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Baseline and Center-Level Variation in Simultaneous Liver-Kidney Listing in the United States

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Abstract

Background—The OPTN has implemented medical criteria to determine which candidates are most appropriate for simultaneous liver-kidney transplantation (SLK) in comparison to liver-alone transplantation. We investigated prepolicy center-level variation among SLK-listing practice, in light of such criteria.

Methods—We identified 4,736 SLK-eligible candidates after Share-35 in the U.S. We calculated the proportion of candidates at each center who were listed for SLK within 6 months of eligibility. Multi-level logistic regression and parametric survival model was used to estimate the center-specific probability of SLK-listing, adjusting for patient and center-level characteristics.

Results—Among 4,736 SLK-eligible candidates, 64.8% were listed for SLK within 6-months of eligibility. However, the percentage of SLK-listing ranged from 0% to 100% across centers. African American race, male gender, prior transplant history, diabetes, and hypertension were associated with a higher likelihood of SLK-listing. Conversely, older age, was associated with a lower likelihood of SLK-listing. After adjusting for candidate characteristics, the percentage of SLK-listing still ranged from 3.8% to 80.2% across centers; this wide variation persisted even after further adjusting for center-level characteristics.

Conclusions—There was significant prepolicy center-level variation in SLK-listing for SLK-eligible candidates. Implementation of standardized SLK listing practices may reduce center-level variation and equalize access for SLK candidates across the US.

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INTRODUCTION

Simultaneous liver-kidney transplantation (SLK) is preferred to liver-alone transplantation (LAT) for candidates with renal dysfunction that will not recover after LAT[1,2]. Prior to August 2017, it was the discretion of individual transplant centers to determine candidacy for SLK and to list appropriately. At that time, if a liver was allocated to a SLK candidate, the candidate received priority for a kidney from the same donor (if the donor and candidate are within the same DSA)[3]. This allocation paradigm prioritized SLK candidates to receive kidney allografts over kidney-alone transplant (KAT) candidates, regardless of their time on the waiting list or comorbidity. However, in an attempt to standardize allocation equity between SLK and LAT candidates, the Organ Procurement and Transplantation Network (OPTN) recently accepted medical eligibility criteria to help determine which transplant candidates are most appropriate for SLK[3]. This proposal only prioritizes SLK candidates who meet at least 1 of several key criteria: chronic kidney disease (CKD), sustained acute kidney injury, or certain types of metabolic diseases (Table 1)[3].

The proposed medical criteria were driven by a rise in SLK transplantation (from 135 in 2000 to 557 in 2014)[4] in the absence SLK candidacy requirements. Medical criteria for SLK have been discussed in great detail[4–7] over the past decade, but until recently there was not a consensus. Some observational studies have identified subgroups of liver transplant candidates who may benefit from SLK[4,6–13]. Specifically, Sharma et al reported higher survival with SLK vs LAT in nondialysis patients who receive high quality donor kidneys, and similar survival between SLK and LAT in dialysis patients[12]. However, previous studies have shown minimal short-term survival benefit for SLK recipients compared to LAT[14] and high rates of renal recovery in acute dialysis LAT recipients[14,15]. Thus, clearly defining the appropriate medical criteria for SLK is imperative to creating an allocation system that maximizes organ usage and allocation equity.

Prior to the new OPTN SLK policy, a recent survey of 57 US transplant centers demonstrated a wide array of medical criteria for SLK-listing[16]. However, this center level variation has never been quantified. It is unclear how the likelihood of SLK-listing varies across transplant centers for a given transplant candidate. Additionally, it is unclear how well SLK-listing practices correlate with the new OPTN medical eligibility criteria. Characterization of prior center level SLK-listing practice is necessary to estimate changes in practice due to the recent policy implementation. Therefore, the goal of this study was to explore and quantify center variation of SLK-listing practices, in light of the new SLK-eligible criteria.

METHODS

Data source

This study used data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data on all donors, waitlisted candidates, and transplant recipients in the US, submitted by the members of the Organ Procurement and Transplantation Network (OPTN) as per reported[17]. The Health Resources and Services

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Administration (HRSA), US Department of Health and Human Services, provides oversight to the activities of the OPTN and SRTR contractors.

Study population

We studied 55,396 adult active liver transplant candidates between June 18, 2013 (post-Share-35) and February 28, 2017 in the United States. Among all liver transplant candidates, 4,736 were SLK-eligible and met the new OPTN SLK medical criteria, i.e. having 1 of the following 3 conditions:

1. Chronic kidney disease - eGFR ≤ 60mL/min for greater than 90 consecutive days, and subsequent 1 time eGFR ≤ 30mL/min
2. Sustained acute kidney injury - Dialysis or eGFR ≤ 25ml/min for at least 6 weeks
3. Metabolic disease - Hyperoxaluria, atypical HUS from mutations in factor H/I, familial nonneuropathic systemic amyloidosis, or methylmalonic aciduria.

We calculated eGFR by the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) equation[18]. Clinical information was only available in SRTR after candidates were wait-listed; as such, to determine eligibility resulting from 90 days eGFR ≤ 60mL/min, we excluded the first 90 days of person time to allow 90 days of data prior to determination.

Center level variation of SLK-listing

The primary outcome of this study was SLK-listing. We determined the overall and center-level percentage of SLK-eligible candidates who were listed within 6 months of eligibility. Six months was chosen because the majority of SLK-eligible candidates that were listed for SLK (96.2%) did so within this time frame. SLK-listing is reported as incidence rate of SLK-listing per 6 months at each center.

Patient-Level Adjustment—Based on observed SLK-listing among SLK-eligible candidates, we identified 2 distinct patient populations: candidates that were listed for SLK immediately upon eligibility, and candidates who were listed later in the study period, after becoming eligible (Figure 1). Therefore, we explored SLK-listing using 2 unique models based on the distribution of our observed data: (1) multilevel logistic regression for immediate listing and (2) multilevel mixed-effects parametric survival regression for listing after eligibility. We adjusted both models for age (per 10 years), gender, race (African-American vs non-African-American), biologic MELD score (per 5 points), eGFR (per 5 ml/min/1.73), previous transplant, hypertension, and diabetes. For the logistic regression model that described immediate SLK-listing among SLK-eligible candidates, we reported an odds ratio for listing. For this population, an odds ratio (OR) of greater than one indicates a higher chance of SLK-listing. For the parametric survival regression model that described SLK-listing after becoming eligible, we reported a time ratio (TR) to listing. A time ratio of greater than one indicates a longer time to SLK-listing and thus, a lower likelihood of listing.

We further used empirical Bayes estimates of center-level random intercepts to calculate an estimated percentage of 6-month SLK-listing at each center for a reference candidate. The

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reference candidate was defined using the median value for specific covariates: a 60 year old, non-African American male with a MELD of 25, a GFR of 30, and no history of hypertension, diabetes or previous solid organ transplant.

Center-level adjustment—After patient-level adjustment, we explored the association of SLK-listing with center-level characteristics. Center-level characteristics were modeled and reported as continuous variables: per 5% increase in percentage of AA liver candidates, per 10 liver transplants for liver transplant volume, per 10 kidney transplants for kidney transplant volume, and per 10 SLKs for SLK volume. Transplant volume was recorded as a cumulative volume over the entire study period. We used empirical Bayes estimates to calculate the center-specific percentage of 6-month SLK-listing for the reference candidate, adjusting for candidate and center level characteristics.

Posttransplant mortality

Among SLK-eligible candidates during our study period, there were 1,132 SLK recipients and 613 LAT recipients. Kaplan-Meier methods and Log-Rank test were used to compare posttransplant mortality between SLK and LAT recipients. Cox regression was used to adjust for recipient gender, race, age, biologic MELD, eGFR, previous transplant, hypertension, diabetes, and the Donor Risk Index (DRI).

Sensitivity analysis

Based on the 90 day history of eGFR≤60 criterion for CKD in SLK criteria, we excluded 16,903 candidates with less than 90 days of follow-up on the waitlist. This exclusion criterion may exclude some SLK-eligible candidates. Therefore, as a sensitivity analysis, we included candidates with less than 90 days of follow-up on the waitlist and redefined SLK eligibility of CKD as 1-time eGFR ≤ 30mL/min. We repeated the analysis previously outlined to determine the stability of our inferences, and our inferences remained the same under these conditions.

Statistical analysis

Likelihood ratio tests were used to test the statistical significance of multi-level random effects by transplant centers. Confidence intervals and interquartile range are reported as per the method of Louis and Zeger[19]. All analyses were performed using Stata 14.0/MP for Linux (College Station, Texas).

RESULTS

Study population

Among adult active liver transplant candidates, 4,736 (8.5%) were SLK-eligible. Among SLK-eligible candidates, 1,525 (32.2%) had CKD, 3,173 (67.0%) had sustained acute kidney injury, and 38 (0.8%) had metabolic disease (Table 2). SLK-listing rates were 30.5%, 84.7%, and 97.4% for eligible candidates with CKD, sustained acute kidney injury, and metabolic diseases, respectively. Overall, 67.4% of SLK-eligible candidates (n=3,191) were listed (Table 2), while 1,545 SLK-eligible candidates were not listed.

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Among SLK-eligible candidates, SLK-listed candidates and unlisted candidates had clinically similar MELD ($_{20}22_{25}$ vs $_{20}23_{28}$, p<0.001), although there were statistically significantly differences (Table 3). SLK-listed candidates were less likely to have MELD exception points (10.8% vs 14.8%, p<0.001). SLK-listed candidates also had lower eGFR ($_{9.6}16.6_{24.9}$ vs $_{20.6}25.6_{28.4}$, p<0.001). However, SLK-listed candidates were more likely to be younger ($_{53}59_{63}$ vs $_{57}62_{66}$, p<0.001), African-American (15.1% vs 4.5%, p<0.001), male (61.4% vs 49.7%, p<0.001), to have had a prior transplant (11.3% vs 6.1%, p<0.001), diabetes (50.6% vs 43.0%, p<0.001), or hypertension (41.2% vs 23.4%, p<0.001).

At the 120 transplant centers with SLK-eligible liver candidates, the median percentage of African-American liver candidates was 6.6% (IQR: 3.9%–13.2%), median liver transplant volume was 156 (IQR: 79–280), median kidney transplant volume was 238 (IQR: 152–409), median SLK transplant volume was 14 (IQR: 7–27), and median MELD at transplant was 29 (IQR: 25–33) (Table 4).

Center level variation of SLK-listing

Over the study period, the total number of SLK-eligible candidates ranged from 1 to 185 across 120 transplant centers (Figure 2). Centers listed between 0% and 100% of their SLK-eligible candidates for SLK within 6 months of eligibility. Even among larger-volume centers with more than 50 total SLK-eligible candidates, the percentage of SLK-listing varied widely from 1.6% to 89.0%.

Among SLK-eligible candidates (Table 5), African-American race (OR=$_{1.75}2.23_{2.84}$, p<0.001), male gender (OR=$_{1.22}1.41_{1.62}$, p<0.001), prior transplant (OR=$_{1.30}1.68_{2.17}$, p<0.001), diabetes (OR=$_{1.18}1.35_{1.56}$, p<0.001), and hypertension (OR=$_{1.83}2.13_{2.48}$, p<0.001) were associated with increased immediate SLK-listing. However, SLK-eligible candidates with higher MELD were less likely to be immediately listed for SLK (OR=$_{0.77}0.82_{0.88}$, p<0.001).

Among SLK-eligible candidates not immediately listed for SLK (Table 5), African-American race (TR=$_{0.40}0.55_{0.75}$, p<0.001), male gender (TR=$_{0.66}0.79_{0.94}$, p=0.007), higher MELD (TR=$_{0.44}0.47_{0.51}$, p<0.001), and diabetes (TR=$_{0.62}0.74_{0.89}$; p=0.001) were associated with shorter time to listing for SLK.

After adjustment, on average, across all centers, 55.5% of SLK-eligible candidates were listed for SLK. However, the center specific percentage ranged from 3.8% to 80.2% (Figure 3). Out of 120 centers, 38 (31.7%) listed less than 50% of candidates within 6 months of eligibility.

SLK-listing among SLK-eligible candidates was also independently associated with some center level characteristics (Table 5). SLK-listing decreased as liver transplant volume increased (OR=$_{0.94}0.96_{0.97}$, p<0.001; TR=$_{1.02}1.03_{1.06}$, p<0.001) and median MELD at transplant increased (TR=$_{1.00}1.04_{1.09}$, p=0.04). However, SLK-listing increased with increased SLK volume (OR=$_{1.32}1.50_{1.70}$, p<0.001; TR=$_{0.63}0.72_{0.82}$, p<0.001). After adjusting for patient and center level characteristics, SLK-listing (for a reference candidate) still varied significantly by center, from 9.3% to 70.7% (likelihood ratio test: p<0.001).

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Posttransplant mortality

During our study period among SLK-eligible candidates, 1,132 underwent SLK (68.9% CKD, 78.1% acute kidney injury, 2.3% metabolic disease) with median (IQR) MELD of 25 (21–32), and 613 underwent LAT (49.8% CKD, 15.3% acute kidney injury, 0.2% metabolic disease) with median (IQR) MELD of 28 (22–35). SLK recipients had lower mortality than LAT recipients after transplant (Figure 4). One-year mortality was 9.1% for SLK recipients and 14.2% for LAT recipients (Log-Rank, p=0.003). After adjustment, SLK was associated with 39% lower mortality than LAT ($HR=_{0.43}0.61_{0.87}$, p=0.006).

DISCUSSION

In this national study of SLK-listing practices, we found that 67.4% of SLK-eligible candidates were listed for SLK, with wide variation across the US centers (0%–100% listed). African American race, male gender, prior transplant history, diabetes, and hypertension were independently associated with a higher likelihood of SLK-listing. Conversely, older age, and higher eGFR were independently associated with a lower likelihood of SLK-listing. The adjusted percentage of SLK-listing varied substantially from 3.8% to 80.2% across centers for a reference candidate, even after adjusting for multiple patient and center level characteristics. Additionally, mortality risk after transplantation was 39% lower for SLK recipients compared to LAT recipients.

Qualitative proof of center variation in SLK-listing practices has been reported[16]. Our study is the first to quantify the center-level variation in SLK-listing. After adjustment, patient case mixture and center-level characteristics were unable to fully explain the variation in listing practices. This quantified variation has led to disparity in access to SLK transplantation throughout the US. In centers with lower listing rates, SLK-eligible candidates who might benefit from SLK are potentially being disadvantaged. The SLK allocation policy may help to address some of the disparities currently seen in SLK-listing and decrease listing variation throughout the US.

In addition to center level variation, there is variation in SLK transplantation for specific candidate populations. Sharma et al[12] and Mindikoglu et al[10] previously demonstrated that male gender and African-American race were associated with higher rates of SLK in comparison to LAT. Our study shows that these differences not only exist in transplantation, but exist in SLK-listing among SLK-eligible candidates. The disparities in SLK-listing might be biased by concern that male gender and African-American race were associated with faster decline of GFR and progression in CKD[20–22]. Particularly, African-American race has been shown to be associated with ESRD after LAT[2]. Therefore, lack of standard medical criteria for SLK might lead to the disparities in listing practice and access to transplantation. Implementation of SLK medical criteria may reduce the disparities in SLK-listing.

Our findings showed that increased MELD was associated with lower likelihood of immediate SLK-listing, but higher likelihood of SLK-listing over time, after becoming SLK-eligible. These 2 temporal SLK-listing processes may represent different SLK-eligible populations. For those that were immediately listed, the negative association of higher

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MELD and listing may reflect the theoretical concern of performing an SLK in a patient with high medical acuity. This issue was addressed by Lunsford et al as they showed that SLK recipients with higher MELD had greater mortality or need for renal replacement therapy at 3 months after SLK, making kidney transplant during that high medical acuity more futile[23]. The latter population likely represents SLK-eligible candidates with long-term progressive renal dysfunction. In this population, the association with listing and MELD is not surprising, as the MELD is likely driven by progression renal decline, with normal kidney function.

Based on the recently accepted medical criteria for SLK eligibility, 32.6% of eligible candidates were not listed for SLK. Wadei and colleagues, in an editorial to the American Journal of Transplantation, expressed concern that such medical criteria would lead to an inappropriate increase in SLK, specifically for individuals who may not benefit from SLK[24]. However, Formica et al argued that the SLK medical criteria can help clinicians make more appropriate decisions regarding SLK candidacy and uphold the OPTN's Final Rule[25,26]. It is unclear how the policy implementation will affect listing practices given the substantial variation in documentation prior to the allocation change, notably the definition of CKD. Our results demonstrate only 30.5% of CKD SLK-eligible patients are listed for SLK prior to policy implementation. This CKD group will likely be affected after the new policy with additional data collection, but we will need to follow SLK-listing practices after implementation to know the true effect. Our study provides a quantified report of listing practices prior to the SLK allocation change, and we will be well equipped to assess changes in listing practices with the policy change.

Mortality and survival benefit after SLK versus LAT have been previously studied. Sharma et al reported lower mortality with SLK vs LAT in nondialysis patients with high quality donor kidneys and similar mortality between SLK and LAT in dialysis patients[12]. However, Brennan et al demonstrated lower 1-year mortality for SLK versus LAT, but minimal short-term survival benefit for SLK recipients due to inherent differences in the patient populations that led to the choice of transplantation[14]. Our results show lower mortality for SLK vs LAT recipients in the population of SLK-eligible patients. This may predict the mortality we will see with new policy implementation, but patients selected for SLK and SLK-listing were not based on standardized criteria.

Given that this is a retrospective analysis of registry data, our study is subject to the known limitations associated with secondary database analysis including missing data, misclassification and data-entry error. For example, certain metabolic diseases in the SLK criteria (atypical HUS, familial nonneuropathic systemic amyloidosis, or methylmalonic aciduria) are not coded as primary diagnosis in the registry data. However, it should also be noted that these diagnosis are rare diseases in adults in the U.S. and therefore inaccuracies in coding are unlikely to dramatically affect our inferences[27,28]. Furthermore, registry data lack serum creatinine and GFR information prior to listing. We excluded candidates who were listed for less than 90 days and without AKI and certain metabolic diseases since their SLK-eligible status was unknown. However, after inclusion of these candidates in a sensitivity analysis, our conclusions remained the same. Finally, GFR information was not available in the registry data and was calculated from serum creatinine and other candidate

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characteristics using the CKD-EPI equation. While this only provided estimated GFR, the CKD-EPI equation we used is a validated tool and has been cited as one of the most accurate GFR estimation methods[29].

Our study is the first to quantify center variation in listing practices for SLK-eligible candidates accounting for the patient case mixture and possible future changes in allocation policy. Overall, more than half of candidates who met OPTN eligibility criteria were listed, and substantial center level variation in listing practices remained after adjusting for patient and center-level factors. The SLK-listing policy will possibly address some of the disparity in listing practices, but postimplementation practices will need to be followed closely to determine the ultimate downstream effects on both liver and kidney allocation.

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Abbreviations

OPTN	organ procurement and transplantation network
CKD	chronic kidney disease
SLK	simultaneous liver-kidney transplantation
MELD	model for end-stage liver disease
OR	odds ratio
TR	time ratio
LAT	liver-alone transplantation
DSA	donor service area
KAT	kidney-alone transplantation
SRTR	scientific registry of transplant recipients
HRSA	health resources and services administration
eGFR	estimated glomerular filtration rate
HUS	hemolytic-uremic syndrome
IQR	interquartile range

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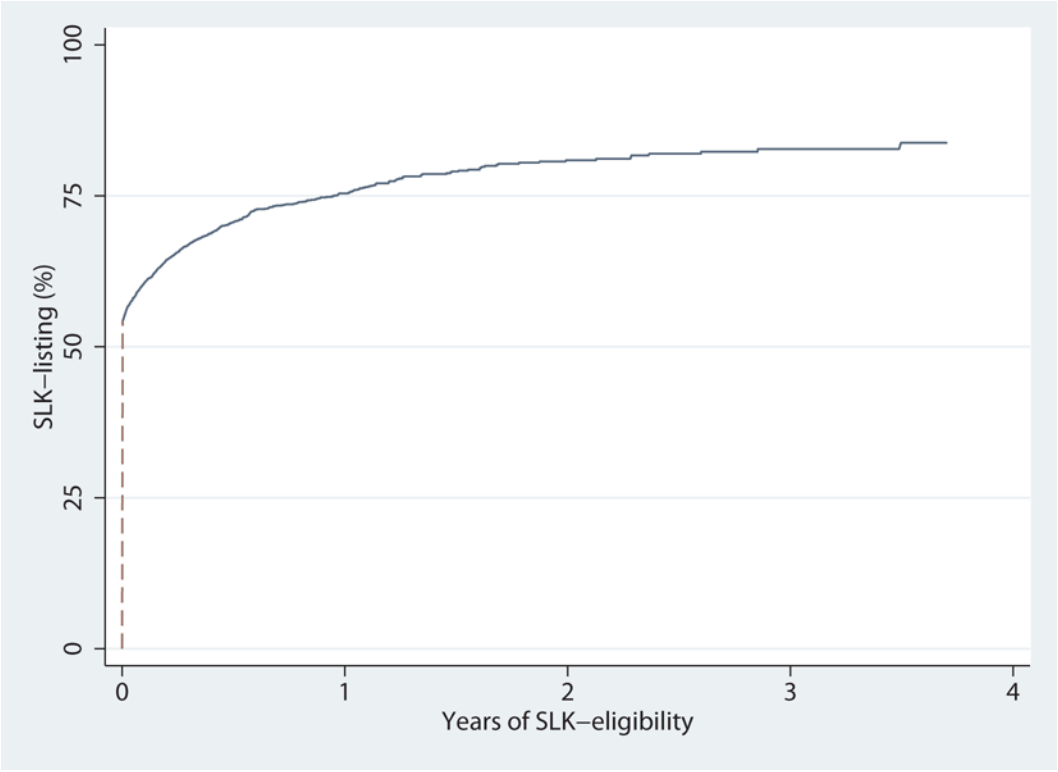

Figure 1.

Percentage of SLK-listing among SLK-eligible candidates. More than 50% of SLK-eligible candidates were listed immediately when eligible (dash line). Among SLK-eligible candidates listed for SLK, 96.2% were listed within 6 months after becoming eligible. We explored SLK-listing using 2 unique models based on the distribution of our observed data: (1) multilevel logistic regression for immediate listing (dash line) and (2) multilevel mixed-effects parametric survival regression for listing after eligibility (solid line).

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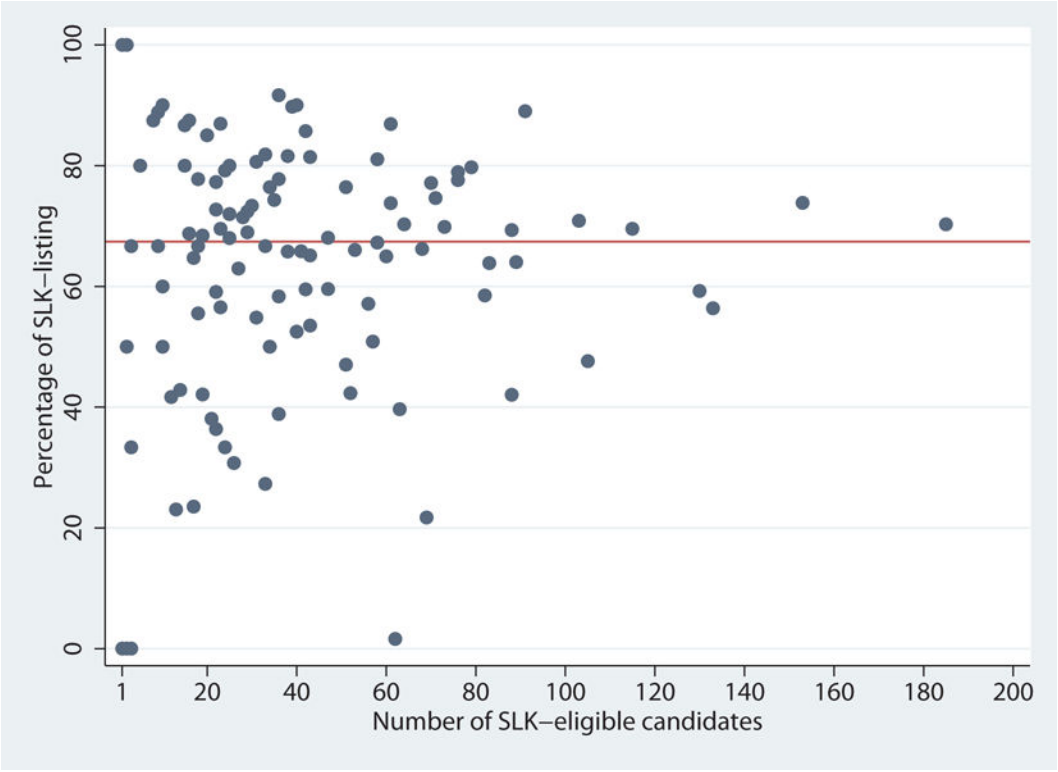

Figure 2.

Percentage of SLK-listing (within 6 months of eligibility) by number of SLK-eligible liver candidates. The number of SLK-eligible candidates over the study period ranged from 1 to 185 across centers. The percentage of SLK-listing ranged from 0% to 100%. Even among centers with > 50 total SLK-eligible candidates, the percentage listed for SLK ranged from 1.6% to 89.0%.

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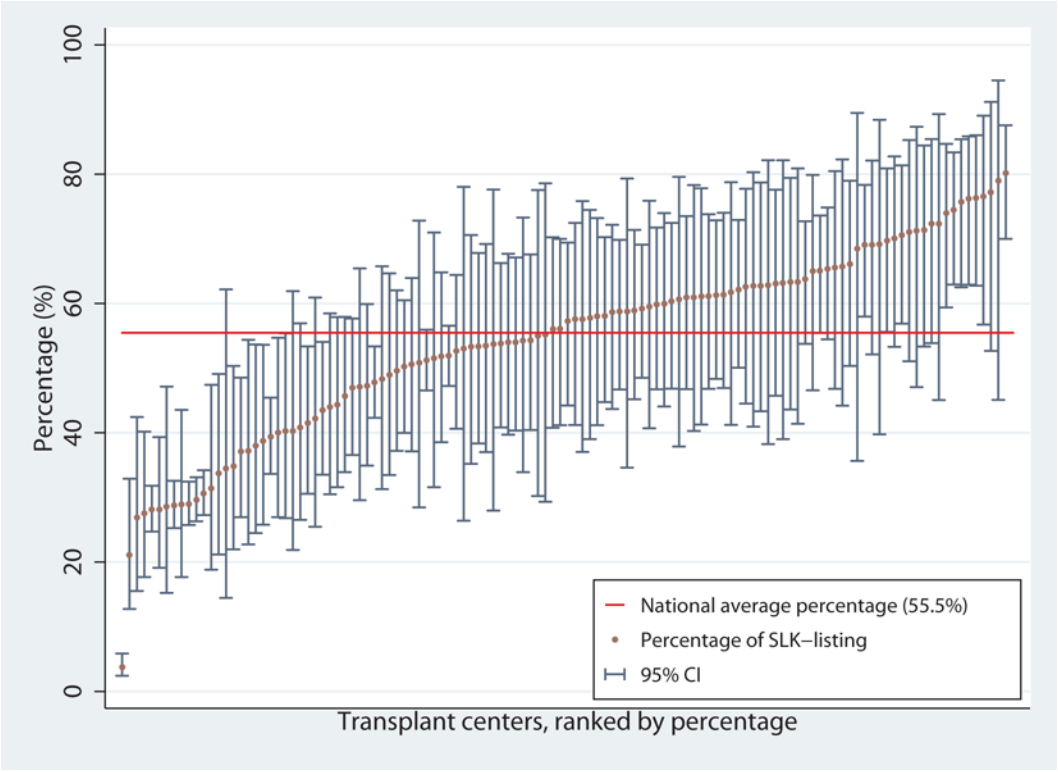

Figure 3.

Casemix-adjusted SLK-listing percentage (within 6 months of eligibility) among SLK-eligible liver candidates by center. The percentage was calculated for a 60 year old, non-African American male with a MELD of 25, a GFR of 30, with no history of hypertension, diabetes or any previous transplant. The national average percentage for SLK-listing was 55.5% (red horizontal line), and ranged from 3.8% to 80.2%. There were 38 (31.7%) centers that had SLK-listing percentage less than 50%.

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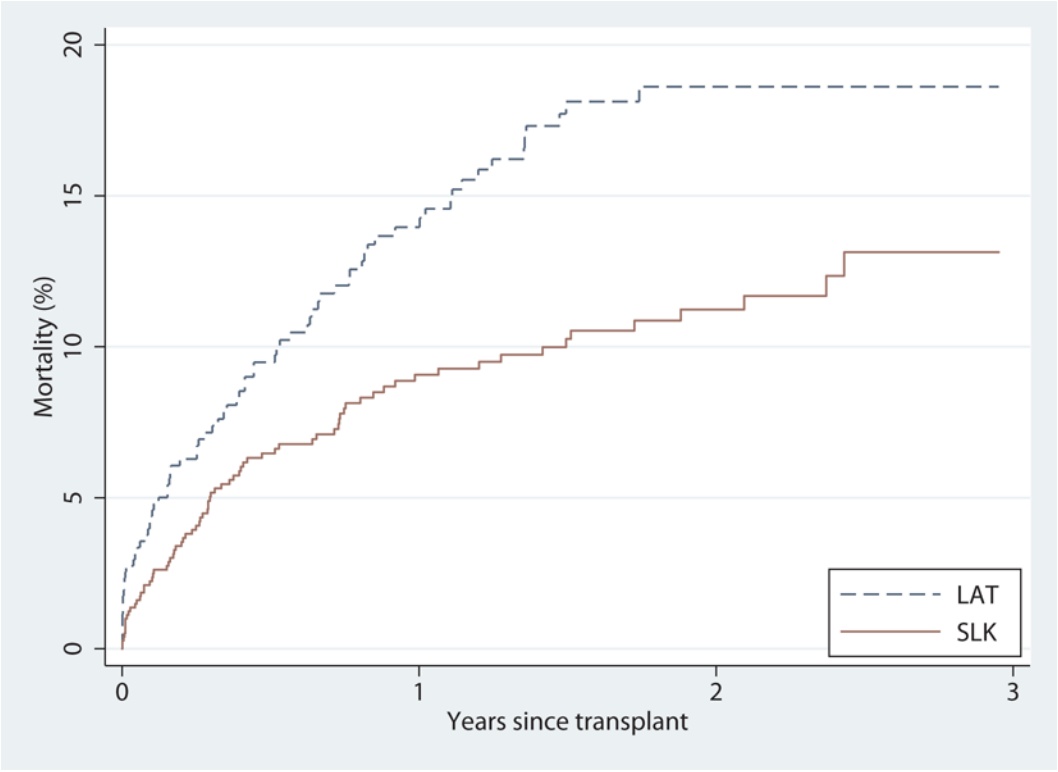

Figure 4.

Posttransplant mortality of SLK and LAT (liver-alone transplantation) among SLK-eligible candidates. SLK recipients had higher posttransplant survival than LAT recipients ($p<0.001$). After adjusting for recipient gender, race, age, biologic MELD, eGFR, previous transplant, hypertension, diabetes, and the Donor Risk Index (DRI), posttransplant survival was still higher among SLK recipients (hazard ratio=$_{0.43}0.61_{0.87}$, p=0.006).

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Table 1

OPTN proposed SLK medical eligibility criteria.[3]

For adult SLK candidates, they must meet 1 of the 3 criteria listed below:	
If the candidate's transplant nephrologist confirms a diagnosis of:	Then the transplant program must report in the UNOS computer system and document in the candidate's medical record:
1) Chronic kidney disease (CKD) with a measured or calculated glomerular filtration rate (GFR) less than or equal to 60 mL/min for greater than 90 consecutive days	At least 1 of the following: • That the candidate has begun regularly administered dialysis as an end-stage renal disease (ESRD) patients in a hospital based, independent nonhospital based, or home setting. • At the time of registration on the kidney waiting list, that the candidate's most recent measured or calculated creatinine clearance (CrCl) or GFR is less than or equal to 30 mL/min. • On a date after registration on the kidney waiting list, that the candidate's measured or CrCl or GFR is less than or equal to 30 mL/min.
2) Sustained acute kidney injury	At least 1 of the following, or a combination of both of the following, for the last 6 weeks: • That the candidate has been on dialysis at least once every 7 days. • That the candidate has a measured or calculated CrCl or GFR less than or equal to 25 mL/min at least once every 7 days. If the candidate's eligibility is not confirmed at least once every 7 days for the last 6 weeks, the candidate is not eligible to receive a liver and a kidney from the same donor.
3) Metabolic disease	A diagnosis of at least 1 of the following: • Hyperoxaluria • Atypical HUS from mutations in factor H or factor I • Familial nonneuropathic systemic amyloidosis • Methylmalonic aciduria

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Table 2

SLK-eligible and listed candidates by individual medical criteria

The majority of the SLK-eligible candidates with sustained acute kidney injury or certain metabolic diseases were listed for SLK. However, the majority of the eligible candidates with chronic kidney disease were not listed for SLK.

Diagnosis	Criteria	SLK-eligible N	SLK-listing N (%)	Eligible Nonlisting N (%)
Chronic kidney disease	eGFR ≤ 60mL/min ≥ 90 consecutive days and subsequent 1 time eGFR ≤ 30mL/min	1,525	465 (30.5)	1060 (69.5)
Sustained acute kidney injury	dialysis or eGFR ≤ 25ml/min ≥ 6 weeks	3,173	2,689 (84.7)	484 (15.3)
Metabolic disease	hyperoxaluria, atypical HUS, systemic amyloidosis, or methylmalonic aciduria	38	37 (97.4)	1 (2.6)
Total		4,736	3,191 (67.4)	1,545 (32.6)

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Table 3
SLK-eligible candidate demographics and characteristics

Among 4,736 adult SLK-eligible candidates between June 18, 2013 and February 28, 2017, 67.4% were listed for SLK.

	Listed SLK-eligible candidates (N=3,191)	Unlisted SLK-eligible candidates (N=1,545)	p value
Age, median (IQR)	59 (53–63)	62 (57–66)	<0.001
Male (%)	61.4	49.7	<0.001
African American (%)	15.1	4.5	<0.001
MELD, median (IQR) *	22 (20–25)	23 (20–28)	<0.001
Exception points (%) *	10.8	14.8	<0.001
eGFR, median (IQR) *	16.6 (9.6–24.9)	25.6 (20.6–28.4)	<0.001
Prior transplant (%)	11.3	6.1	<0.001
Diabetes (%)	50.6	43.0	<0.001
Hypertension (%)	41.2	23.4	<0.001

* These time-varying characteristics were obtained at eligibility.

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Table 4

Center level characteristics of the 120 transplant centers with SLK-eligible candidates.

	Minimum	25th percentile	Median	75th percentile	Maximum
AA liver candidates, %	0.0%	3.9%	6.6%	13.2%	24.8%
Liver transplant volume *	0	79	156	280	765
Kidney transplant volume *	0	152	238	409	871
SLK transplant volume *	0	7	14	27	120
Median MELD at transplant	22	25	29	33	40

* Liver, kidney, and SLK transplant volumes were cumulative transplant volumes over the study period. AA, African American.

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Table 5
Characteristics associated with SLK-listing among SLK-eligible liver candidates

Odds ratios (ORs) represent likelihood of immediate SLK-listing; OR>1 indicates **higher** likelihood of immediate SLK listing. Time ratios (TRs) represent ratio of time to SLK-listing if candidates were not listed for SLK immediately; TR>1 indicates **longer** time and **lower** likelihood to SLK-listing.

	OR of immediate SLK-listing	P value	TR of later SLK-listing	P value
Patient-level characteristics				
Age (per 10 year increments)	$_{0.50}$ 0.55 $_{0.60}$	<0.001	$_{1.25}$ 1.39 $_{1.56}$	<0.001
Male	$_{1.22}$ 1.41 $_{1.62}$	<0.001	$_{0.66}$ 0.79 $_{0.94}$	0.007
African American	$_{1.75}$ 2.23 $_{2.84}$	<0.001	$_{0.40}$ 0.55 $_{0.75}$	<0.001
MELD (per 5 point increments)	$_{0.77}$ 0.82 $_{0.88}$	<0.001	$_{0.44}$ 0.47 $_{0.51}$	<0.001
eGFR (per 5 ml/min/1.73 increments)	$_{0.67}$ 0.70 $_{0.73}$	<0.001	$_{1.21}$ 1.25 $_{1.30}$	<0.001
Prior transplant	$_{1.30}$ 1.68 $_{2.17}$	<0.001	$_{0.81}$ 1.15 $_{1.63}$	0.4
Diabetes	$_{1.18}$ 1.35 $_{1.56}$	<0.001	$_{0.62}$ 0.74 $_{0.89}$	0.001
Hypertension	$_{1.83}$ 2.13 $_{2.48}$	<0.001	$_{0.68}$ 0.82 $_{1.01}$	0.06
Center-level characteristics				
Percentage of AA liver candidates	$_{0.90}$ 1.01 $_{1.14}$	0.8	$_{0.99}$ 1.13 $_{1.28}$	0.07
Liver transplant volume *	$_{0.94}$ 0.96 $_{0.97}$	<0.001	$_{1.02}$ 1.03 $_{1.06}$	<0.001
Kidney transplant volume *	$_{0.99}$ 1.00 $_{1.01}$	0.3	$_{0.98}$ 0.99 $_{1.00}$	0.02
SLK transplant volume *	$_{1.32}$ 1.50 $_{1.70}$	<0.001	$_{0.63}$ 0.72 $_{0.82}$	<0.001
Median MELD at transplant	$_{0.93}$ 0.97 $_{1.00}$	0.054	$_{1.00}$ 1.04 $_{1.09}$	0.04

*For liver, kidney, and SLK transplant volume, the adjusted OR is per 10 transplants. Liver, kidney, and SLK transplant volumes are cumulative transplant volumes over the study period.

**We explored SLK-listing using 2 unique models based on the distribution of our observed data: (1) multilevel logistic regression for immediate listing and (2) multilevel mixed-effects parametric survival regression for listing after eligibility. For the logistic regression model that described immediate SLK-listing among SLK-eligible candidates, we reported an odds ratio for listing. For this population, an odds ratio (OR) of greater than one indicates a higher chance of SLK-listing. For the parametric survival regression model that described SLK-listing after becoming eligible, we reported a time ratio (TR) to listing. A time ratio of greater than one indicates a longer time to SLK-listing and thus, a lower likelihood of listing.