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Access to Kidney Transplantation Among Remote- and Rural-Dwelling Patients With Kidney Failure in the United States

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Context US residents with end-stage renal disease (ESRD) may live far away from the closest transplant center, which could compromise their access to kidney transplantation.

Objective To assess access to kidney transplantation as a function of distance from the closest transplant center or as a function of rural rather than urban residence.

Design, Setting, and Participants Observational study of 699 751 adult patients with kidney failure who had initiated renal replacement in the United States between 1995 and 2007 and were thus placed on a prospective mandatory registry list.

Main Outcome Measures Time to placement on the kidney transplant waiting list and time to kidney transplantation, both measured at the start of renal replacement.

Results During a median follow-up of 2.0 years (range, 0.0-12.5 years), 122 785 (17.5%) patients received a kidney transplant. Median distance to the closest transplant center was 15 miles. Participants were classified into distance categories by miles from a transplant center with 0 to 15 miles serving as the referent category. Compared with the referent category, the adjusted hazard ratios of deceased or living donor transplantation within each category follows: 16 to 50 miles, 1.03 (95% CI, 1.02-1.05); 51 to 100 miles, 1.11 (95% CI, 1.09-1.12); 101 to 136 miles, 1.14 (95% CI, 1.11-1.17); 137 to 231 miles, 1.16 (95% CI, 1.13-1.20); 232 to 310 miles, 1.20 (95% CI, 1.12-1.28); and more than 310 miles, 1.16 (95% CI, 1.09-1.23). When residence location was classified using rural-urban commuter areas, 79.6% of patients lived in urban; 10.3%, micropolitan; and 10.0%, rural areas. Compared with those living in metropolitan areas, the adjusted hazard ratios of deceased or living donor transplantation among patients residing in micropolitan communities was 1.13 (95% CI, 1.11-1.15) and 1.15 (95% CI, 1.13-1.18) for rural areas. Results were similar for both deceased donor and living donor transplantation and were consistent in multiple sensitivity analyses.

Conclusion Remote or rural residence was not associated with increased time to kidney transplantation among people treated for ESRD in the United States.

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Kidney transplantation is a life-saving medical procedure for which the demand far exceeds the supply of the resource (ie, transplantable organs). Transplantation improves clinical outcomes compared with dialysis,[1,2] and it is generally accepted that access to transplantation among suitable candidates should not be influenced by characteristics such as age, sex, race, socioeconomic status, or residence location.[3]

A recent study suggested that rural location of residence within the United States was associated with lower rates of solid organ transplantation compared with those living in urban areas.[4] This finding is consistent with other work showing that rural dwellers have reduced access to health services[5,6] and raises the possibility that current organ allocation schemes may discriminate against people living farther away from transplant centers. However, this study did not account for potential differences in the need for transplantation between rural and urban populations. In addition, although almost all remote communities are rural, some rural communities may be in close geographic proximity to a transplant center and thus rural location of residence may not necessarily represent a geographic barrier to transplantation.

We examined the association between distance from the closest transplant center and time to placement on the kidney transplantation waiting list or time to kidney transplantation. Be-

See also Patient Page.

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cause the mandatory pretransplantation medical evaluation is more likely to be available in major medical centers, we hypothesized that people residing farther from the nearest transplant center would be less likely to undergo transplantation.

METHODS

Study Population and Data Sources

Data from the United States Renal Data System (USRDS) were used for this study, which was approved by the local research ethics review boards at the University of Alberta and the University of British Columbia. We studied adult patients, aged 18 to 70 years, who initiated renal replacement (chronic dialysis or transplantation) between January 1, 1995, and September 30, 2007, in the continental United States. Because patients with health insurance coverage from the Department of Veterans Affairs may be selectively transplanted at 1 of 4 Veteran Affairs transplant facilities and not at the transplant facility closest to their residence, we excluded such patients from analysis (n = 10 437). The zip code for each patient's residence location at the time of first renal replacement (dialysis or transplantation) was obtained from the USRDS standard analysis residence file. A list of transplant centers approved to provide renal transplant services in the continental United States (and the zip codes of these centers) were obtained from the United Network for Organ Sharing database (http://www.unos.org). The population of each zip code was obtained using data from the 2000 US census and mapped onto zip code tabulation areas.[7]

Estimation of Distance

The geographic coordinates for each 5-digit zip code were determined using the US 5-Digit ZIP Code Database (ZIP Code Download, Provo, Utah). These coordinates were entered into ArcGIS 9.2 software (ESRI Inc, Redlands, California) to determine the shortest distance by road (in miles) between the closest transplant center and the residence of each patient at initiation of renal replacement.[8-10] Distance to the closest transplant center was classified using categories corresponding to the 0 to 50th, higher than 50th to 75th, higher than 75th to 90th, higher than 90th to 95th, higher than 95th to 99th, higher than 99th to 99.5th, and higher than the 99.5th percentiles. To assess the effect of changes in residence location over time, patients were categorized into distance categories as above using the zip code associated with their residence at the time of the last follow-up visit. Patient residence data were only available at the zip code level, and thus a change in residence location was defined as a move to another zip code.

We classified states in terms of the proportion of patients with remote residence location (group 1: states in which 95% of patients reside ≤50 miles from the closest transplant center; group 2: states not in group 1 but in which 95% of patients reside ≤136 miles from the closest transplant center; group 3: states not in groups 1 or 2 but in which 95% of patients reside ≤231 miles from the closest transplant center; group 4: states not in groups 1, 2, or 3 but in which >50% of patients reside >231 miles from the closest transplant center). The thresholds of 50, 136, and 231 miles were chosen because these represented the 75th, 95th, and 99th percentiles, respectively. To convert miles to kilometers, multiply by 1.6.

Classification of Rural Status

We used the rural-urban commuting area (RUCA) code to classify the extent to which the residence location of each patient was rural or urban.[4] RUCA codes are assigned to each US zip code based on markers of population density, with values ranging from 1.0 (most urban) to 10.6 (most rural). Information on population density is supplemented by data on employment commuting to ensure that suburban areas with low population density in which many residents work in nearby large urban centers are classified as urban. As in previous work,[4] we classified each patient in the current analysis as belonging to 1 of 3 mutually exclusive RUCA groups: metropolitan (RUCA, 1.0-3.9, cities with population of >50 000 and their associated suburban areas); micropolitan (RUCA, 4.0-6.0, towns or cities with population of 10 000-50 000); and rural (RUCA, >6.0, towns with population of <10 000).

Statistical Analyses

Time to transplantation was determined from the date of first renal replacement using the Kaplan-Meier method, and group differences were compared with the log-rank test. Patients were followed up until death or end of follow-up (September 30, 2007). Cox multivariate regression analysis was performed to determine the likelihood of transplantation among patients in the different distance categories after adjustment for the following potential confounders: patient age, sex, race (as submitted to the USRDS on the initial Medical Evidence form: white, black, American Indian, other), cause of ESRD (diabetes, glomerulonephritis, hypertension, other causes), median within-neighborhood household income (determined by linkage of patient zip codes to data from the 2000 US census), insurance status (Medicare only, private insurance only, both forms of insurance), current smoking status, ambulatory status, comorbid conditions (coronary artery disease, peripheral vascular disease, cerebrovascular disease, congestive heart failure, malignancy, chronic obstructive pulmonary disease, alcohol or drug dependence), body mass index, quintiles of living and deceased kidney donation rate, estimated glomerular filtration rate, and blood group type. In cases for which data were missing, a category of unknown was created and entered into the model. Subgroups of patients who were progressively more likely to be good transplant candidates were defined by combinations of age younger than 50 years, absence of diabetes, and absence of major comorbidity (coronary disease, heart failure, and cancer).

To account for differences in organ availability between geographic regions, we categorized each state into quintiles based on its living and deceased kidney donation rate per million population and adjusted for these 2 variables in the multivariable models. Donated organs in the United States are allocated within 69 donor service areas, and thus practice patterns related to transplantation may be correlated for patients treated within a given service area. Although we did not have data on the geographic area served by each service area, these areas are strongly linked to state boundaries, suggesting that state of residence is an acceptable proxy for information on donor service area.[11] Therefore, to account for correlation between patients who underwent transplantation in the same service area, we performed all Cox models using robust estimates of variance with state of residence as the cluster (grouping) variable.

We also performed separate models to determine the time from first renal replacement to activation on the waiting list and the time from activation to the waiting list until deceased donor transplantation (censoring follow-up at time of living donor or multiorgan transplantation). Patients who received preemptive kidney transplants were included in analyses and were assigned a time to wait-listing and a time to kidney transplantation of 0 days.

Tests for interaction were performed using cross-product terms in the Cox proportional hazards models. The proportional hazards assumption was tested using log-negative-log plots of the within-group survivorship probabilities vs log-time as well as time-dependent covariates in the Cox model. Statistical significance was set at $P<.05$, and all statistical tests were 2-sided. All eligible patients with a valid zip code and initiating renal replacement therapy during the study period were included in analyses. The resulting sample size (n=699 751) gave statistical power of more than 99.9% ($\alpha=.05$) to detect a 10% increase in the likelihood of transplantation among patients living more than 136 miles from the transplant center compared with those living within 15 miles. Analyses were performed with SAS version 9.1 (SAS Institute Inc, Cary, North Carolina) and S-PLUS version 7.0 (Insightful Software, Palo Alto, California).

RESULTS

Patient Characteristics

Among the 704 194 individuals who initiated renal replacement (either dialysis or transplantation) during the study period, distance between their residence and the closest transplant center could be determined for 699 751 (99.4%). Only 4443 (0.6%) patients with missing or invalid zip codes were excluded. The participants were classified into the following groups based on distance to the closest transplant center: 0 to 15 miles (0-50th percentile), 16 to 50 miles (>50th-75th percentile), 51 to 100 miles (>75th-90th percentile), 101 to 136 miles (>90th-95th percentile), 137 to 231 miles (>95th-99th percentile), 232 to 310 miles (>99th-99.5th percentile), and more than 310 miles (>99.5th percentile; **TABLE 1**). Patients who lived farther away from the closest transplant center were less likely to be black or to be insured solely by Medicare, had higher body mass index, and were more likely to have diabetic nephropathy, coronary artery disease, or peripheral vascular disease than those living closer. Patients residing farther from the transplant center were more likely to live in a rural area (Table 1). However, among patients residing in a rural area, a substantial proportion (24%) lived within 50 miles of the closest transplant center.

Although changes in residence location were relatively common during follow-up (17.8%), most patients (92.9%) remained in the same distance category throughout the study. Of those changing distance categories during follow-up, 46.3% (3.3% of the total) remained within 50 miles of the closest transplant center (ie, moved either from ≤15 miles to 16-50 miles or vice versa). Overall, 169 625 patients (24%) were placed on the waiting list for transplantation at some point during follow-up, and 20 677 (12%) died while on the waiting list. The rate of death while awaiting transplantation was slightly higher among those living farther from the transplant center (rate of death on the waiting list, expressed per 100 000 patient years: 6339 for 0 to 15 miles, 6952 for 16 to 50 miles, 7081 for 51 to 100 miles, 7052 for 101 to 136 miles, 7662 for 137 to 231 miles, 6059 for 232 to 310 miles, and 6543 for >310 miles, $P<.001$).

Likelihood of Transplantation by Distance Category

During the median follow-up period of 2.0 years (25th percentile, 0.8 years; 75th percentile, 4.0 years), 122 785 (17.5%) of patients received a kidney transplant. Of these, 74 229 (60%) were from a deceased donor and 48 556 (40%) were from a living donor. **TABLE 2** shows the adjusted time to kidney transplantation by distance from the closest transplant center.

The interval between initiation of dialysis and wait-listing was significantly shorter among those residing more than 15 miles from the transplant center than for those living closer. However, the time between wait-listing and transplantation did not significantly differ across distance categories (**TABLE 3**). When analyses were stratified by donor source, time to transplantation was significantly shorter among those residing more than 50 miles from the transplant center for both living and deceased donor transplantation (Table 3).

Tests for interaction demonstrated that race, sex, and insurance status all significantly modified the relation between distance from the transplant center and the likelihood of transplantation (all $P<.001$). Therefore, we performed analyses that examined the association between time to transplantation and distance from the closest transplant center after stratifying on these potential confounders. The time to transplantation was not significantly lower among remote dwellers for any of these subgroups than for those

Table 1. Demographics and Clinical Characteristics Among Patients Initiating Renal Replacement Therapy, by Distance to the Closest Transplant Center[a]

	Distance From Closest Transplant Center, Miles							
	0-15 (n = 349 970)	16-50 (n = 174 900)	51-100 (n = 104 942)	101-136 (n = 34 986)	137-231 (n = 27 938)	232-310 (n = 3508)	>310 (n = 3507)	*P* Value
Age, mean (SD), y	53.2 (12.1)	54.0 (11.9)	54.3 (12.0)	54.3 (11.9)	54.2 (11.9)	53.8 (12.1)	53.3 (12.4)	<.001
18-39	55 354 (16)	25 058 (14)	14 479 (14)	4862 (14)	3812 (14)	511 (15)	572 (16)	<.001
40-59	170 287 (49)	82 741 (47)	48 854 (47)	16 480 (47)	13 434 (48)	1694 (48)	1630 (46)	
60-70	124 329 (36)	67 101 (38)	41 609 (40)	13 644 (39)	10 692 (38)	1303 (37)	1305 (37)	
Female sex, No. (%)	159 302 (46)	76 906 (44)	48 159 (46)	16 132 (46)	13 003 (47)	1610 (46)	1605 (46)	<.001
Race, No. (%)								
White	171 046 (49)	122 208 (70)	71 156 (68)	23 773 (68)	19 070 (68)	2877 (82)	2954 (84)	<.001
Black	155 425 (44)	42 951 (25)	30 132 (29)	9643 (28)	6473 (23)	74 (2)	34 (1)	
American Indian	3403 (1)	1580 (1)	1908 (2)	1021 (3)	1746 (6)	508 (14)	440 (13)	
Other	20 096 (6)	8161 (5)	1746 (2)	549 (2)	649 (2)	49 (1)	79 (2)	
Cause of ESRD, No. (%)								
Diabetes	162 504 (46)	84 298 (48)	52 072 (50)	17 924 (51)	15 109 (54)	1784 (51)	1882 (54)	<.001
Glomerulonephritis	35 870 (10)	19 017 (11)	10 508 (10)	3611 (10)	2849 (10)	516 (15)	529 (15)	
Hypertension	81 151 (23)	33 502 (19)	21 231 (20)	6580 (19)	4708 (17)	370 (11)	272 (8)	
Other	70 445 (20)	38 083 (22)	21 131 (20)	6871 (20)	5272 (19)	838 (24)	824 (23)	
BMI >30	98 652 (31)	51 778 (33)	32 735 (34)	10 717 (33)	8377 (33)	887 (32)	870 (34)	<.001
Blood group, No. (%)[b]								
A	27 971 (32)	16 873 (35)	8629 (36)	2701 (35)	2465 (34)	378 (38)	406 (42)	<.001
B	14 017 (16)	6376 (13)	2980 (12)	977 (13)	821 (12)	100 (10)	81 (8)	
AB	3623 (4)	1904 (4)	933 (4)	292 (4)	218 (3)	35 (3)	26 (3)	
O	42 483 (48)	22 623 (48)	11 359 (48)	3715 (48)	3660 (51)	486 (49)	455 (47)	
Comorbidities, No. (%)								
CAD	58 974 (17)	35 991 (21)	23 606 (22)	7627 (22)	5652 (20)	815 (23)	716 (20)	<.001
PVD	34 939 (10)	21 067 (12)	14 537 (14)	5097 (15)	3845 (14)	529 (15)	501 (14)	<.001
CVD	24 275 (7)	12 676 (7)	8754 (8)	3020 (9)	2139 (8)	290 (8)	223 (6)	<.001
CHF	85 055 (24)	45 486 (26)	30 620 (29)	10 136 (29)	7941 (28)	886 (25)	861 (25)	<.001
Cancer	12 772 (4)	7649 (4)	4688 (4)	1488 (4)	1054 (4)	192 (5)	144 (4)	<.001
COPD	16 319 (5)	10 493 (6)	8032 (8)	2505 (7)	1707 (6)	294 (8)	237 (7)	<.001
History of drug or alcohol abuse, No. (%)	13 086 (4)	4388 (3)	2864 (3)	1000 (3)	885 (3)	124 (4)	92 (3)	<.001
Smoker, No. (%)	21 317 (6)	11109 (6)	9271 (9)	3121 (9)	2150 (8)	412 (12)	306 (9)	<.001
Nonambulatory, No. (%)	13 080 (4)	6080 (3)	4309 (4)	1460 (4)	963 (3)	93 (3)	103 (3)	<.001
Initial modality, No. (%)								
Hemodialysis	310 151 (90)	148 778 (86)	89 771 (86)	29 881 (86)	23 705 (86)	2835 (81)	2724 (78)	<.001
Peritoneal dialysis	27 971 (8)	18 440 (11)	11 525 (11)	3905 (11)	3291 (12)	500 (14)	578 (17)	
Transplantation	7338 (2)	5479 (3)	2558 (2)	855 (2)	692 (3)	146 (4)	174 (5)	
eGFR at time of dialysis initiation, mean (SD)	8.7 (4.6)	9.0 (4.6)	9.2 (4.6)	9.0 (4.6)	8.9 (4.5)	8.8 (4.3)	9.0 (4.3)	<.001
Insurance status, No. (%)								
Medicare	191 720 (55)	80 591 (46)	56 183 (54)	19 693 (57)	15 865 (57)	1718 (49)	1533 (44)	<.001
Private	113 265 (32)	65 014 (37)	30 378 (29)	9461 (27)	7680 (27)	1060 (30)	1242 (35)	
Both	44 985 (13)	29 295 (17)	18 381 (18)	5832 (17)	4393 (16)	730 (21)	732 (21)	
RUCA score, No. (%)[c]								
1.0-3.9	327 357 (94)	145 405 (83)	51 247 (49)	15 720 (45)	14 273 (52)	1142 (33)	1625 (46)	<.001
4.0-6.0	17 520 (5)	17 575 (10)	22 123 (21)	7562 (22)	6012 (22)	800 (23)	695 (20)	
>6.0	4960 (1)	11 802 (7)	31 550 (30)	11 703 (33)	7428 (27)	1566 (45)	1187 (34)	
Median annual income, No. (%), $								
0-28 999	95 459 (28)	16 265 (10)	26 326 (26)	12 284 (36)	9945 (37)	789 (23)	604 (18)	<.001
29 000-35 999	78 617 (23)	30 053 (18)	33 648 (33)	11 268 (33)	8399 (32)	1396 (41)	1314 (38)	
36 000-45 999	86 251 (25)	46 854 (28)	28 948 (29)	8085 (24)	6328 (24)	1020 (30)	885 (26)	
≥46 000	83 797 (24)	76 823 (45)	12 578 (12)	2125 (6)	1938 (7)	240 (7)	643 (19)	

Abbreviations: BMI, body mass index, calculated as weight in kilograms divided by height in meters squared; CAD, coronary artery disease; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVD, cerebrovascular disease; eGFR, estimated glomerular filtration rate; ESRD, end-stage renal disease; PVD, peripheral vascular disease; RUCA, rural-urban commuting area.

Conversion factor: To convert miles to kilometers, multiply by 1.6.

[a] Totals do not always add to 100% because of rounding. Data were available for BMI (n=636 873), dialysis modality (n=691 297), eGFR (n=661 662), RUCA score (n=699 252), and median annual income (n=682 882) of the study population.

[b] Available only from patients who were eventually placed on the waiting list (n=176 587).

[c] For RUCA categories, see the "Methods" section.

living closer (FIGURE 1 and FIGURE 2). Although the point estimates for the likelihood of transplantation among black or other races who lived more than 310 miles from the closest transplant center were less than 1, the confidence intervals (CIs) were wide due to small numbers of people in these categories. When results from those living 232 to 310 and more than 310 miles were pooled, the hazard ratios for the likelihood of transplantation in people of black and other races were 1.44 (95% CI, 0.88-2.33) and 0.89 (95% CI, 0.60-1.33), respectively, compared with people of the same race who resided within 15 miles of a transplant center.

Similarly, a test for interaction showed that the proportion of remote dwellers within a state significantly modified the association between distance from a transplant center and the likelihood of transplantation ($P < .001$). Stratified analyses (which grouped states with similar proportions of remote dwellers together) did not show

Table 2. Relation Between Distance to the Closest Transplant Center and Time to Kidney Transplantation[a]

	Distance From Transplantation Center, Miles						
	0-15	**16-50**	**51-100**	**101-136**	**137-231**	**232-310**	**>310**
No. of transplants/ No. of patients (%)	58 267/ 349 970 (16.6)	34 634/ 174 900 (19.8)	17 612/ 104 942 (16.8)	5692/ 34 986 (16.3)	4678/ 27 938 (16.7)	890/ 3508 (25.4)	1012/ 3507 (28.9)
Adjusted factors by models, HR (95% CI)							
1, Age, sex, and race only	1 [Reference]	1.15 (1.13-1.16)	1.01 (0.99-1.03)	0.99 (0.96-1.02)	1.00 (0.97-1.03)	1.14 (1.07-1.23)	1.09 (1.00-1.19)
2, Clinical characteristics plus model 1[b]	1 [Reference]	1.16 (1.15,1.18)	1.06 (1.04-1.08)	1.04 (1.01-1.07)	1.03 (1.00-1.06)	1.15 (1.08-1.24)	1.08 (0.99-1.18)
3, Socioeconomic characteristics plus model 2[c]	1 [Reference]	1.04 (1.02-1.05)	1.11 (1.09-1.13)	1.16 (1.12-1.19)	1.17 (1.14-1.21)	1.32 (1.23-1.42)	1.11 (1.01-1.21)
4, Regional organ supply plus model 3[d]	1 [Reference]	1.03 (1.02-1.05)	1.11 (1.09-1.12)	1.14 (1.11-1.17)	1.16 (1.13-1.20)	1.20 (1.12-1.28)	1.16 (1.09-1.23)

Abbreviations: CI, confidence interval; HR, hazard ratio.
Conversion factor: To convert miles to kilometers, multiply by 1.6.
[a] All analyses were adjusted for cluster effects at the level of the state of residence.
[b] Cause of end-stage renal disease, body mass index, comorbidities, smoking, drug or alcohol use, nonambulatory status.
[c] Insurance status, median neighborhood household income.
[d] State quintile of living donor kidney donation rate and deceased donor kidney donation rate.

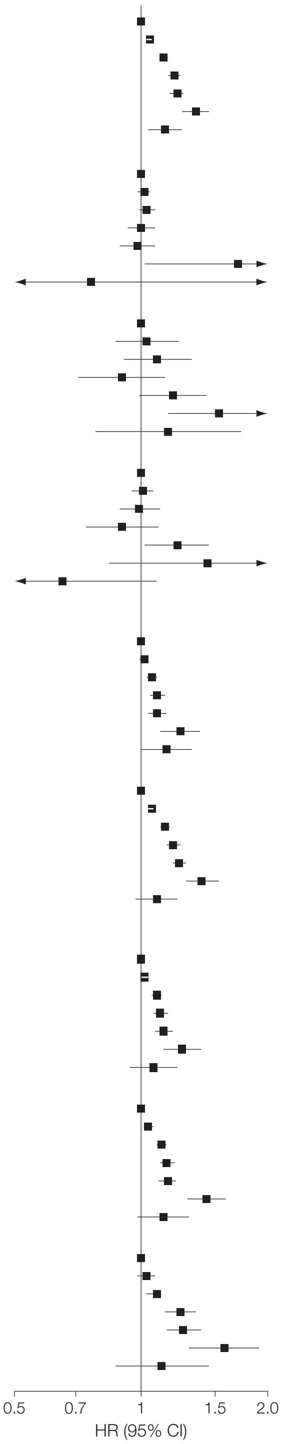
Table 3. Relation Between Distance to the Closest Transplant Center and Time to Placement on the Waiting List or Time to Kidney Transplantation[a]

	Distance From Transplantation Center, Miles						
	0-15	**16-50**	**51-100**	**101-136**	**137-231**	**232-310**	**>310**
No./total (%) of patients with deceased donor transplant	36 194/ 349 970 (10.3)	19 959/ 174 900 (11.4)	10 906/ 104 942 (10.4)	3498/ 34 986 (10.0)	2668/ 27 938 (9.5)	500/3508 (14.3)	504/3507 (14.4)
Time to deceased donor transplant HR (95% CI)	1 [Reference]	1.02 (1.00-1.04)	1.10 (1.08-1.13)	1.13 (1.09-1.18)	1.07 (1.03-1.12)	1.29 (1.17-1.41)	1.07 (0.94-1.22)
No./total (%) of patients living donor transplant	22 073/ 349 970 (6.3)	14 675/ 174 900 (8.4)	6706/ 104 942 (6.4)	2194/ 34 986 (6.3)	2010/ 27 938 (7.2)	390/3508 (11.1)	508/3507 (14.5)
Time to living donor transplant, HR (95% CI)	1 [Reference]	1.07 (1.04-1.09)	1.12 (1.09-1.15)	1.20 (1.14-1.26)	1.34 (1.28-1.40)	1.38 (1.24-1.53)	1.15 (1.01-1.31)
No./total (%) of patients on waiting list	84 541/ 349 970 (24.2)	45 887/ 174 900 (26.2)	22 980/ 104 942 (21.9)	7376/ 34 986 (21.1)	6952/ 27 938 (24.9)	958/3508 (27.3)	931/3507 (26.5)
Time from first dialysis wait-listing, HR (95% CI)	1 [Reference]	1.06 (1.05-1.07)	1.12 (1.10-1.14)	1.16 (1.13-1.19)	1.30 (1.26-1.33)	1.36 (1.28-1.46)	1.29 (1.17-1.41)
No./total (%) of wait-listed patients receiving a transplant	45 344/ 84 541 (53.6)	26 111/ 45 887 (56.9)	13 053/ 22 980 (56.8)	4185/ 7376 (56.7)	3512/ 6952 (50.5)	618/958 (64.5)	626/931 (67.2)
Time from wait-listing to transplant, HR (95% CI)[b]	1 [Reference]	1.01 (0.99-1.02)	1.01 (0.99-1.03)	1.01 (0.98-1.05)	0.92 (0.89-0.96)	1.04 (0.95-1.13)	0.96 (0.86-1.08)

Abbreviations: CI, confidence interval; HR, hazard ratio.
Conversion factor: To convert miles to kilometers, multiply by 1.6.
[a] All analyses were adjusted for age, sex, race, cause of end-stage renal disease, body mass index, comorbidities, smoking, drug or alcohol use, nonambulatory status, median household income, insurance status, and estimated glomerular filtration rate and were adjusted for cluster effects at the level of the state of residence.
[b] Adjusted for blood group type, which was only available for wait-listed patients.

Figure 1. Likelihood of Transplantation Based on Distance by Race, Sex, and Insurance Status

Distance, miles	No. of Events	No. of Participants	HR (95% CI)	*P* for Trend
Race				
White				
≤15	35 452	171 046	1 [Reference]	<.001
16-50	27 297	122 208	1.05 (1.03-1.06)	
51-100	14 083	71 156	1.13 (1.11-1.16)	
101-136	4660	23 773	1.20 (1.16-1.24)	
137-231	3784	19 070	1.22 (1.17-1.26)	
232-310	786	2877	1.35 (1.25-1.45)	
>310	912	2954	1.14 (1.04-1.25)	
Black				
≤15	18 064	155 425	1 [Reference]	.38
16-50	5202	42 951	1.02 (0.98-1.05)	
51-100	2932	30 132	1.03 (0.99-1.08)	
101-136	823	9643	1.00 (0.93-1.08)	
137-231	525	6473	0.98 (0.89-1.08)	
232-310	16	74	1.70 (1.02-2.83)	
>310	6	34	0.76 (0.27-2.18)	
American Indian				
≤15	433	3403	1 [Reference]	.04
16-50	207	1580	1.03 (0.87-1.23)	
51-100	194	1908	1.09 (0.91-1.32)	
101-136	102	1021	0.90 (0.71-1.14)	
137-231	231	1746	1.19 (0.99-1.43)	
232-310	73	508	1.53 (1.16-2.03)	
>310	70	440	1.16 (0.78-1.73)	
Other				
≤15	4318	20 096	1 [Reference]	.80
16-50	1928	8161	1.01 (0.95-1.07)	
51-100	403	1746	0.99 (0.89-1.11)	
101-136	107	549	0.90 (0.74-1.10)	
137-231	138	649	1.22 (1.02-1.45)	
232-310	15	49	1.44 (0.84-2.46)	
>310	24	79	0.65 (0.39-1.09)	
Sex				
Female				
≤15	23 891	159 302	1 [Reference]	<.001
16-50	13 523	76 906	1.02 (0.99-1.40)	
51-100	6864	48 159	1.06 (1.03-1.09)	
101-136	2223	16 132	1.09 (1.05-1.14)	
137-231	1810	13 003	1.09 (1.04-1.15)	
232-310	350	1610	1.24 (1.11-1.38)	
>310	407	1605	1.15 (1.00-1.32)	
Male				
≤15	34 376	190 668	1 [Reference]	<.001
16-50	21 111	97 994	1.06 (1.04-1.07)	
51-100	10 748	56 783	1.14 (1.11-1.17)	
101-136	3469	18 854	1.19 (1.15-1.24)	
137-231	2868	14 935	1.23 (1.19-1.28)	
232-310	540	1898	1.39 (1.28-1.53)	
>310	605	1902	1.09 (0.97-1.22)	
Socioeconomic status				
Private				
≤15	24 610	191 720	1 [Reference]	<.001
16-50	13 203	80 591	1.02 (1.00-1.04)	
51-100	7573	56 183	1.09 (1.06-1.12)	
101-136	2558	19 693	1.11 (1.07-1.16)	
137-231	2171	15 865	1.13 (1.08-1.19)	
232-310	383	1718	1.25 (1.13-1.39)	
>310	382	1553	1.07 (0.94-1.22)	
Medicare				
≤15	28 992	113 265	1 [Reference]	<.001
16-50	18 275	65 014	1.04 (1.02-1.07)	
51-100	8131	30 378	1.12 (1.09-1.15)	
101-136	2476	9461	1.15 (1.11-1.20)	
137-231	1941	7680	1.16 (1.10-1.21)	
232-310	386	1060	1.43 (1.29-1.59)	
>310	516	1242	1.13 (0.98-1.30)	
Both				
≤15	4665	44 985	1 [Reference]	<.001
16-50	3156	29 295	1.03 (0.98-1.08)	
51-100	1908	18 381	1.09 (1.03-1.08)	
101-136	658	5832	1.24 (1.14-1.35)	
137-231	566	4393	1.26 (1.15-1.39)	
232-310	121	730	1.58 (1.30-1.91)	
>310	114	732	1.12 (0.87-1.45)	



The figure shows the adjusted hazard ratios (HRs) and 95% confidence intervals (CIs) associated with the likelihood of transplantation (from deceased or living donor). *P* values for interaction between distance and race, sex, and socioeconomic status were all <.001. To convert miles to kilometers, multiply by 1.6.

significantly longer time to transplantation among those living more than 50 miles from a transplant center (compared with those living within 15 miles) for any of the 4 state groups. When results from the 75th to 90th and 90th to 100th percentiles were pooled for state group 4 (states including the highest proportion of remote dwellers), the hazard ratio for the likelihood of transplantation was 1.05 (95% CI, 0.92-1.20).

Finally, we performed 2 additional sensitivity analyses. First, in the analysis in which we included only young (<50 years) patients who would be expected to be suitable candidates for kidney transplantation compared with those living 15 or fewer miles, the adjusted hazard ratio of deceased or living donor transplantation was 1.06 (95% CI, 1.04-1.08) for those living 16 to 50 miles; 1.13 (95% CI, 1.10-1.16), 51 to 100 miles; 1.17 (95% CI, 1.12-1.21), 101 to 136 miles; 1.21 (95% CI, 1.16-1.26), 137 to 231 miles; 1.26 (95% CI, 1.14-1.38), 232 to 310 miles; and 1.06 (95% CI, 0.94, 1.19), more than 310 miles. Second, in the analysis in which we excluded all participants who moved during the study period, compared with those living 15 or fewer miles, the adjusted hazard ratio of deceased or living donor transplantation was 1.04 (95% CI, 1.03-1.06) for those living 16 to 50 miles; 1.12 (95% CI, 1.10-1.15), 51 to 100 miles; 1.18 (95% CI, 1.14-1.22), 101 to 136 miles; 1.19 (95% CI, 1.15-1.24), 137 to 231 miles; 1.23 (95% CI, 1.14-1.33), 232 to 310 miles; and 1.17 (95% CI, 1.08-1.26), 310 or more miles.

Likelihood of Transplantation by Rural vs Urban Location of Residence

After adjustment for distance from the closest transplant center, residents of rural areas had a small but statistically significant increase in the adjusted likelihood of transplantation compared with those residing in urban areas ($P<.001$; TABLE 4). A significant interaction between rural location of residence and the distance from the closest transplant center was noted ($P<.001$). However, time to transplantation was not significantly longer for rural dwellers than for those living in metropolitan areas within any of the distance categories (Figure 1 and Figure 2).

Incidence of Renal Replacement Therapy by Residence Location

We performed additional analyses that expressed the number of patients who initiated renal replacement therapy during the study period, expressed per million population and stratified by distance from the closest transplant center and by RUCA category (**Figure 3**). The incidence of renal replacement therapy was 3.6% higher for rural areas (RUCA >6) than urban areas (RUCA <4). However, the incidence of patients with renal replacement who would be expected to be suitable transplant candidates based on age, diabetic status, and comorbidity was markedly (24.6%) lower for rural areas than for urban areas (Figure 3).

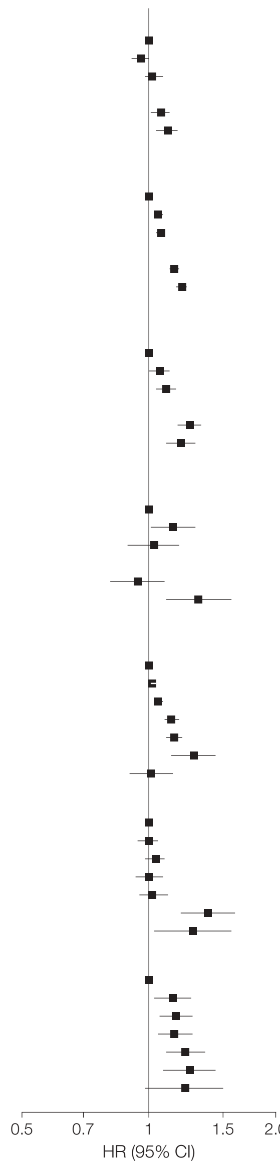
COMMENT

Although most patients initiating ESRD treatment in the United States resided within 50 miles of the closest transplant center, more than 30 000 such individuals lived more than 136 miles away—which is a potential barrier to transplantation. In contrast to our a priori hypotheses, we found that the likelihood of receiving a kidney transplant from a deceased or living donor among patients living farther away was similar to or greater than those residing within 15 miles of kidney transplant centers. Similarly, and again in contrast to our hypotheses, the adjusted likelihood of kidney transplantation was slightly lower among rural dwellers. These 2 key findings were independent of demographic factors, comorbidity, and measured socioeconomic characteristics, and were consistent in a variety of sensitivity analyses.

These results are surprising because multiple studies from the United States and other countries indicate that remote and rural dwellers are less likely to access primary care and specialized medical services,[12-15] may present with more advanced disease,[5,16] and often experience worse clinical outcomes.[6,17-20] In addition, a previously published report has documented regional differences in transplantation rates within the United States—suggesting that geographical factors (such as local differences in the demand for or supply of transplantable organs) can influence access to kidney transplantation.[21] Our analyses included all patients com-

Figure 2. Likelihood of Transplantation Based on Distance by State Rural-Urban Commuting Areas and State Group Categories

	No. of Events	No. of Participants	HR (95% CI)	*P* for Trend
State Group				
1				
Quartile				
1	3721	27 945	1 [Reference]	
2	4710	27 387	0.96 (0.91-1.00)	
3	6007	27 538	1.02 (0.98-1.08)	<.001
Percentile				
75-90	3747	16 799	1.07 (1.01-1.12)	
91-100	2126	11 070	1.11 (1.04-1.17)	
2				
Quartile				
1	20 374	136 737	1 [Reference]	
2	22 751	134 119	1.05 (1.03-1.08)	
3	24 836	135 513	1.07 (1.04-1.08)	<.001
Percentile				
75-90	12 788	81 277	1.15 (1.12-1.18)	
91-100	8125	54 186	1.20 (1.16-1.23)	
3				
Quartile				
1	2448	9493	1 [Reference]	
2	3333	10 712	1.06 (1.00-1.12)	
3	2915	10 129	1.10 (1.04-1.16)	.56
Percentile				
75-90	1815	6098	1.25 (1.17-1.33)	
91-100	1045	4050	1.19 (1.10-1.29)	
4				
Quartile				
1	538	1674	1 [Reference]	
2	525	1674	1.14 (1.01-1.29)	
3	473	1671	1.03 (0.89-1.18)	.04
Percentile				
75-90	299	1009	0.94 (1.81-1.09)	
91-100	209	670	1.31 (1.10-1.57)	
Rural-urban commuting area, distance, miles				
Metropolitan 1.0-3.9				
≤15	55 015	327 357	1 [Reference]	
16-50	29 423	145 405	1.02 (1.01-1.04)	
51-100	8860	51 247	1.05 (1.03-1.08)	
101-136	2693	15 720	1.13 (1.09-1.18)	<.001
137-231	2251	14 273	1.15 (1.10-1.20)	
232-310	303	1142	1.28 (1.13-1.44)	
>310	531	1625	1.01 (0.90-1.14)	
Micropolitan 4.0-6.0				
≤15	2660	17 520	1 [Reference]	
16-50	3165	17 575	1.00 (0.94-1.05)	
51-100	3711	22 123	1.04 (0.98-1.09)	
101-136	1152	7562	1.00 (0.93-1.08)	<.001
137-231	1008	6012	1.02 (0.95-1.11)	
232-310	228	800	1.38 (1.19-1.60)	
>310	196	695	1.27 (1.03-1.57)	
Rual >6.0				
≤15	576	4960	1 [Reference]	
16-50	2029	11 802	1.14 (1.03-1.26)	
51-100	5039	31 550	1.16 (1.06-1.27)	
101-136	1847	11 703	1.15 (1.05-1.27)	.001
137-231	1394	7428	1.22 (1.10-1.36)	
232-310	359	1566	1.25 (1.08-1.44)	
>310	285	1187	1.22 (0.98-1.50)	



The figure shows the adjusted hazard ratios (HRs) and 95% confidence intervals (CIs) associated with the likelihood of transplantation (from deceased or living donor). State groups are defined in the "Methods" section. *P* values for interaction between state group and rural-urban commuuting area were both <.001. To convert miles to kilometers, multiply by 1.6.

mencing renal replacement in the United States during the study period and adjusted for differences in living and deceased donation rates between states. Our findings therefore account for differences in both the demand and supply of organs between regions.

Despite its potential to serve as a geographic barrier to kidney transplantation, data on how remote residence location influences access to this essential medical service are sparse. A previous study from our group found that the likelihood of kidney transplantation among Canadian patients receiving dialysis was also not influenced by distance from the closest transplant center.[22] A smaller Scottish study found that time to placement on the waiting list was shorter among patients living more than 100 km from the closest transplant center than among those living closer,[23] although time to transplantation was not reported. A recent study from the United States did not report on transplant rates but found that post-transplantation clinical outcomes were similar for those living closer to and farther from a transplant center.[24]

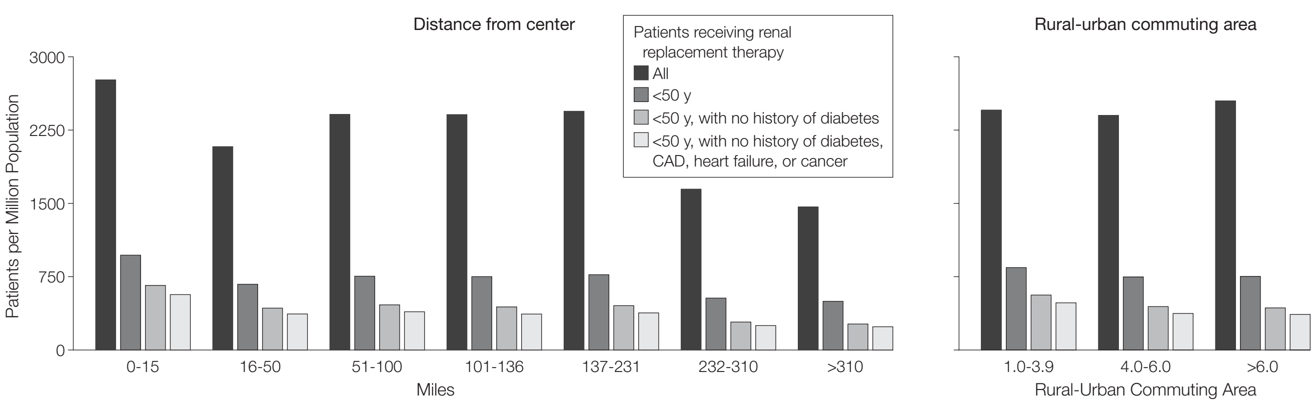
Aside from proximity to a transplant center, a second geographic consideration that might influence access to and utilization of kidney transplantation is rural residence—sometimes defined as living outside a major urban area.[25] In the United States, there currently is considerable interest in providing rural dwellers with equitable access to medical services.[26] Although most remote dwellers live in rural areas, the converse is not necessarily true, and barriers to accessing health care may differ for remote and rural populations.[27] We used a data set that included all incident patients treated with renal replacement therapy and had access to individual-level data on comorbidity and other characteristics that might influence medical suitability for transplantation. Although prior work suggests that rural location of resi-

Table 4. Likelihood of Any Transplantation by Rurality of Residence Location[a]

	Rural-Urban Commuting Area, Score[b]		
	Metropolitan 1.0-3.9	Micropolitan 4.0-6.0	Rural >6
No./total (%) of patients receiving any transplantion	99 076/556 769 (17.8)	12 120/72 287 (16.8)	11 529/70 196 (16.4)
Time to any transplantation, HR (95% CI)	1 [Reference]	1.13 (1.11-1.15)	1.15 (1.13-1.18)
No./total (%) of patients placed on a waiting list	140 162/556 769 (25.2)	15 103/72 287 (20.9)	14 269/70 196 (20.3)
Time to first dialysis to wait-listing, HR (95% CI)	1 [Reference]	1.08 (1.06-1.10)	1.09 (1.07-1.11)
No./total (%) of patients receiving a transplant	76 254/140 162 (54.4)	8831/15 103 (58.5)	8315/14 269 (58.3)
Time from wait-listing to transplantation, HR (95% CI)[c]	1 [Reference]	1.05 (1.02-1.07)	1.06 (1.03-1.08)

Abbreviations: CI, confidence interval; HR, hazard ratio.
[a] All analyses were also adjusted for cluster effects at the level of the state of residence and were adjusted for age, sex, race, cause of end-stage renal disease, body mass index, comorbidities, smoking, drug or alcohol use, nonambulatory status, median household income, insurance status, estimated glomerular filtration rate, and distance from the closest transplant center.
[b] For rural-urban commuting area categories, see “Methods” section.
[c] Was also adjusted for blood group type, which was only available for wait-listed patients.

Figure 3. Incidence of Renal Replacement Therapy During Study Period



The figure shows the incidence of renal replacement therapy (expressed per million population) as a function of distance from the closest transplant center and as a function of the rurality of residence location, expressed as rural-urban commuting area. Subgroups of patients who were progressively more likely to be good transplant candidates were defined by combinations of age younger than 50 years, absence of diabetes, and absence of major comorbidity (CAD indicates coronary artery disease). Within each subgroup, *P* values for trend across distance categories and for trend across rural-urban commuting area categories are all <.001. To convert miles to kilometers, multiply by 1.6.

dence within the United States is associated with lower rates of kidney transplantation per million population,[4] our findings suggest that this does not reflect reduced access to kidney transplantation but is due to a lower proportion of suitable transplant candidates among rural-dwelling dialysis patients than among urban dwellers. In fact, we found that the adjusted time to kidney transplantation was significantly shorter among rural-dwelling patients than among urban dwellers.

Although unexpected, our findings are encouraging because determining eligibility for kidney transplantation is a logistically challenging process that requires sequential diagnostic tests and encounters with health care clinicians.[28] The finding that time to transplantation is similar or even shorter among remote and rural-dwelling patients with kidney failure suggests that disparities in access for remote and rural dwellers with other diseases could be reduced or eliminated. In addition, our findings suggest that efforts to improve equitable access to transplantation should not focus on populations defined solely by residence location. Instead, existing initiatives to improve access for ethnic minorities and those of lower socioeconomic status may be more likely to reduce disparities in access. However, future studies should consider the possibility that current schemes for organ allocation place patients who live in major urban centers at a relative disadvantage.

Why might the waiting time for a kidney transplant be shorter among people living farther from a transplant center? One possibility is that remote dwellers who choose to initiate renal replacement are more highly motivated to pursue transplantation than apparently comparable urban dwellers. This explanation is plausible because it is likely that traveling to dialysis units is more inconvenient in remote areas than in urban areas. It is also possible that remote dwellers are less likely to initiate dialysis when kidney failure occurs (than those living in urban areas) leaving a selected pool of remote-dwelling dialysis patients to compete for kidney transplants with a more heterogeneous group of urban dwellers. This latter possibility is supported by our finding that uptake of renal replacement therapy is less common per million population in remote areas than in areas located within 15 miles of the closest transplant center. Alternatively, we speculate that physicians may be aware of the potential logistical barriers associated with remote residence location and expedite the workup of potential transplant recipients accordingly. Finally, despite our best efforts to account for the effects of race, socioeconomic status, age, and comorbidity using stratification and adjustment, it is possible that residual confounding accounts for the apparently shorter time to transplantation observed among remote and rural dwellers. Although we cannot exclude this possibility, it seems unlikely that remote and rural dwellers are actually disadvantaged with respect to kidney transplantation.

Our study has several limitations. First, we excluded participants without a valid residential zip code; however, these individuals accounted for only 0.6% of those initiating dialysis during the study period. Second, our primary classification of residence location was based on data at the time of dialysis inception. Because some participants moved after commencing dialysis but before transplantation, the resulting misclassification may have introduced bias. However, the low proportion of patients who moved and the consistent results of the sensitivity analysis in which such patients were excluded both suggest that such misclassification is unlikely to have changed our conclusions. Third, the method we used to calculate distance and rural or urban location of residence necessitates some approximations. We attempted to reduce the effect of this imprecision by categorizing distance from the closest transplant center into relatively broad categories, reducing the risk of misclassification. Finally, although we studied all eligible patients who initiated renal replacement during the study period, it is possible that patients residing in remote areas are less likely to receive renal replacement therapy than those living closer. Although we cannot exclude this possibility, we believe that it is unlikely to have influenced our conclusions.

In conclusion, we found no evidence that the likelihood of kidney transplantation was lower among remote- or rural-dwelling patients treated for kidney failure in the United States. These data suggest that efforts to improve equitable access to transplantation should not focus on populations defined solely by residence location.

Author Contributions: Dr Gill had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Tonelli, Klarenbach, Gill.
Acquisition of data: Wiebe, Gill.
Analysis and interpretation of data: Tonelli, Klarenbach, Rose, Gill.
Drafting of the manuscript: Tonelli, Rose.
Critical revision of the manuscript for important intellectual content: Tonelli, Klarenbach, Rose, Wiebe, Gill.
Statistical analysis: Rose, Wiebe, Gill.
Obtained funding: Gill.
Administrative, technical, or material support: Wiebe
Study supervision: Tonelli, Gill.
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A large part of altruism, even when it is perfectly honest, is grounded upon the fact that it is uncomfortable to have unhappy people about one.
—H. L. Mencken (1880-1956)

