2016
4. Mohan S, Chiles MC, Patzer RE, Pastan SO, Husain SA, Carpenter DJ, et al.: Factors leading to the discard of deceased donor kidneys in the United States. *Kidney Int* 94: 187–198, 2018
5. Trump DJ: Executive order on Advancing American Kidney Health, 2019. Available at: <https://www.whitehouse.gov/presidential-actions/executive-order-advancing-american-kidney-health/>. Accessed October 29, 2020
6. Kasiske BL, Stewart DE, Bista BR, Salkowski N, Snyder JJ, Israni AK, et al.: The role of procurement biopsies in acceptance decisions for kidneys retrieved for transplant. *Clin J Am Soc Nephrol* 9: 562–571, 2014
7. Aubert O, Reese PP, Audry B, Bouatou Y, Raynaud M, Viglietti D, et al.: Disparities in acceptance of deceased donor kidneys between the United States and France and estimated effects of increased US acceptance. *JAMA Intern Med* 179: 1365–1374, 2019
8. Massie AB, Luo X, Chow EK, Alejo JL, Desai NM, Segev DL: Survival benefit of primary deceased donor kidney transplantation with high-KDPI kidneys. *Am J Transplant* 14: 2310–2316, 2014
9. Carpenter D, Husain SA, Brennan C, Batal I, Hall IE, Santoriello D, et al.: Procurement biopsies in the evaluation of deceased donor kidneys. *Clin J Am Soc Nephrol* 13: 1876–1885, 2018
10. Lentine KL, Naik AS, Schnitzler MA, Randall H, Wellen JR, Kasiske BL, et al.: Variation in use of procurement biopsies and its implications for discard of deceased donor kidneys recovered for transplantation. *Am J Transplant* 19: 2241–2251, 2019
11. Cockfield SM, Moore RB, Todd G, Solez K, Gourishankar S: The prognostic utility of deceased donor implantation biopsy in determining function and graft survival after kidney transplantation. *Transplantation* 89: 559–566, 2010
12. Remuzzi G, Grinyò J, Ruggerenti P, Beatini M, Cole EH, Milford EL, et al.; Double Kidney Transplant Group (DKG): Early experience with dual kidney transplantation in adults using expanded donor criteria. *J Am Soc Nephrol* 10: 2591–2598, 1999
13. MuniVenkatappa RB, Schweitzer EJ, Papadimitriou JC, Drachenberg CB, Thom KA, Perencevich EN, et al.: The Maryland aggregate pathology index: A deceased donor kidney biopsy scoring system for predicting graft failure. *Am J Transplant* 8: 2316–2324, 2008
14. De Vusser K, Lerut E, Kuypers D, Vanrenterghem Y, Jochmans I, Monbaliu D, et al.: The predictive value of kidney allograft baseline biopsies for long-term graft survival. *J Am Soc Nephrol* 24: 1913–1923, 2013
15. Wang CJ, Wetmore JB, Crary GS, Kasiske BL: The donor kidney biopsy and its implications in predicting graft outcomes: A systematic review. *Am J Transplant* 15: 1903–1914, 2015
16. Maenosono R, Tullius SG: Saving lives by saving kidneys for transplant [published online ahead of print August 26, 2019]. *JAMA Intern Med* 1001/jamainternmed.2019.2609
17. Organ Procurement and Transplantation Network (OPTN). Available at: <https://optn.transplant.hrsa.gov/data/about-data/>. Accessed October 29, 2020
18. Haas M, Sis B, Racusen LC, Solez K, Glotz D, Colvin RB, et al.; Banff meeting report writing committee: Banff 2013 meeting report: Inclusion of c4d-negative antibody-mediated rejection and antibody-associated arterial lesions [published correction appears in *Am J Transplant* 15: 2784, 2015 10.1111/ajt.13517]. *Am J Transplant* 14: 272–283, 2014
19. Rao PS, Schaubel DE, Guidinger MK, Andreoni KA, Wolfe RA, Merion RM, et al.: A comprehensive risk quantification score for deceased donor kidneys: The kidney donor risk index. *Transplantation* 88: 231–236, 2009
20. Lamb KE, Lodhi S, Meier-Kriesche HU: Long-term renal allograft survival in the United States: A critical reappraisal. *Am J Transplant* 11: 450–462, 2011
21. Efron B: Bootstrap methods: Another look at the jackknife. *Ann Stat* 7: 1–26, 1979
22. Rosenbaum PR: Optimal matching for observational studies. *J Am Stat Assoc* 84: 1024–1032, 1989
23. Austin PC: Optimal caliper widths for propensity-score matching when estimating differences in means and differences in proportions in observational studies. *Pharm Stat* 10: 150–161, 2011
24. Zubizarreta J: Using mixed integer programming for matching in an observational study of kidney failure after surgery. *J Am Stat Assoc* 107: 1360–1371, 2012
25. Austin PC: Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples. *Stat Med* 28: 3083–3107, 2009
26. de Los Angeles Resa M, Zubizarreta JR: Evaluation of subset matching methods and forms of covariate balance. *Stat Med* 35: 4961–4979, 2016
27. Zubizarreta J, Kilcioglu C, Vielma J: Package 'designmatch': Matched samples that are balanced and representative by design, 2018. Available at: <https://cran.r-project.org/web/packages/designmatch/designmatch.pdf>. Accessed October 26, 2019
28. Greifer N: Cobalt: Covariate balance tables and plots, 2019. Available at: <https://cran.r-project.org/web/packages/cobalt/index.html>. Accessed October 26, 2019
29. Wolfe RA, Ashby VB, Milford EL, Ojo AO, Ettenger RE, Agodoa LY, et al.: Comparison of mortality in all patients on dialysis, patients on dialysis awaiting transplantation, and recipients of a first cadaveric transplant. *N Engl J Med* 341: 1725–1730, 1999
30. Stewart DE, Garcia VC, Rosendale JD, Klassen DK, Carrico BJ: Diagnosing the decades-long rise in the deceased donor kidney discard rate in the United States. *Transplantation* 101: 575–587, 2017
31. Marrero WJ, Naik AS, Friedewald JJ, Xu Y, Hutton DW, Lavieri MS, et al.: Predictors of deceased donor kidney discard in the United States. *Transplantation* 101: 1690–1697, 2017
32. Muruve NA, Steinbecker KM, Luger AM: Are wedge biopsies of cadaveric kidneys obtained at procurement reliable? *Transplantation* 69: 2384–2388, 2000
33. Schold J, Srinivas TR, Sehgal AR, Meier-Kriesche HU: Half of kidney transplant candidates who are older than 60 years now placed on the waiting list will die before receiving a deceased-donor transplant. *Clin J Am Soc Nephrol* 4: 1239–1245, 2009
34. Merion RM, Ashby VB, Wolfe RA, Distant DA, Hulbert-Shearon TE, Metzger RA, et al.: Deceased-donor characteristics and the survival benefit of kidney transplantation. *JAMA* 294: 2726–2733, 2005
35. Cohen JB, Potluri V, Porrett PM, Chen R, Roselli M, Shults J, et al.: Leveraging marginal structural modeling with Cox regression to assess the survival benefit of accepting vs declining kidney allograft offers. *Am J Transplant* 19: 1999–2008, 2019
36. Bae S, Massie AB, Thomas AG, Bahn G, Luo X, Jackson KR, et al.: Who can tolerate a marginal kidney? Predicting survival after deceased donor kidney transplant by donor-recipient combination. *Am J Transplant* 19: 425–433, 2019
37. Kadatz M, Gill JS: Compelling evidence of the need for policy change to decrease deceased donor kidney discard in the United States: Waste not want less. *Clin J Am Soc Nephrol* 13: 13–15, 2018
38. Moeckli B, Sun P, Lazeyras F, Morel P, Moll S, Pascual M, et al.: Evaluation of donor kidneys prior to transplantation: An update of current and emerging methods. *Transpl Int* 32: 459–469, 2019
39. Azancot MA, Moreso F, Salcedo M, Cantarell C, Perello M, Torres IB, et al.: The reproducibility and predictive value on outcome of renal biopsies from expanded criteria donors. *Kidney Int* 85: 1161–1168, 2014
40. Pokorná E, Vitko S, Chadimová M, Schück O, Ekberg H: Proportion of glomerulosclerosis in procurement wedge renal biopsy cannot alone

- discriminate for acceptance of marginal donors. *Transplantation* 69: 36–43, 2000
41. Wang JH, Skeans MA, Israni AK: Current status of kidney transplant outcomes: Dying to survive. *Adv Chronic Kidney Dis* 23: 281–286, 2016
 42. Merion RM, Goodrich NP, Johnson RJ, McDonald SP, Russ GR, Gillespie BW, et al.: Kidney transplant graft outcomes in 379 257 recipients on 3 continents. *Am J Transplant* 18: 1914–1923, 2018
 43. Ayorinde JO, Summers DM, Pankhurst L, Laing E, Deary AJ, Hemming K, et al.: Preimplantation Trial of Histopathology In renal Allografts (PITHIA): A stepped-wedge cluster randomised controlled trial protocol. *BMJ Open* 9: e026166, 2019
 44. Ibrahim M, Vece G, Mehew J, Johnson R, Forsythe J, Klassen D, et al.: An international comparison of deceased donor kidney utilization: What can the United States and the United Kingdom learn from each other? *Am J Transplant* 20: 1309–1322, 2020

AFFILIATIONS

¹Université de Paris, Institut National de la Santé et de la Recherche Médicale U970, Paris Translational Research Centre for Organ Transplantation, Paris, France

²Renal-Electrolyte and Hypertension Division, Department of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania

³Center for Clinical Epidemiology and Biostatistics, Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania

⁴Department of Kidney Transplantation, Necker Hospital, Assistance Publique—Hôpitaux de Paris, Paris, France

⁵Department of Nephrology and Renal Transplantation, University Hospitals Leuven, Leuven, Belgium

⁶Division of Nephrology, Department of Medicine, Comprehensive Transplant Center, Cedars Sinai Medical Center, West Hollywood, California

⁷Department of Nephrology, Dialysis and Transplantation, Centre Hospitalier Universitaire de Liege, Liege, Belgium

⁸Department of Nephrology and Kidney Transplantation, Saint-Louis Hospital, Assistance Publique—Hôpitaux de Paris, Paris, France

⁹Cardiology and Heart Transplant Department, Pitié-Salpêtrière Hospital, Assistance Publique—Hôpitaux de Paris, Paris, France

Supplement

1. SUPPLEMENTARY METHODS

- 1.1. Interpretation of statistical analyses
- 1.2. Kidney Donor Risk Index calculation

2. SUPPLEMENTARY TABLES

Appendix Table 1: Association of day-0 biopsy results with kidney allograft loss (derivation cohort)

Appendix Table 2: Factors associated with kidney allograft loss in univariate analysis in the validation cohort.

Appendix Table 3: Baseline characteristics of the US discarded kidneys matched to transplanted French kidneys based on histology and the KDRI, and the unmatched US and French kidneys.

Appendix Table 4: Distribution of KDRI and biopsy characteristics in the pre and post-match cohorts

Appendix Table 5: Determinants of non-death censored kidney allograft loss in the derivation cohort: univariate and multivariable analyses

Appendix Table 6: Distribution of donor age and biopsy characteristics in the pre and post-match cohorts

Appendix Table 7: Baseline characteristics of the US discarded kidneys matched with transplanted French kidneys based on histology and the donor's age and the unmatched transplanted French kidneys.

3. SUPPLEMENTARY FIGURES

Appendix Figure 1: Distributional balance of the donor's age and biopsy characteristics before and after matching French transplanted kidneys with kidneys discarded in the US due to biopsy findings..

Appendix Figure 2: Kaplan-Meier curves of allograft survival rates for kidneys transplanted in France and kidneys transplanted matched to US discarded kidneys using donor's age instead of KDRI for matching.

1. SUPPLEMENTARY METHODS

1.1. Interpretation of statistical analyses

The aim of discrimination is to distinguish between patients who experience an event and those who do not. The C-index estimates the proportion of all pairwise patient combinations from the sample data whose survival time can be ordered such that the patient with the highest predicted survival is the one who actually survived longer (discrimination). The C-index ($0 \leq C \leq 1$) is the probability of concordance between predicted and observed survival, with C-index=0.5 for random predictions and C-index=1 for a perfectly discriminating model.

1.2. Calculation of the Kidney Donor Risk Index (KDRI) and the Kidney Donor Profile Index (KDPI)

The KDRI and KDPI are scores derived from 10 deceased donor variables and predict risk of kidney allograft failure after transplantation. Lower values for the KDRI and KDPI indicate kidneys with better projected allograft survival. These indices were developed for the purpose of enabling clinicians to try to make rough assessments of allograft quality and graft failure risk across donors with different attributes.¹¹ A guidance document from the United Network for Organ Sharing states “The Kidney Donor Profile Index (KDPI) is a numerical measure that combines ten donor factors, including clinical parameters and demographics, to summarize into a single number the quality of deceased donor kidneys relative to other recovered kidneys.”²⁶

The KDRI score for any kidney allograft estimates the risk of failure for that allograft compared to a kidney from a reference donor. This reference donor is defined as 40 years old, non-African-American, 170 cm tall, weighing 80 kg, with a creatinine level of 1 mg/dL, as well as negative history of hypertension, diabetes and hepatitis C virus serostatus. Notably, race/ethnicity for organ donors cannot be collected and reported according to French national bioethics rules. As a result, as we entered “non-black” as the race for all French donors when calculating KDRI. This approach to calculating the KDRI of the French pool of donated kidneys will have the net effect of slightly over-estimating the quality of these organs. Nonetheless, as shown in the results, French transplant centers are still much more likely to accept kidneys with the highest KDRI scores (i.e. lowest quality kidneys) compared to US centers.

The KDRI is not formally used in kidney allocation in France, but donor characteristics used to calculate the scores (with the exception of donor race) are presented to transplant centers with organ offers.

2. SUPPLEMENTARY TABLES

Appendix Table 1A: Association of day-0 biopsy results with kidney allograft loss: univariate analysis.

			Number of patients	Number of events	HR	95% CI	P
Day-0 biopsy ^a	Percentage of glomerulosclerosis	0-5%	818	143	1	-	
		6-10%	278	47	1.014	(0.730 – 1.410)	
		11-15%	180	49	1.817	(1.313 – 2.515)	
		16-20%	129	35	1.734	(1.198 – 2.510)	
		> 20%	224	61	1.828	(1.353 – 2.468)	<0.0001
	Interstitial fibrosis and tubular atrophy	Low score: 0 or 1	1,537	306	1	-	
		High score: ≥ 2	92	29	2.100	(1.433 – 3.078)	0.0001
	Arteriolar hyalinosis	Low score: 0 or 1	1,302	249	1	-	
		High score: ≥ 2	322	84	1.487	(1.161 – 1.904)	0.0017
	Arteriosclerosis	Low score: 0 or 1	1,083	200	1	-	
		High score: ≥ 2	546	135	1.494	(1.200 – 1.859)	0.0003

Appendix Table 1B: Determinants of kidney allograft loss in multivariate analysis with

addition of day-0 biopsy results

		Number of patients	Number of events	HR	95% CI	P
KDRI (log transformation)		1,540	312	2.500	(1.839 - 3.397)	<0.0001
Prior kidney transplant	No	1,270	244	1	-	
	Yes	270	68	1.338	(1.007 - 1.778)	0.0447
Anti-HLA DSA on day 0	No	1,206	222	1	-	
	Yes	334	90	1.761	(1.362 - 2.277)	<0.0001
Interstitial fibrosis and tubular atrophy	Low score: 0 or 1	1,450	284	1	-	
	High score: \geq 2	90	28	1.507	(1.004 - 2.263)	0.0480

Abbreviations: CI, Confidence interval; HR, Hazard ratio; ECD, Expanded criteria donor.; HLA, human leucocyte antigen; KDRI, Kidney Donor Risk Index

Appendix Table 2: Factors associated with kidney allograft loss in univariate analysis in the validation cohort.

			Number of patients	Number of events	HR	95% CI	P
Baseline recipients characteristics	Age (per 1-yr increment)		1,107	163	1.012	(0.999 – 1.025)	0.0604
Baseline donor characteristics	Age (per 1-yr increment)		1,096	163	1.017	(1.005 – 1.029)	0.0043
	Gender	Female	493	79	1	-	
		Male	607	84	0.856	(0.630 – 1.164)	0.6297
	Death of CV disease	No	528	73	1	-	
		Yes	579	90	1.132	(0.831 – 1.541)	0.4321
	Hypertension	No	759	96	1	-	
		Yes	192	35	1.451	(0.985 – 2.138)	0.0594
	ECD	No	825	109	1	-	
		Yes	282	54	1.706	(1.230 – 2.366)	0.0014
	KDRI* (Log transformation)		888	129	3.238	(1.804 – 5.814)	0.0001
Transplant characteristics	Prior kidney	No	953	134	1	-	
	Transplant	Yes	154	29	1.315	(0.880 – 1.965)	0.1808
Immunologic factor	No. of HLA A/B/DR mismatches		1,107	163	1.134	(0.998 – 1.288)	0.0529

Abbreviations: CI, Confidence interval; HR, Hazard ratio; CV, Cardio-vascular; ECD, Expanded criteria donor; DSA, Donor-specific anti-HLA antibodies; HLA, human leucocyte antigen; KDRI, Kidney Donor Risk Index

* The KDRI score was calculated based on the following donor parameters: age, height, weight, history of hypertension, history of diabetes, cause of death (cerebral stroke), serum creatinine at donation, hepatitis C virus (HCV) serostatus, and donation after circulatory death status.

Appendix Table 3: Baseline characteristics of the US discarded kidneys matched to transplanted French kidneys based on histology and the KDRI, and the unmatched US and French kidneys

	Matched discarded kidneys (US) (n=493)		Matched transplanted kidneys (France) (n=493)		Unmatched discarded kidneys (US) (n=610)		Unmatched transplanted kidneys (France) (n=1,136)		p [*]
	n		n		n		n		
Donor's characteristics									
Donor age (years), mean (SD)	493	55.16 (11.88)	493	61.73 (11.33)	610	55.64 (10.16)	1,136	48.65 (17.08)	<0.0001
Donor male gender , No. (%)	493	236 (47.87)	493	268 (54.36)	610	341 (55.90)	1,136	690 (60.74)	<0.0001
Height (cm), mean (SD)	493	169.17 (10.71)	493	168.44 (9.19)	610	169.08 (10.40)	1,135	170.89 (10.69)	<0.0001
Weight (kg), mean (SD)	493	84.86 (22.38)	493	74.64 (16.03)	610	86.04 (22.36)	1,135	73.44 (15.35)	<0.0001
BMI , mean (SD)	493	29.62 (7.31)	493	26.26 (5.15)	610	30.08 (7.38)	1,135	25.05 (4.52)	<0.0001
Hypertension , No. (%)	493	337 (68.36)	493	219 (44.42)	594	465 (78.28)	1,094	254 (23.22)	<0.0001
Diabetes mellitus , No. (%)	493	150 (30.43)	493	52 (10.55)	594	172 (28.96)	1,078	74 (6.86)	<0.0001
Donor serum creatinine (mg/dL), mean (SD)	493	1.82 (1.34)	493	1.05 (0.51)	610	1.95 (1.32)	1,120	1.02 (0.58)	<0.0001
Death from cerebrovascular disease , No. (%)	493	396 (80.32)	493	335 (67.95)	610	530 (86.89)	1,136	576 (50.70)	<0.0001
Expanded criteria donor , No. (%)	493	286 (58.01)	493	344 (69.78)	610	373 (61.15)	1,133	343 (30.27)	<0.0001
KDRI , mean (SD)	493	1.88 (0.53)	493	1.88 (0.55)	592	1.88 (0.42)	1,047	1.45 (0.63)	<0.0001

Data are the mean (SD) or n (%).
 Abbreviations: KDRI, Kidney Donor Risk Index; BMI, Body Mass Index.
^a χ^2 tests were conducted for the comparison of proportions, and ANOVA were conducted for the comparison of continuous variables.
^{*} Ethnicity for donors is not permitted to be collected per the French data protection regulations (CNIL)

Appendix Table 4: Distribution of KDRI and biopsy characteristics in the pre and post-match cohorts

	Pre-Match		Post-Match		Pre-Match	Post-Match
	Discarded	Transplanted	Discarded	Transplanted	Standardized	Standardized
	Kidneys	Kidneys	Kidneys	Kidneys	difference	difference
	(US)	(France)	(US)	(France)		
	N = 1085	N = 1540	N = 493	N = 493		
KDRI, mean (SD)	1.89 (0.47)	1.59 (0.64)	1.88 (0.53)	1.88 (0.55)	-0.5265	-0.0044
% Glomerulosclerosis						
0 – 5 (%)	185 (17.1%)	765 (49.7%)	104 (21.1%)	104 (21.1%)	0.3262	0
6 – 10 (%)	159 (14.7%)	261 (17%)	97 (19.7%)	97 (19.7%)	0.0229	0
11 – 15 (%)	145 (13.4%)	172 (11.2%)	67 (13.6%)	67 (13.6%)	-0.022	0
16 – 20 (%)	123 (11.3%)	124 (8.1%)	54 (11%)	51 (10.3%)	-0.0328	-0.0061
>20 (%)	473 (43.6%)	218 (14.2%)	171 (34.7%)	174 (35.3%)	-0.2944	0.0061
IFTA Score						
0	174 (16%)	1081 (70.2%)	174 (35.3%)	177 (35.9%)	0.5416	0.0061
1	240 (22.1%)	369 (24%)	240 (48.7%)	240 (48.7%)	0.0184	0
2	663 (61.1%)	68 (4.4%)	71 (14.4%)	68 (13.8%)	-0.5669	-0.0061
3	8 (0.7%)	22 (1.4%)	8 (1.6%)	8 (1.6%)	0.0069	0
CV Score						
0	273 (25.2%)	494 (32.1%)	147 (29.8%)	144 (29.2%)	0.0692	-0.0061
1	154 (14.2%)	524 (34%)	139 (28.2%)	142 (28.8%)	0.1983	0.0061
2	634 (58.4%)	442 (28.7%)	187 (37.9%)	184 (37.3%)	-0.2973	-0.0061
3	24 (2.2%)	80 (5.2%)	20 (4.1%)	23 (4.7%)	0.0298	0.0061

Abbreviations: SD, Standard deviation; KDRI, Kidney Donor Risk Index; IFTA, Interstitial Fibrosis and Tubular Atrophy; CV, Cardio-vascular

Appendix Table 5: Determinants of non-death censored kidney allograft loss in the derivation cohort: univariate and multivariable analyses

			Number of patients	Number of events	HR	95% CI	P
Univariate analysis							
Baseline recipient characteristics	Age (per 1-yr increment)		1,629	578	1.036	(1.029 – 1.043)	<0.0001
	Gender	Female	663	229	1	-	
		Male	966	349	1.054	(0.892 – 1.245)	0.5364
	Prior kidney transplant	No	1,346	456	1	-	
		Yes	283	122	1.312	(1.074 – 1.602)	0.0078
Baseline donor characteristics	Age (per 1-yr increment)		1,629	578	1.028	(1.022 – 1.033)	<0.0001
	Gender	Female	671	255	1	-	
		Male	958	323	0.862	(0.732 – 1.016)	0.0770
	Death of CV disease	No	718	199	1	-	
		Yes	911	379	1.632	(1.375 – 1.938)	<0.0001
	Hypertension	No	1,114	335	1	-	
		Yes	473	226	1.882	(1.589 – 2.229)	<0.0001
	Diabetes mellitus	No	1,445	491	1	-	
		Yes	126	62	1.671	(1.283 – 2.176)	0.0001
	Creatinine (mg/dL)	< 1.5	1,401	486	1	-	
		≥ 1.5	212	85	1.300	(1.032 – 1.637)	0.0257
	ECD	No	939	250	1	-	
		Yes	687	326	2.159	(1.830 – 2.547)	<0.0001
	KDRI* (Log transformation)		1,540	312	3.533	(2.843 – 4.392)	<0.0001
	Baseline Immunologic factors	No. of HLA A/B/DR mismatches		1,628	578	0.997	(0.934 – 1.063)
Anti-HLA DSA on Day 0		No	1,286	435	1	-	
		Yes	343	143	1.542	(1.275 – 1.866)	<0.0001
Multivariable analysis							
	Recipient’s age (per 1-yr increment)		1,540	543	1.018	(1.009 - 1.028)	<0.0001
	KDRI* (log transformation)		1,540	543	2.624	(1.932 - 3.563)	<0.0001
	Prior kidney transplant	No	1,270	428	1	-	
		Yes	270	115	1.4947	(1.199 - 1.863)	<0.0001
	Anti-HLA DSA on Day 0	No	1,206	405	1	-	
		Yes	334	138	1.546	(1.262 - 1.894)	<0.0001

Abbreviations: CI, Confidence interval; HR, Hazard ratio; CV, Cardio-vascular; ECD, Expanded criteria donor; DSA, Donor-specific anti-HLA antibodies; HLA, human leukocyte antigen; KDRI, Kidney Donor Risk Index

* The KDRI score was calculated based on the following donor parameters: age, height, weight, history of hypertension, history of diabetes, cause of death (cerebral stroke), serum creatinine at donation, hepatitis C virus (HCV) serostatus, and donation after circulatory death status.

Appendix Table 6: Distribution of donor age and biopsy characteristics in the pre and post-match cohorts*

	Pre-Match		Post-Match		Pre-Match	Post-Match
	Discarded	Transplanted	Discarded	Transplanted	Standardized	Standardized
	Kidneys	Kidneys	Kidneys	Kidneys	difference	difference
	(US)	(France)	(US)	(France)		
	N = 1103	N = 1629	N = 496	N = 496		
Donor Age in years, mean	55.4 (11)	52.6 (16.7)	56.1 (11.9)	56.2 (12.1)	-0.2003	0.0086
(SD)						
% Glomerulosclerosis						
0 – 5 (%)	190 (17.2%)	818 (50.2%)	114 (23%)	117 (23.6%)	0.3299	0.006
6 – 10 (%)	161 (14.6%)	278 (17.1%)	101 (20.4%)	100 (20.2%)	0.0247	-0.002
11 – 15 (%)	145 (13.2%)	180 (11.1%)	66 (13.3%)	69 (13.9%)	-0.021	0.006
16 – 20 (%)	124 (11.2%)	129 (7.9%)	60 (12.1%)	58 (11.7%)	-0.0332	-0.004
>20 (%)	483 (43.8%)	224 (13.8%)	155 (31.3%)	152 (30.7%)	-0.3004	-0.006
IFTA Score						
0	175 (15.9%)	1154 (70.8%)	175 (35.3%)	178 (35.9%)	0.5498	0.006
1	241 (21.9%)	383 (23.5%)	241 (48.6%)	242 (48.8%)	0.0166	0.002
2	679 (61.6%)	69 (4.2%)	72 (14.5%)	69 (13.9%)	-0.5732	-0.006
3	8 (0.7%)	23 (1.4%)	8 (1.6%)	7 (1.4%)	0.0069	-0.002
CV Score						
0	274 (24.8%)	523 (32.1%)	152 (30.7%)	149 (30%)	0.0726	-0.006
1	159 (14.4%)	560 (34.4%)	129 (26%)	132 (26.6%)	0.1996	0.006
2	644 (58.4%)	463 (28.4%)	197 (39.7%)	194 (39.1%)	-0.2996	-0.006
3	26 (2.4%)	83 (5.1%)	18 (3.6%)	21 (4.3%)	0.0274	0.006

Abbreviations: SD, Standard deviation; KDRI, Kidney Donor Risk Index; IFTA, Interstitial Fibrosis and Tubular Atrophy; CV, Cardio-vascular

*Sensitivity analysis – matching on donor age instead of the KDRI

Appendix Table 7: Baseline characteristics of the US discarded kidneys matched with transplanted French kidneys based on histology and the donor's age and the unmatched transplanted French kidneys*

	Matched discarded kidneys (US) (n=496)		Matched transplanted kidneys (France) (n=496)		Unmatched kidneys (US) (n=607)		Unmatched kidneys (France) (n=1,133)		p [*]
	n		n		n		n		
Donor's characteristics									
Donor age (years), mean (SD)	496	56.06 (11.95)	496	56.20 (12.05)	607	54.91 (10.06)	1,133	51.03 (18.13)	<0.0001
Donor male gender , No. (%)	496	233 (46.98)	496	313 (63.10)	607	344 (56.67)	1,133	645 (56.93)	<0.0001
Height (cm), mean (SD)	496	168.95 (10.50)	496	170.73 (9.10)	607	169.26 (10.57)	1,132	169.90 (10.80)	0.0305
Weight (kg), mean (SD)	496	83.95 (22.07)	496	75.94 (15.16)	607	86.79 (22.55)	1,132	72.87 (15.66)	<0.0001
BMI , mean (SD)	496	29.39 (7.28)	496	26.04 (4.93)	607	30.27 (7.40)	1,132	25.15 (4.65)	<0.0001
Hypertension , No. (%)	493	338 (68.56)	487	178 (36.55)	594	464 (78.11)	1,100	295 (26.82)	<0.0001
Diabetes mellitus , No. (%)	491	146 (29.74)	481	50 (10.40)	596	176 (29.53)	1,090	76 (6.97)	<0.0001
Donor serum creatinine (mg/dL), mean (SD)	496	1.76 (1.26)	493	1.09 (0.57)	607	2.00 (1.37)	1,120	1.01 (0.55)	<0.0001
Death from cerebrovascular disease , No. (%)	496	401 (80.85)	496	296 (59.68)	607	525 (86.49)	1,133	615 (54.28)	<0.0001
Expanded criteria donor , No. (%)	496	297 (59.88)	494	256 (51.82)	607	362 (59.64)	1,132	431 (38.07)	<0.0001
KDRI , mean (SD)	491	1.91 (0.54)	473	1.64 (0.51)	594	1.86 (0.40)	1,067	1.56 (0.69)	<0.0001

Data are the mean (SD) or n (%).

Abbreviations: KDRI, Kidney Donor Risk Index; BMI, Body Mass Index.

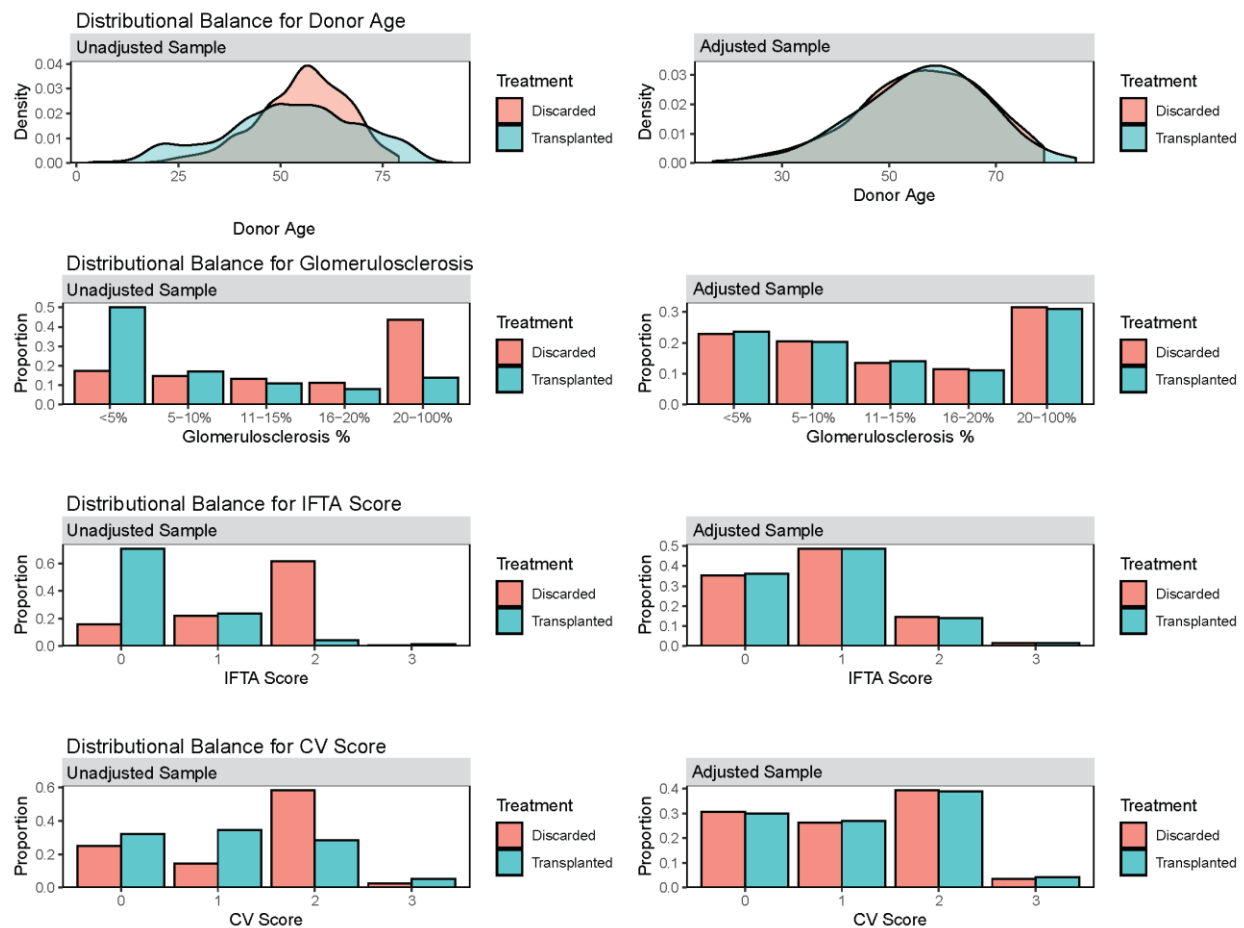
^a χ^2 tests were conducted for the comparison of proportions, and Annova were conducted for the comparison of continuous variables.

*Sensitivity analysis – matching on donor age instead of the KDRI

* Ethnicity for donors is not permitted to be collected per the French data protection regulations (CNIL)

3. SUPPLEMENTARY FIGURES

Appendix Figure 1: Distributional balance of the donor's age and biopsy characteristics before and after matching French transplanted kidneys with kidneys discarded in the US due to biopsy findings.



Appendix Figure 2: Kaplan-Meier curves of allograft survival rates for kidneys transplanted in France matched and unmatched to US discarded kidneys using donor’s age instead of KDRI for matching. Panel A shows the allograft survival probability of the kidneys transplanted matched to US discarded kidneys (red curve) to the rest of the population (unmatched kidneys; black curve). Panel B shows the allograft survival probability of the matched kidneys (red curve) to the rest of the population according to the ECD status (kidneys transplanted with standard criteria donor; solid black curve, kidneys transplanted with expanded criteria donor; dashed black curve).

