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Characterization of Waiting Times in a Simulation of Kidney Paired Donation

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A national kidney paired donation (KPD) program will substantially increase transplant opportunities for recipients with blood type incompatible or cross-match positive donors. It seems likely that donor–recipient pairs with certain blood types, races or restrictions will wait longer than others for a match, although no data exist to confirm this assumption. We simulated patients and characterized the predicted waiting times for different blood type sub-groups, as well as the effects of patient-imposed restrictions on waiting time. We also compared waiting times of different racial sub-groups. Almost all patients with panel-reactive antibody (PRA) less than 80% match within a few months in a national KPD program, with the longest waiting time seen by O recipients with AB donors. Highly sensitized patients wait considerably longer, especially those unwilling to travel or accept older donors, and those with AB or B donors may not match in a timely manner. Although patients are better served by matching in a combined pool than within their own race, racial inequalities exist and bonus points can offset some of these differences. These data provide the first waiting time predictions that can aid patients with incompatible donors in choosing between KPD and desensitization, and can also facilitate planning for a national KPD program.

Key words: Kidney swap, live donor kidney transplantation, paired kidney exchange (PKE)

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Introduction

In 2004, more than 27 000 patients with end-stage renal disease were added to the deceased donor waiting list, while fewer than 16 000 underwent kidney transplantation (1). While deceased donor kidney transplantation has increased only 18% in the last decade, live donor transplantation has nearly doubled. Still, it is predicted that an additional 3500 potential live donors per year are excluded from donating to their intended recipients because of blood type incompatibility or positive cross-match (2). These patients can choose from deceased donor transplantation, desensitization strategies (3–11), or paired donation (2,12–18).

We have previously shown that the most efficient and cost-effective way of transplanting incompatible donor–recipient pairs is through live donor kidney paired donation (KPD), a program where pairs with complementary incompatibilities are matched to receive compatible kidneys (2,12). Preliminary programs have been implemented on local or regional levels (1,13), but data clearly demonstrate that an optimized national system will yield the greatest benefit for the most people (12,18). As a result, a consensus conference was convened in March 2005, and the agenda included the discussion of a national KPD program (19). Furthermore, a similar proposal is under consideration by the kidney/pancreas committee of UNOS (20).

One advantage of live donor kidney transplantation is immediate organ availability, whereas a possible barrier to patient participation in a KPD program is the unknown waiting time for a matched pair. A nationwide registry of incompatible pairs has never been created. Simulations have suggested that some sub-groups may be better served by KPD than others (2), but no data exist regarding predicted waiting times based on donor and recipient characteristics, including blood group, sensitization and race. Since several options now exist for patients with incompatible donors, this information will be critical to clinical decision making.

Furthermore, racial equity may be considered in the creation of a national KPD program. Of the candidates currently awaiting kidney transplantation, 40% are Caucasian, 35% African American and 17% Hispanic, yet of the patients receiving kidney transplants in 2004, 55% were Caucasian, 23% African American and 13% Hispanic (1). This disparity for African Americans is magnified by the fact that deceased donor outcomes are significantly worse for African American patients than for Caucasians (21–24). Live donor transplantation seems to afford African American patients graft function similar to other races (25), but unfortunately this sub-group has the lowest rate of live donation. Of patients who received a kidney in 2004, 48%

of Caucasians received a kidney from a live donor as compared with 26% of African Americans (1). KPD offers a potential opportunity for expanding the live donor pool for patients who are not sufficiently served by currently available modalities.

We followed a cohort of simulated patients through a KPD program for several years to predict median waiting times for blood type and sensitization sub-groups of recipients. Furthermore, we determined the effects of time between match runs, patient preferences and restrictions, race, minority bonuses and the accumulation of patients on the KPD waiting list.

Methods

Simulated patients

We simulated incompatible donor–recipient pairs using a decision tree model that we recently described (2), based on a model from prior studies (12,26,27). In brief, each patient and his potential donor pool of parents, siblings, spouse, friends and children are simulated with ages, races, geographic regions, blood types, panel-reactive antibody (PRA) sensitization and HLA antigens. From these potential donors, it is assumed that two will be willing to donate, and these donors undergo medical and psychosocial clearance as well as cross-matching with the recipient. Any willing, medically eligible donor who is blood type compatible undergoes direct donation. Similarly, any patient who remains with only a medically acceptable, ABO incompatible or positive cross-match donor is offered entry into a KPD program.

Estimated number of incompatible pairs

On the basis of the number of live donor kidney transplants performed in 2003, we previously estimated that 3584 incompatible pairs would be eligible per year for KPD (2). Of these pairs, some will pursue desensitization, although this is currently available in very few centers and 5% is likely an overestimate for the number of patients currently served by this modality. There are no other options for these patients to receive a live donor kidney. Assuming that 5% of pairs will seek desensitization, and an additional 10% of patients or donors will decline to participate in a paired donation program and opt for deceased donor transplantation, we estimate that 3000 pairs per year, or 250 pairs per month, will apply for KPD when a national program becomes available.

KPD matching

Optimized KPD matching was performed on a personal computer as previously described (12), using a matching procedure based on the Edmonds algorithm (28,29). In an optimized match, every possible combination of compatible matches from the donor–recipient pool was considered, and the combination that yielded the most and highest quality transplants was selected. For experiments where more than one round of KPD matching was simulated, bonus points were given to pairs according to the time waiting in the KPD program.

Likelihood of matching

To determine the likelihood of matching after one round of KPD, cohorts of various sizes were simulated and entered into an optimized match. The fraction of patients that successfully matched from each blood type and PRA sub-group was calculated.

Median waiting time

We followed cohorts of incompatible pairs through 3 years of KPD matches to determine the median waiting time for each blood type and PRA subgroup. Each experiment was repeated 30 times. For most experiments, an optimized match was performed monthly. An initial cohort of 250 donor–recipient pairs was simulated and followed throughout the 3-year period. Each month, an optimized match was performed, and 250 new pairs were added to the incompatible pool. Waiting time of all patients from the initial cohort was determined, and median waiting time was calculated for each blood type and PRA sub-group. The fraction of patients from the initial cohort that matched after each of the 3 years was also calculated. In one set of experiments, an interval of 4 months was compared with monthly intervals to determine if waiting times would change when 1000 pairs were allowed to accumulate between each round of KPD. In another set of experiments, the 13th cohort generated (i.e. the cohort generated after 1 year of a KPD program) was followed for 3 years and compared to the initial cohort, to determine the effect of an accumulated queue of patients on subsequent waiting time of new patients.

Matching by race

Since blood type distributions and cohort sizes vary by race, we compared median waiting times for patients of different races. In a first scenario, patients were entered into an optimized match only within their race. In a second scenario, patients of all races were entered into a combined optimized match, and median waiting time was reported by race. In a final scenario, bonus points were given in an effort to balance matching inequalities for minority races. In all cases, a cohort of 250 patients was followed for 3 years as above, with a racial distribution based on UNOS data (1,12). On average, each cohort included 136.9 Caucasian, 27.1 African American and 18.7 Hispanic patients with PRA $<80\%$ and 49.8 Caucasian, 9.8 African American and 7.6 Hispanic patients with PRA $\geq 80\%$.

Statistics

For every experiment, we generated random cohorts of donor–recipient pairs as described above. Each experiment was executed multiple times, each time using a newly simulated cohort, such that 50 000 patients were generated for each experiment. Statistical significance between numbers of pairs matched was calculated using Wilcoxon rank-sum.

Results

Likelihood of matching

Matching rates after one round of KPD differed greatly according to PRA (Table 1). For patients with PRA $<80\%$, the likelihood of matching was approximately 50% for most blood type sub-groups. Some benefit, but no more than approximately 10%, was seen with increasing cohort sizes. Very few pairs with blood type AB donors or blood type O recipients (except those with O donors) were matched. For highly sensitized patients (PRA $\geq 80\%$), match likelihood varied directly with cohort size for almost all blood type subgroups. As with less sensitized patients, pairs with blood type AB donors or O recipients fared the worst.

Median waiting time

Overall median waiting time was 0 (i.e. over 50% matched on the first round) for recipients of blood type A, B and AB, and 2 months for blood type O. Table 2 shows the breakdown of median waiting times for each sub-group of patients.

Table 1: Mean sub-group size and likelihood of matching after one round of KPD, based on donor/recipient blood types, recipient sensitization and size of cohort

		Mean sub-group size					
Blood type		100 pairs		250 pairs		1000 pairs	
Donor	Recipient	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80
O	O	10.32	8.45	24.91	21.05	103.34	81.50
A	O	26.08	3.54	65.42	8.84	263.12	34.42
B	O	8.55	1.12	21.73	3.00	86.66	11.18
AB	O	1.23	0.16	3.15	0.43	11.76	1.34
O	A	3.87	3.33	9.77	7.82	39.06	32.32
A	A	6.47	5.63	16.44	14.13	65.44	55.84
B	A	4.08	0.54	10.40	1.56	41.72	5.96
AB	A	2.67	0.35	6.31	0.91	26.62	4.24
O	B	1.36	1.05	3.38	2.50	12.74	10.38
A	B	4.21	0.56	10.84	1.39	43.64	5.34
B	B	1.42	1.13	3.32	2.84	13.68	11.00
AB	B	1.77	0.24	4.56	0.63	17.80	2.42
O	AB	0.18	0.14	0.44	0.37	2.04	1.44
A	AB	0.36	0.32	1.02	0.84	4.16	3.50
B	AB	0.22	0.27	0.61	0.57	2.04	1.66
AB	AB	0.18	0.19	0.44	0.46	2.00	1.64
		% Matched after 1 round					
Blood type		100 pairs		250 pairs		1000 pairs	
Donor	Recipient	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80
O	O	53%	3%	53%	5%	56%	14%
A	O	13%	1%	15%	1%	17%	2%
B	O	12%	0%	13%	1%	14%	1%
AB	O	0%	0%	1%	0%	2%	0%
O	A	54%	12%	56%	25%	55%	52%
A	A	50%	2%	52%	5%	54%	12%
B	A	70%	1%	76%	4%	83%	8%
AB	A	8%	0%	12%	0%	13%	0%
O	B	56%	7%	58%	14%	55%	34%
A	B	67%	2%	75%	3%	81%	12%
B	B	42%	1%	47%	2%	54%	3%
AB	B	6%	0%	9%	0%	9%	0%
O	AB	57%	19%	54%	34%	59%	63%
A	AB	53%	6%	55%	11%	54%	27%
B	AB	45%	2%	52%	5%	55%	19%
AB	AB	7%	0%	23%	0%	44%	1%

PRA = panel reactive antibody.

Likelihood to match after one round of KPD may not correlate with median waiting times for a given cohort. Even though only 10–15% of patients with PRA <80%, type O recipients, and type A or B donors matched after one round of KPD, a waiting time bonus allowed most of these patients to match within 3 months of entry into the program. Similar findings were seen for less sensitized pairs with type AB donors. For example, the fact that only 1% of PRA <80%, type O recipients with type AB donors match after 1 round of KPD may dissuade these patients from joining KPD programs. However, with an appropriate waiting time bonus, 75% match after 1 year, with a median waiting time of 10 months.

When compared with less sensitized patients, highly sensitized patients experienced significantly longer waiting times overall (14 months vs. 0 months, $p < 0.0001$) and within each blood type sub-group ($p < 0.0001$). As seen with less sensitized patients, but with greater differences, pairs with type O donors or AB recipients matched faster than other pairs.

Interval between match rounds

Although allowing larger cohort accumulation by waiting longer intervals between matches afforded higher match likelihood on the first round (Table 1), overall median waiting times were not improved but rather significantly worse with a longer interval (Table 3, $p < 0.0001$). Beyond a certain cohort size, the moderate increase in ability to match after one round is offset by the added time required to wait between rounds.

Table 2: Median waiting time (in months) and likelihood of matching after 1, 2 and 3 years through KPD

Blood type		Waiting time		% Matched After 1 year		After 2 year		After 3 Year	
Donor	Recipient	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80
O	O	0	11	100%	55%	100%	74%	100%	83%
A	O	3	*	100%	19%	100%	35%	100%	48%
B	O	3	*	100%	7%	100%	14%	100%	24%
AB	O	10	*	75%	0%	99%	0%	100%	2%
O	A	0	2	100%	87%	100%	95%	100%	97%
A	A	0	14	100%	48%	100%	67%	100%	77%
B	A	0	25	100%	32%	100%	51%	100%	61%
AB	A	3	*	100%	3%	100%	9%	100%	15%
O	B	0	5	100%	73%	100%	90%	100%	95%
A	B	0	19	100%	39%	100%	60%	100%	73%
B	B	0	*	100%	16%	100%	29%	100%	41%
AB	B	4	*	99%	3%	100%	5%	100%	10%
O	AB	0	3	100%	85%	100%	93%	100%	97%
A	AB	0	9	100%	60%	100%	79%	100%	87%
B	AB	0	12	100%	53%	100%	71%	100%	84%
AB	AB	0	*	100%	9%	100%	18%	100%	22%

Waiting time of 0 = matched on first round; * = fewer than half matched after 36 months; PRA = panel reactive antibody.

Table 3: Median waiting time (in months) by interval between match rounds

Blood type		Match round intervel 1 Month		4 Month	
Donor	Recipient	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80
O	O	0	11	0	16
A	O	3	*	8	*
B	O	3	*	12	*
AB	O	10	*	32	*
O	A	0	2	0	0
A	A	0	14	0	20
B	A	0	25	0	28
AB	A	3	*	12	*
O	B	0	5	0	4
A	B	0	19	0	24
B	B	0	*	0	*
AB	B	4	*	12	*
O	AB	0	3	0	0
A	AB	0	9	0	12
B	AB	0	12	0	16
AB	AB	0	*	0	*

Waiting time of 0 = matched on first round; * = fewer than half matched after 36 months; PRA = panel reactive antibody.

Patient preferences

Two of the most common restrictions requested by patients are unwillingness to match with a pair whose donor is significantly older than the patient's intended donor, and unwillingness to travel outside of a patient's geographic region. To determine the effects that these restrictions would have on waiting time for KPD match, we simulated cohorts with different preferences and followed them for 3 years of KPD rounds (Table 4). An overall significant difference was seen in median waiting time when recipients who accepted older donors when compared with those who refused older donors ($p < 0.0001$). Similarly, patients unwilling to travel outside of their region waited longer than those willing to travel ($p < 0.0001$).

Matching by race

Median waiting times for most PRA <80% blood type subgroups were similar between Caucasian, African American and Hispanic patients when all races were grouped together in the KPD match (Table 5). For each race, median waiting time was longer if the match was run only on the fraction of the cohort that was the same race.

Highly sensitized (PRA ≥ 80%) African American and Hispanic patients have longer waiting times than highly sensitized Caucasian patients ($p < 0.0001$). Matching within each racial sub-group, however, would not solve this problem, as overall median waiting time was worse for each race if races were matched separately ($p < 0.0001$). A minority bonus for African American and Hispanic patients partially offsets the waiting time disparity for these subgroups, but somewhat prolongs waiting times for highly sensitized Caucasian patients (Table 5).

Accumulation of waiting patients

When compared with waiting times for the initial cohort, overall median waiting times were significantly longer for a cohort of patients who entered the KPD program 1 year after the first cohort ($p < 0.0001$, Table 6). This is because of the added competition of unmatched patients who had accumulated bonus points after a year of waiting on the "KPD waiting list." For patients with PRA <80%, subgroups where most patients matched on the first round were unaffected (O donors, A and B recipients with non-AB donors). Highly sensitized (PRA ≥ 80%) patients were

Table 4: Median waiting time (in months) by patient preferences

Blood type		Patient preferences: older donors				Patient preferences: travel			
		Unrestricted		Restricted		Unrestricted		Restricted	
Donor	Recipient	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80
O	O	0	17	0	28	0	14	0	28
A	O	2	*	3	*	2	*	4	*
B	O	2	*	3	*	2	*	4	*
AB	O	10	*	13	*	10	*	13	*
O	A	0	3	0	5	0	2	0	5
A	A	0	21	0	35	0	19	0	33
B	A	0	*	0	*	0	28	0	*
AB	A	3	*	4	*	2	*	4	*
O	B	0	6	0	9	0	6	0	10
A	B	0	22	0	*	0	25	0	*
B	B	0	*	0	*	0	*	0	*
AB	B	4	*	5	*	3	*	5	*
O	AB	0	2	0	5	0	2	0	3
A	AB	0	7	0	20	0	9	0	16
B	AB	0	31	0	*	0	20	0	24
AB	AB	1	*	1	*	0	*	1	*

Waiting time of 0 = matched on first round; * = fewer than half matched after 36 months; PRA = panel reactive antibody.

most affected, with only 5 of 16 sub-groups matching over 50% of patients within 3 years as compared with 9 of 16 sub-groups with 50% matched from the original cohort. Depending on how many patients decide to defer KPD for desensitization or deceased donor transplantation, a significant queue of patients awaiting a KPD match may potentially accumulate over time and prolong median waiting times for many blood type sub-groups.

Discussion

In the past, patients with willing donors who were blood type incompatible or cross-match positive were excluded from live donor transplantation, and left only with the choice of waiting on the deceased donor registry. Recently, a number of options have become available including desensitization and paired donation (live donor and list paired donation) (2–18). Desensitization appears promising but is not yet widely available, list paired donation likely plays a minimal role on a national level (2), and live donor KPD has been limited to 56 patients and more than 40% of these patients have been transplanted at a single institution (1,13). Furthermore, while there is a great deal of interest in a national KPD program, one has not yet been implemented. Patients are thus left with a limited number of real options and even more limited information to distinguish between the options available.

Simulations suggest that the most cost-effective modality for transplanting incompatible donor–recipient pairs is a national KPD program utilizing an optimized matching algorithm (12). Almost all patients who would benefit from list paired donation are predicted to be better served by a national KPD program (2). With this evidence, and reports of excellent clinical outcomes from KPD (13), planning for a national KPD program should be a priority for the transplantation community (19,20).

KPD can be performed at any center capable of live donor kidney transplantation. The critical barrier to a successful national KPD program will be the acceptability of protocols by centers leading to a high level of participation. However, both patient and provider are likely to be wary of new modalities where clinical predictions are not available. While actual clinical data will not be available for several years after a national KPD program has been in practice, we are able to make reasonable assumptions now on the basis of available data and a model of the consequences of a national match.

Many factors will impact the waiting time for a particular incompatible pair to match in a national KPD program. One of the most significant factors is the blood type of the donor and recipient. In any paired donation program, donors with blood type O will be in demand, while donors with blood type AB will be difficult to match. Recipients with blood type AB will be more readily matched than those with blood type O, because AB recipients can accept many more kidneys than can O recipients.

Another significant factor for matching time is degree of recipient sensitization. For recipients with PRA <80%, waiting times will be relatively short if they have a cross-match positive donor of a compatible blood type, or if the donor/recipient blood type incompatibilities are A/B or B/A. However, even recipients with PRA <80% will experience lengthy waiting times if they need a donor of a blood type in greater demand than the donor with whom they register. Highly sensitized patients (PRA ≥ 80%) face

Table 5: Median waiting time (in months) by race and matching scenario

		Caucasian					
Blood type		Within race		All race		Minority bonus	
Donor	Recipient	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80
O	O	0	12	0	9	0	17
A	O	3	*	3	34	3	*
B	O	3	*	3	*	3	*
AB	O	10	*	10	*	10	*
O	A	0	2	0	2	0	2
A	A	0	15	0	12	0	19
B	A	0	24	0	19	0	22
AB	A	3	*	3	*	3	*
O	B	0	6	0	4	0	4
A	B	0	20	0	16	0	24
B	B	0	*	0	*	0	*
AB	B	4	*	4	*	3	*
O	AB	0	2	0	2	0	2
A	AB	0	8	0	9	0	8
B	AB	0	21	0	9	0	21
AB	AB	1	*	0	*	0	*
		African American					
Blood type		Within race		All race		Minority bonus	
Donor	Recipient	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80
O	O	0	*	0	21	0	15
A	O	3	*	4	*	3	*
B	O	3	*	3	*	3	*
AB	O	19	*	10	*	11	*
O	A	0	21	0	4	0	4
A	A	0	*	0	28	0	22
B	A	0	*	0	*	0	29
AB	A	6	*	4	*	4	*
O	B	0	23	0	7	0	7
A	B	0	*	0	*	0	32
B	B	0	*	0	*	0	*
AB	B	7	*	4	*	4	*
O	AB	0	10	0	3	0	4
A	AB	0	*	0	17	0	18
B	AB	0	*	0	29	0	12
AB	AB	3	*	1	*	1	*
		Hispanic					
Blood type		Within race		All race		Minority bonus	
Donor	Recipient	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80	PRA < 80	PRA ≥ 80
O	O	0	*	0	13	0	16
A	O	3	*	3	*	3	*
B	O	4	*	3	*	3	*
AB	O	27	*	11	*	12	*
O	A	0	15	0	2	0	3
A	A	0	*	0	20	0	18
B	A	0	*	0	*	0	33
AB	A	10	*	3	*	3	*
O	B	0	30	0	7	0	7
A	B	0	*	0	17	0	19
B	B	1	*	0	*	0	*
AB	B	13	*	4	*	4	*
O	AB	0	8	0	3	0	5
A	AB	0	*	0	6	0	5
B	AB	0	*	0	15	0	15
AB	AB	3	*	0	*	0	*

Waiting time of 0 = matched on first round; * = fewer than half matched after 36 months; PRA = panel reactive antibody.

Table 6: Median waiting time (in months) after accumulation of 1 year of patients

Blood type		Accumulated months			
		0 Month		12 Month	
Donor	Recipient	PRA $<$ 80	PRA $\geq$ 80	PRA $<$ 80	PRA $\geq$ 80
O	O	0	11	0	*
A	O	3	*	*	*
B	O	3	*	*	*
AB	O	10	*	*	*
O	A	0	2	0	0
A	A	0	14	0	*
B	A	0	25	0	*
AB	A	3	*	*	*
O	B	0	5	0	9
A	B	0	19	0	*
B	B	0	*	0	*
AB	B	4	*	*	*
O	AB	0	3	0	0
A	AB	0	9	0	15
B	AB	0	12	0	33
AB	AB	0	*	0	*

Waiting time of 0 = matched on first round; * = fewer than half matched after 36 months; PRA = panel reactive antibody.

longer waiting times regardless of blood type, but those with type O donors can expect to be matched relatively quickly.

Registrants can influence their waiting times by deciding on geographic restrictions for their match search. Since matching for a highly sensitized patient depends on the rare find of a cross-match negative donor, we anticipate that most highly sensitized patients will be willing to travel to increase their chances of finding a match. As previously demonstrated, the use of mathematical optimization helps minimize the need for traveling without adversely affecting match outcomes (12).

Racial disparities exist in renal transplantation, and a national KPD program may potentially assuage some of these inequities. Currently, median time to transplantation of Caucasian patients is 840 days, as compared with 1891 days for African Americans (1). Fortunately, a national KPD program is predicted to offer similar waiting times between races for most PRA $<$80% blood type sub-groups. Racial differences still exist, however, in KPD for highly sensitized (PRA $\geq$ 80%) patients, and matching within one's race does not correct but rather exacerbates these differences. A minority bonus can partially improve matching opportunities for African American and Hispanic patients, but at the expense of matching opportunities for Caucasians. The use of bonus points to offset racial differences remains an ethical question that will need to be resolved when planning a national KPD program. Regardless, all sub-groups will benefit from any program which increases live donor transplantation and thereby shrinks the deceased donor list.

As the paired donation program matures, we expect an accumulation of O recipients that mimics that of the deceased donor waiting list and indeed this is confirmed by the data presented here. Similarly, recipients with AB donors will accumulate on a KPD registry. As a result, the disparity between easy to match groups (with median waiting times less than 1 year) and more difficult to match groups (with median waiting times of 2 or more years) will likely grow. Potential methods of decreasing accrual of pairs that are difficult to match include desensitization for patients with low antibody titers, who are broadly sensitized (especially those with non-O donors), or matching high-titer pairs with the goal of a lower-titer match that is more amenable to desensitization (12).

A national optimized KPD program offers the most cost-effective modality for transplanting incompatible donor–recipient pairs (12). Clinical outcomes from KPD are excellent (13), and planning for a national KPD program is ongoing (19,20). A high level of participation will be critical to achieve the best possible results. We provide the first waiting time predictions, by blood type, sensitization, restrictions and race, to assist in the effective management of patients with incompatible donors and to facilitate planning for a national KPD program.

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