



A novel allocation scheme for deceased donor kidneys to balance equity and utility

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Background: Patients with sensitization and blood type O experience increased waiting times for deceased-donor kidney transplantation (DDKT). While allocation benefits are needed to resolve inequity in DDKT opportunity, whether DDKT has comparable outcomes in this disadvantaged population requires further study. This study assessed these outcomes and developed a new allocation system that balances equity and utility.

Methods: Patients from national and hospital cohorts from two centers in Korea were categorized as B1 to B4 (according to panel reactive antibody [PRA] positivity and ABO blood type) and A1 to A4 (based on the maximal PRA% and blood type), respectively. Competing risk and Cox regression analyses were performed to assess the effects of PRA and blood type on graft failure and mortality, respectively. Based on DDKT opportunities and posttransplant outcomes, a new scoring system for kidney allocation was developed.

Results: The national and hospital cohorts included 3,311 and 819 patients, respectively, who underwent DDKT. Despite the disparities in DDKT opportunities, the graft failure rates and mortality did not differ among the different PRA and blood type groups. Furthermore, posttransplantation outcomes did not differ according to the categories with different DDKT opportunities. A new scoring system to provide additional points to disadvantaged populations was developed based on the hazard ratios for DDKT.

Conclusion: A new allocation approach based on PRA and ABO blood types offers benefits to disadvantaged patients with fewer DDKT opportunities and could enhance equity without sacrificing utility in Korea, which has a long waiting time for DDKT.

Keywords: ABO blood-group system, Deceased donor kidney transplantation, Kidney allocation system, Panel reactive antibody, Sensitization

Introduction

Kidney transplantation is the optimal therapeutic option

for patients with end-stage renal disease (ESRD) [1]. In Asian countries, the donation rates of deceased donor organs are much lower than those in Western countries

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despite a relatively higher incidence of ESRD [2,3]. This disparity between organ supply and demand for deceased donor kidneys leads to an imbalance, resulting in extended waiting times for deceased-donor kidney transplantation (DDKT) in Asian countries compared with Western countries [4].

Sensitization to human leukocyte antigen (HLA) is a significant hurdle for successful DDKT [5,6]. The presence of anti-HLA antibodies significantly impacts the outcome of posttransplantation graft rejection [7,8]. Therefore, the determination of HLA sensitization is an essential step in the preparation for DDKT. Panel reactive antibodies (PRA) are indicators of sensitization. PRAs are calculated by exposing the serum of waitlisted patients to HLA antigens of the estimated donor pool bound to beads. The PRA results can be reported as a percentage value, providing an approximation of the likelihood of recipient-donor mismatch within a given donor pool as an indicator of overall sensitization [9].

Both PRA and ABO blood types profoundly influence the opportunities for DDKT [10]. We also previously demonstrated that sensitized patients and those with blood type O are unfairly disadvantaged in terms of DDKT accessibility in Korea [11]. Moreover, we developed an integrated system to assess DDKT accessibility that combined PRA status and ABO blood type [11]. These results suggested the need for a revised kidney allocation system that incorporates PRA and ABO blood type, especially given the extremely prolonged wait time for DDKT in Asian countries, including Korea.

The current kidney allocation system in Korea prioritizes waitlisted patients <19 years of age with additional points of 3 to 4, as well as pediatric waitlisted patients for pediatric donors. For kidneys procured from donors aged ≥19 years, waitlisted patients with zero mismatches for HLA A, B, and DR have priority. Among fully matched candidates, ABO-compatible candidates can receive kidneys when there are no candidates with the same ABO blood type. Next to the fully matched HLA candidates, allocation is determined by allocation points within the same ABO blood types. Allocation points are awarded based on several factors, including the degree of HLA match (0–4 points), duration on the waiting list (1 point for each year of waiting), history of previous kidney transplantation or repeated positive cross-match results (2 points), and history of personal or familial organ donation (2–4 points) [12]. Therefore, in

the current Korean kidney allocation system, no additional benefits are considered for inequity related to ABO blood types and sensitization, except for two points for repeated positive cross-match results.

However, severe organ shortages require consideration of the efficient utilization of limited deceased donors as another important aspect of organ allocation. Worse graft or patient outcomes resulting from increasing DDKT opportunities for waitlisted patients with disparity, such as sensitized patients with blood type O, is not the optimal use of limited resources. Therefore, a new allocation scheme to balance equity and utility must be developed. Given this background, we investigated the impact of sensitization and ABO blood types on posttransplant graft failure and mortality and proposed a revised scoring system to improve these disparities without sacrificing the efficiency of organ utilization.

Methods

Study population

Data from two cohorts were analyzed in this study. First, the national cohort was retrieved from the Korean Organ Network for Organ Sharing (KONOS) database between January 1, 2000 and December 31, 2018. A total of 18,974 patients including 3,311 DDKT patients, were included in the study from a total of 35,859 patients; 106 patients aged ≤18 years and 16,779 without PRA data were excluded (Fig. 1A). Second, the hospital cohort comprised 5,322 waitlisted patients from Severance Hospital and Seoul National University Hospital between 2000 and 2021. Of those, 4,722 waitlisted patients including 819 DDKT patients, were included in the study after excluding 133 patients ≤18 years who received additional points in the current Korean kidney allocation scheme and 477 patients without PRA data (Fig. 1B).

This study was performed in accordance with the 2000 Declaration of Helsinki [13] and the Declaration of Istanbul 2008 [14] and was approved by the Institutional Review Boards of Severance Hospital (No. 4-2023-0244) and Seoul National University Hospital (No. H-2304-061-1421). Informed consent was waived owing to the retrospective nature of the study design, which involved medical records without identifiable patient information.

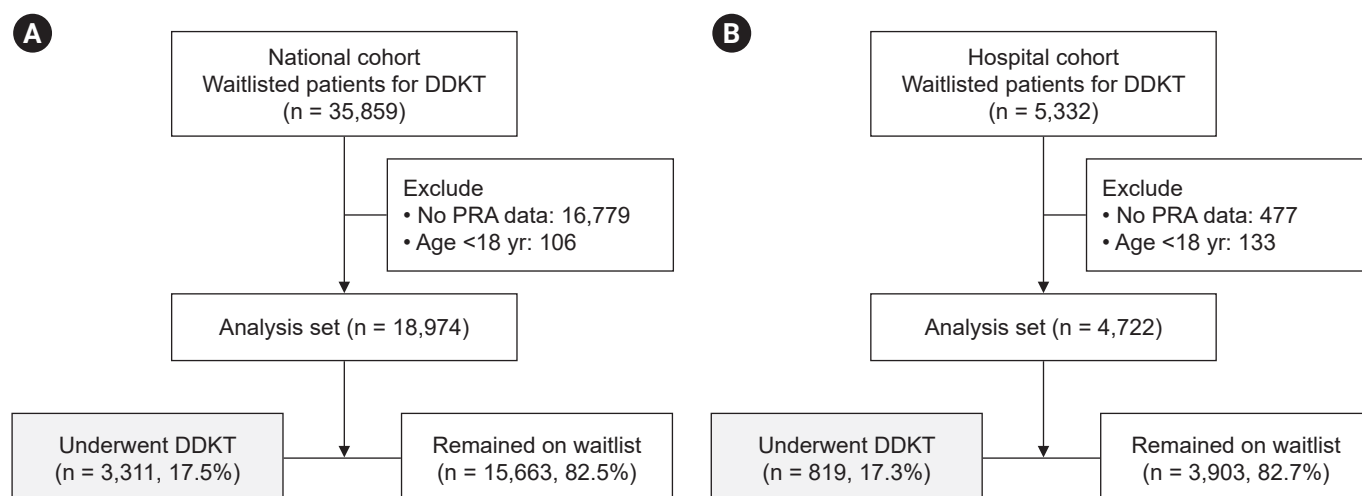


Figure 1. Study flowchart. (A) National cohort. (B) Hospital cohort. DDKT, deceased-donor kidney transplantation; PRA, panel reactive antibody.

Data collection

Clinical information such as age, sex, ABO blood type, PRA, HLA, waiting time for DDKT, status of diabetes mellitus, and donor information including kidney donor profile index (KDPI), sex, and ABO blood type were extracted. Information regarding death-censored graft failure was collected from the National Health Insurance Data Sharing Service. Information on patient deaths was collected through the KONOS and the Ministry of the Interior and Safety.

Panel reactive antibody information

In the hospital cohort, PRA was assessed using LABScreen single-antigen assays, LABScreen identification assays (One Lambda Inc.), LIFECODES single-antigen assays, or LIFECODES identification assays (Immunocor Inc.). Maximum PRA values in percentages (max PRA%) among class I and II PRA values in PRA identification assays or higher values (%) among class I and II calculated PRA (cPRA) in the single-antigen assays were used. In the national cohort, most PRA data were collected as positive or negative instead of as a specific percentage of PRA; therefore, these qualitative PRA results were used in the analysis. We defined a negative PRA as having a value of 0% for both PRA class I and class II. Conversely, we defined a positive PRA

as a case where either class I or class II showed a PRA value greater than 0%. Waitlisted patients were categorized into two or three PRA groups according to the max PRA% as follows: low (PRA < 80%) and high (PRA ≥ 80%) or low (PRA < 80%), intermediate (80% ≤ PRA < 99%), and high (PRA ≥ 99%) in the hospital cohort. They were also categorized into positive and negative PRA groups in the national cohort.

Categorization of waitlisted patients according to the combination of panel reactive antibody and ABO blood types

We categorized the national cohort into category B1 (negative PRA and blood type AB), B2 (negative PRA and blood type A or B; positive PRA and blood type AB), B3 (negative PRA and blood type O; positive PRA and blood type A or B), and B4 (positive PRA and blood type O) using PRA positivity and ABO blood types [11]. We also categorized patients in the hospital cohort into category A1 (PRA < 80% and blood type AB), A2 (PRA < 80% and blood type A or B; 80% ≤ PRA < 99% and blood type AB), A3 (PRA < 80% and blood type O; 80% ≤ PRA < 99% and blood type A or B; PRA ≥ 99% and blood type AB), and A4 (80% ≤ PRA < 99% and blood type O; PRA ≥ 99% and blood type A, B, or O) based on the combination of PRA (<80% or ≥80%) and ABO blood types (AB, A or B, O) [11].

Posttransplant outcomes according to panel reactive antibody, ABO blood types, and category

The primary outcomes were the death-censored graft failure and posttransplant mortality in patients who underwent DDKT.

Development of a scoring system for deceased-donor kidney allocation based on panel reactive antibody and ABO blood types

Based on the posttransplant outcomes and relative opportunity for DDKT reported previously, we developed a new scoring system to provide additional points to disadvantaged populations, such as those who were sensitized or with blood type O. If posttransplant outcomes were comparable between the reference and disadvantaged groups, additional points were derived from the adjusted hazard ratios (HRs) in the multivariate Cox regression analysis for DDKT opportunity.

Statistical analysis

Continuous variables were presented as medians (interquartile range [IQR]), and categorical variables were presented as absolute numbers (percentages). Continuous variables were compared using the Mann-Whitney U test or Kruskal-Wallis tests, while categorical variables were compared using the chi-square or Fisher exact tests, as appropriate. The Kaplan-Meier survival analysis was used to assess cumulative graft failure rates and mortality, and the log-rank test was used to compare outcomes between the PRA, ABO, and categorical groups. The independent associations of PRA groups, ABO blood types, and the categorical group with graft failure were analyzed using Fine and Gray competing risk regression models to estimate the subdistribution HR (sHR), accounting for death with functional graft and death while on the waiting list as a competing risk, respectively [15]. Cox regression analysis was used to examine the impact of PRA, ABO blood type, and categorical group on mortality. A p-value of <0.05 was considered statistically significant. All analyses were conducted using R software (ver. 4.2.2, R Foundation for Statistical Computing; www.r-project.org.).

Results

Clinical characteristics of the national and the hospital cohorts

The national cohort included 3,311 DDKT patients. The median age at DDKT was 56.0 years (IQR, 48.0–63.0 years) and 1,294 (39.4%) were female. Of these, 231 (7.0%) died during the follow-up period and 183 of DDKT recipients (5.5%) experienced graft failure. The patients were stratified into four categories according to comparable DDKT opportunities as follows: B1, 336 (10.1%); B2, 1,472 (44.5%); B3, 1,201 (36.3%); and B4, 302 (9.2%). Patients in category B4 were more likely to be female (Table 1).

A total of 819 patients in the hospital cohort underwent DDKT. The median age at DDKT was 56.0 years (IQR, 47.0–62.0 years), and 324 (39.6%) were female. Of these, 62 (7.6%) died during the follow-up period, and 78 (9.5%) experienced graft failure. The patients were stratified into four categories based on comparable opportunities for DDKT as follows: A1, 108 (13.2%); A2, 479 (58.5%); A3, 209 (25.5%); and A4, 23 (2.8%) (Supplementary Table 1, available online).

Graft failure and mortality according to panel reactive antibody

The cumulative graft failure rates were comparable between the PRA groups in the national ($p = 0.26$) (Fig. 2A) or hospital cohorts ($p = 0.10$) (Supplementary Fig. 1A, available online). Competing risks regression analysis revealed that graft failure rates did not increase in the positive PRA group compared with the negative PRA group (sHR, 0.97; 95% confidence interval [CI], 0.67–1.40; $p = 0.85$) (Table 2). Similarly, graft failure rates did not significantly increase in the high PRA group compared with the low PRA group (sHR, 1.98; 95% CI, 0.92–4.27; $p = 0.08$) (Supplementary Table 2, available online).

The cumulative mortality rates were also similar between the PRA groups in the national ($p = 0.94$) (Fig. 2B) or hospital cohorts ($p = 0.17$) (Supplementary Fig. 1B, available online). Cox regression analysis revealed that PRA sensitization did not significantly affect mortality. The positive PRA group in the national cohort exhibited no increase in mortality compared with the negative PRA group (HR, 1.22;

Table 1. Clinical characteristics of the national cohort

Characteristic	Category				Total	p-value
	B1	B2	B3	B4		
No. of patients	336 (10.1)	1,472 (44.5)	1,201 (36.3)	302 (9.1)	3,311 (100)	
Age at registration (yr)	52.0 (43.0–59.0)	52.0 (43.0–58.0)	51.0 (43.0–57.0)	52.0 (45.0–58.0)	51.0 (43.0–58.0)	0.21
Age at transplantation (yr)	55.0 (46.0–63.0)	56.0 (48.0–63.0)	56.0 (48.0–63.0)	57.0 (51.0–64.0)	56.0 (48.0–63.0)	0.04
Sex						<0.01
Male	236 (70.2)	1,011 (68.7)	638 (53.1)	132 (43.7)	2,017 (60.9)	
Female	100 (29.8)	461 (31.3)	563 (46.9)	170 (56.3)	1,294 (39.1)	
Diabetes mellitus						0.19
None	243 (72.3)	1,076 (73.1)	906 (75.4)	260 (86.1)	2,485 (75.0)	
Yes	93 (27.7)	396 (26.9)	295 (24.6)	42 (13.9)	826 (25.0)	
Graft failure	23 (6.8)	83 (5.6)	64 (5.3)	13 (4.3)	183 (5.5)	0.14
Death during follow-up period	24 (7.1)	108 (7.3)	77 (6.4)	22 (7.3)	231 (7.0)	0.82

Data are expressed as number (%) or median (interquartile range).

Category B1: panel reactive antibody (PRA) negative/AB. Category B2: PRA negative/A or B, PRA positive/AB. Category B3: PRA negative/O, PRA positive/A or B. Category B4: PRA positive/O.

95% CI, 0.92–1.61, $p = 0.17$) (Table 3). When PRA was categorized as high (PRA $\geq 80\%$) or low (PRA $< 80\%$) in the hospital cohort, the high PRA group exhibited no increase in mortality compared with the low PRA group (HR, 1.04; 95% CI, 0.35–3.06; $p = 0.06$) (Supplementary Table 3, available online).

Graft failure and mortality according to ABO blood type

Comparison of cumulative graft failure rates according to ABO blood type revealed no significant differences in the national ($p > 0.99$) (Fig. 3A) or hospital cohorts ($p = 0.45$) (Supplementary Fig. 2A, available online). Compared with patients with blood types A or B, those with blood types AB (sHR, 1.07; 95% CI, 0.43–2.63; $p = 0.89$) and O (sHR, 1.15; 95% CI, 0.56–2.36; $p = 0.71$) in the national cohort did not show a difference in graft failure rates (Table 2). Similar results were observed in the hospital cohort (Supplementary Table 2, available online).

The cumulative mortality rate revealed no significant differences among ABO blood types in the national ($p = 0.90$) (Fig. 3B) or hospital cohorts ($p = 0.77$) (Supplementary Fig. 2B, available online). Compared to blood types A or B, blood types AB (HR, 0.97; 95% CI, 0.67–1.41; $p = 0.88$ in the national cohort) and O (HR, 1.01; 95% CI, 0.73–1.40; $p = 0.96$ in the national cohort) demonstrated no significant differences in mortality (Table 3). The results for the hospital cohort were similar (Supplementary Table 3, available

online).

Graft failure and mortality according to the categorical group

Comparison of cumulative graft failure rates according to categorical groups in both cohorts revealed no significant difference in graft failure rates among categories B1–4 in the national cohort ($p = 0.83$) (Fig. 4A) or categories A1–4 in the hospital cohort ($p = 0.35$) (Supplementary Fig. 3A, available online). Specifically, we observed no significant differences in graft failure rates across categories (B1: reference; B2: sHR, 0.89 [$p = 0.65$]; B3: sHR, 1.02 [$p = 0.96$]; B4: sHR, 0.93 [$p = 0.85$]) in the national cohort (Table 2) and across categories A1–4 as well as categories B1–4 in the hospital cohort (Supplementary Table 2, available online).

The post-DDKT mortality rates did not differ among category B groups in the national cohort ($p = 0.81$) (Fig. 4B) or category A groups in the hospital cohort ($p = 0.77$) (Supplementary Fig. 3B, available online). Analysis of mortality rates showed no significant differences across category B in the national cohort (B1: reference; B2: HR, 1.13 [$p = 0.59$]; B3: HR, 1.13 [$p = 0.60$]; B4: HR, 1.45 [$p = 0.23$]) (Table 3). Mortality rates did not differ across categories A or B in the hospital cohort (Supplementary Table 3, available online).

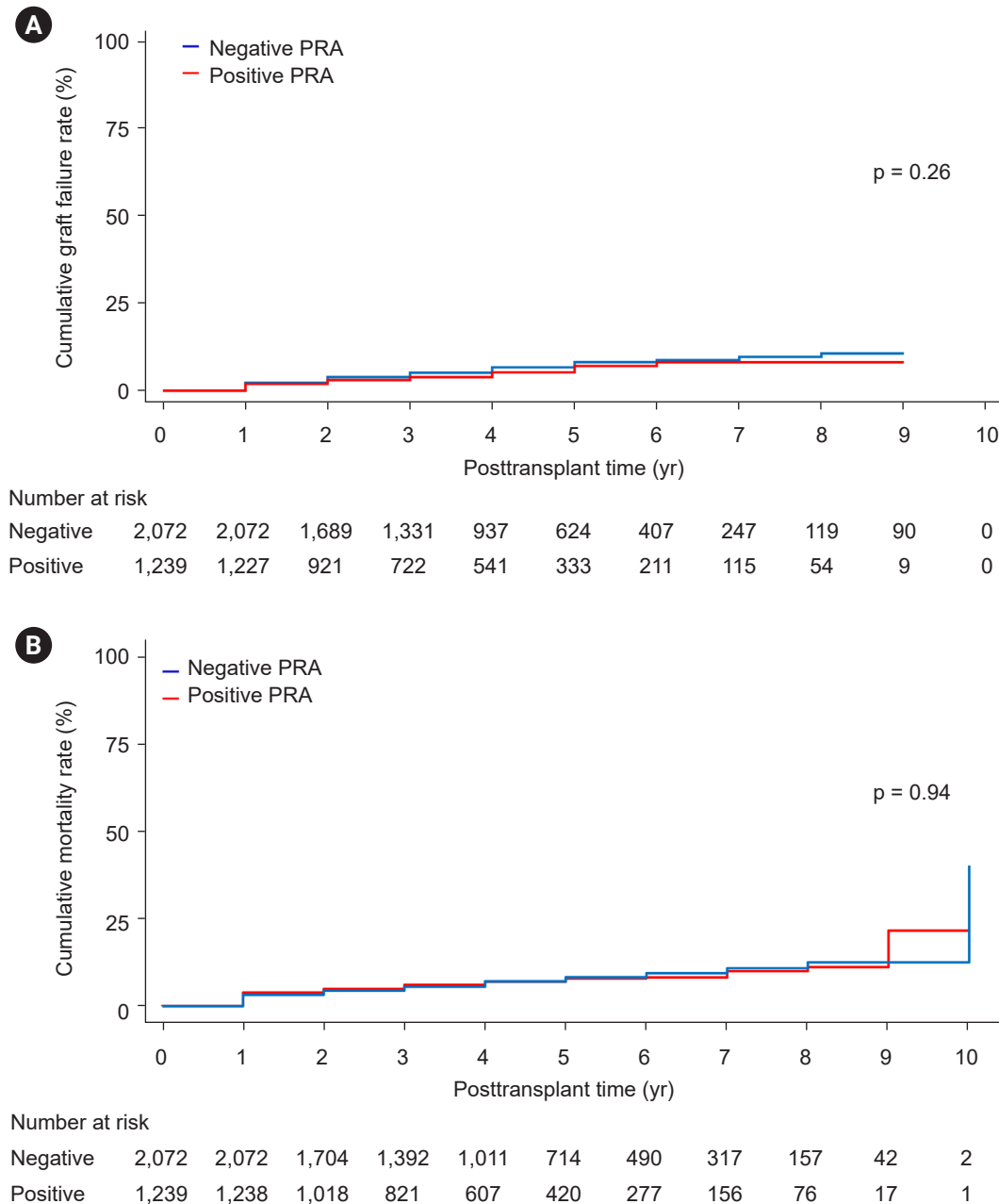


Figure 2. Cumulative graft failure rate and mortality according to PRA in the national cohort. (A) Cumulative graft failure rate according to PRA. (B) Cumulative mortality according to PRA. p-values for comparison between two PRA groups by log-rank test. PRA, panel reactive antibody.

Development of a new scoring system for deceased donor kidneys according to panel reactive antibody and ABO blood types.

Our analysis revealed no significant differences in post-transplant outcomes across different categories despite

differences in DDKT opportunities. Based on these results, we proposed a more equitable kidney allocation system by introducing an additional scoring framework using the reciprocal of DDKT opportunities. We calculated additional points for disadvantaged groups using the following equation: $[(1/\text{sHR}) - 1] \times \text{median waiting time (years) of the r}$

Table 2. Competing risk regression analysis of the impact of PRA, ABO blood type, and category on graft failure rates in the national cohort

National cohort	No. of events (%)	Model 1		Model 2		Model 3	
		sHR (95% CI)	p-value	sHR (95% CI)	p-value	sHR (95% CI)	p-value
PRA							
Negative	127 (69.7)	Reference		Reference		Reference	
Positive	56 (30.3)	0.81 (0.57–1.15)	0.25	0.90 (0.62–1.30)	0.56	0.97 (0.67–1.40)	0.85
ABO blood type							
A or B	116 (63.4)	Reference		Reference		Reference	
AB	28 (15.2)	0.98 (0.62–1.56)	0.95	0.98 (0.62–1.56)	0.95	0.94 (0.59–1.51)	0.81
O	39 (21.4)	1.00 (0.67–1.50)	0.99	1.00 (0.67–1.49)	0.98	1.06 (0.71–1.59)	0.77
Category							
B1	23 (12.4)	Reference		Reference		Reference	
B2	83 (45.5)	0.82 (0.49–1.37)	0.44	0.82 (0.49–1.37)	0.45	0.89 (0.53–1.49)	0.65
B3	64 (35.2)	0.85 (0.50–1.44)	0.54	0.89 (0.52–1.52)	0.68	1.02 (0.58–1.78)	0.96
B4	13 (6.9)	0.70 (0.33–1.50)	0.36	0.77 (0.36–1.67)	0.51	0.93 (0.42–2.04)	0.85

CI, confidence interval; PRA, panel reactive antibody; sHR, subdistribution hazard ratio.

Model 1: unadjusted model. Model 2: adjusted for age, sex, PRA (only in analysis according to ABO group), ABO blood types (only in analysis according to PRA group), and diabetes mellitus. Model 3: model 2 + adjusted for human leukocyte antigen mismatch number, waiting time for deceased-donor kidney transplantation, ABO-identical status, donor sex, and kidney donor profile index.

Category B1: PRA negative/AB. Category B2: PRA negative/A or B, PRA positive/AB. Category B3: PRA negative/O, PRA positive/A or B. Category B4: PRA positive/O.

Table 3. Cox regression analysis of the impact of PRA, ABO blood type, and category on mortality rates in the national cohort

National cohort	No. of events (%)	Model 1 ^a		Model 2 ^b		Model 3 ^c	
		sHR (95% CI)	p-value	sHR (95% CI)	p-value	sHR (95% CI)	p-value
PRA							
Negative	145 (62.8)	Reference		Reference		Reference	
Positive	86 (37.2)	1.01 (0.77–1.32)	0.93	1.11 (0.84–1.46)	0.47	1.22 (0.92–1.61)	0.17
ABO blood type							
A or B	146 (63.2)	Reference		Reference		Reference	
AB	37 (16.0)	1.03 (0.72–1.48)	0.86	1.01 (0.71–1.45)	0.94	0.97 (0.67–1.41)	0.88
O	48 (20.8)	0.94 (0.68–1.31)	0.72	1.00 (0.72–1.39)	0.99	1.01 (0.73–1.40)	0.96
Category							
B1	24 (10.4)	Reference		Reference		Reference	
B2	108 (46.8)	1.00 (0.64–1.56)	0.99	1.03 (0.66–1.61)	0.89	1.13 (0.72–1.78)	0.59
B3	77 (33.3)	0.89 (0.56–1.40)	0.61	1.00 (0.63–1.59)	0.99	1.13 (0.70–1.83)	0.60
B4	22 (9.5)	1.07 (0.60–1.91)	0.82	1.22 (0.68–2.18)	0.51	1.45 (0.79–2.65)	0.23

CI, confidence interval; PRA, panel reactive antibody; sHR, subdistribution hazard ratio.

Model 1: unadjusted model. Model 2: adjusted for age, sex, PRA (only in analysis according to ABO group), ABO blood types (only in analysis according to PRA group), and diabetes mellitus. Model 3: model 2 + adjusted for human leukocyte antigen mismatch number, waiting time for deceased-donor kidney transplantation, ABO-identical status, donor sex, and kidney donor profile index.

Category B1: PRA negative/AB. Category B2: PRA negative/A or B, PRA positive/AB. Category B3: PRA negative/O, PRA positive/A or B. Category B4: PRA positive/O.

reference group. The logic underpinning these equations focused on compensating for the extended wait times experienced by disadvantaged groups. The simulated model of the new scoring system was applied to the national and

hospital cohorts (Table 4). In the category B system in the national cohort, categories B2, B3, and B4 were awarded 4, 9, and 14, additional points, respectively, compared with reference B1, with a median wait time of 8 years. In the

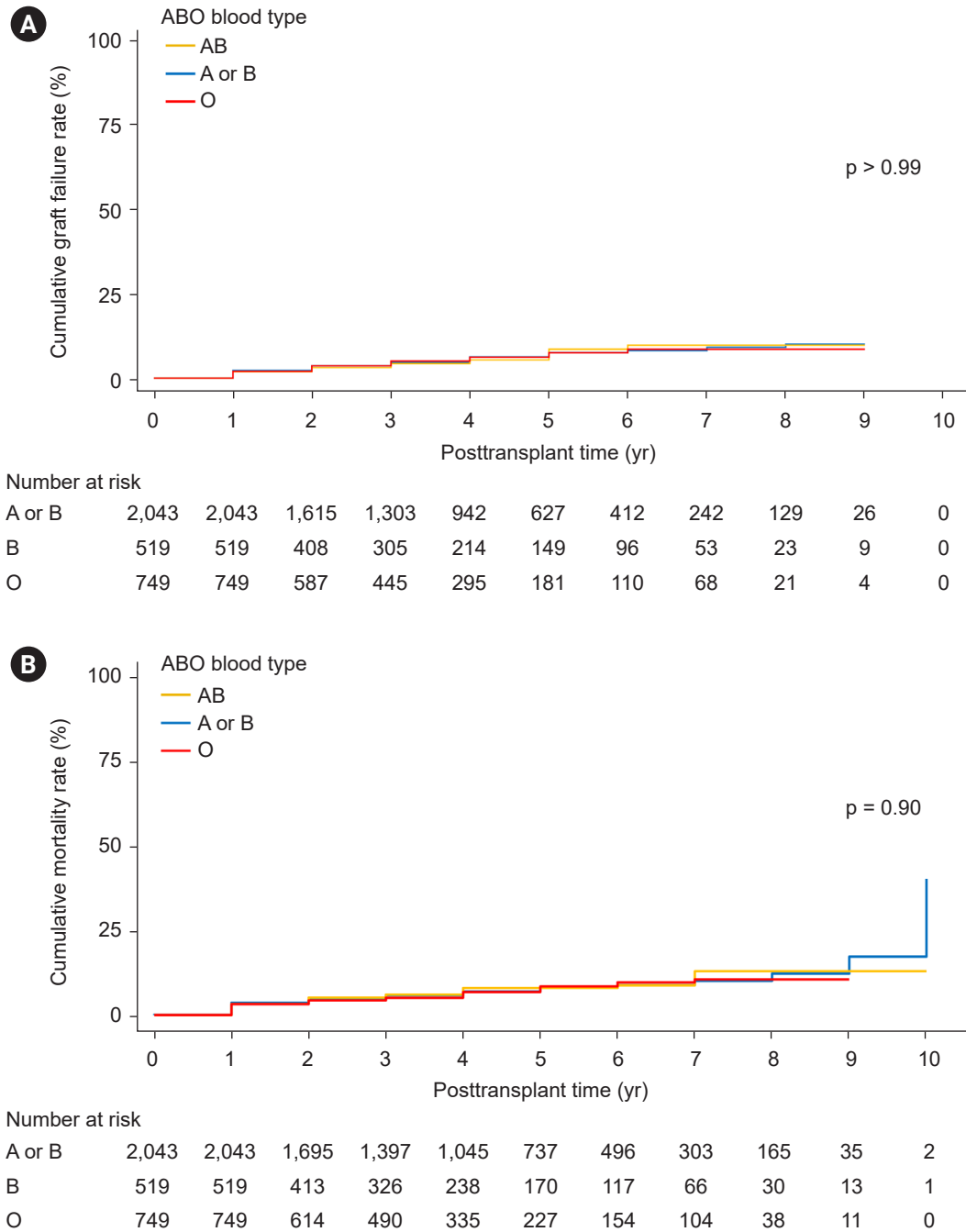


Figure 3. Cumulative graft failure rate and mortality according to ABO blood types in the national cohort. (A) Cumulative graft failure rate according to ABO blood types. (B) Cumulative mortality according to ABO blood types. p -values for comparison among three blood type groups by log-rank test.

category A system in the hospital cohort, categories A2, A3, and A4 were awarded 4, 11, and 28 additional points, respectively, compared with reference A1.

In contrast, we can allocate donor kidneys only to the

same ABO blood type. In this alternative system, we can modify compensatory points only in sensitized candidates. The simulation model using the above equation in this system provides 4 additional points to the positive PRA group,

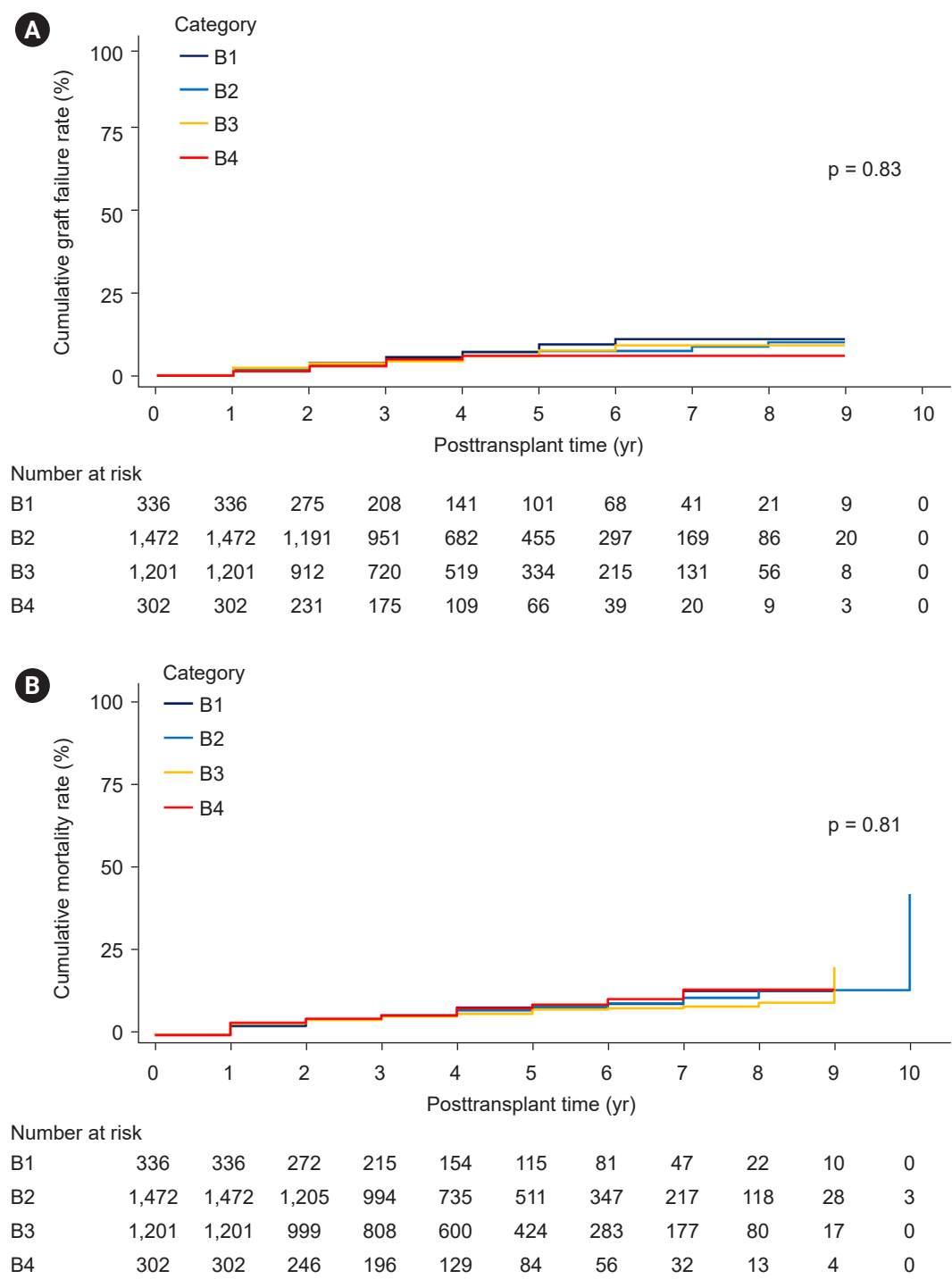


Figure 4. Cumulative graft failure rate and mortality according to category B in the national cohort. (A) Cumulative graft failure rate according to category B. (B) Cumulative mortality according to category B. p-values for comparison among four category B groups by log-rank test. Category B1: panel reactive antibody (PRA) negative/AB. Category B2: PRA negative/A or B, PRA positive/AB. Category B3: PRA negative/O, PRA positive/A or B. Category B4: PRA positive/O.

Table 4. DDKT opportunity according to ABO and PRA categories, and suggestive allocation points

Cohort	sHR (95% CI)	p-value	Median waiting time (year)	Additional score ^a
National cohort				
Category B1	Reference		8	0
Category B2	0.66 (0.59–0.75)	<0.01	11	4
Category B3	0.48 (0.42–0.54)	<0.01	16	9
Category B4	0.36 (0.31–0.42)	<0.01	NA	14
PRA negative	Reference		11	0
PRA positive	0.72 (0.67–0.77)	<0.01	NA	4
Hospital cohort				
Category A1	Reference		11	0
Category A2	0.71 (0.58–0.88)	0.01	12	4
Category A3	0.49 (0.39–0.62)	<0.01	13	11
Category A4	0.28 (0.18–0.44)	<0.01	NA	28
PRA < 80%	Reference		12	0
80% ≤ PRA < 99%	0.64 (0.49–0.83)	<0.01	18	7
PRA ≥ 99%	0.42 (0.26–0.68)	<0.01	NA	17

Multivariate model adjusted for age, sex, ABO blood types (only in analysis according to PRA group), and diabetes mellitus.

CI, confidence interval; DDKT, deceased-donor kidney transplantation; NA, not applicable; PRA, panel reactive antibody; sHR, subdistribution hazard ratio. Category B1: PRA negative/AB. Category B2: PRA negative/A or B, PRA positive/AB. Category B3: PRA negative/O, PRA positive/A or B. Category B4: PRA positive/O.

Category A1: PRA < 80%/AB. Category A2: PRA < 80%/A or B, 80% ≤ PRA < 99%/AB. Category A3: PRA < 80%/O, 80% ≤ PRA < 99%/A or B, PRA ≥ 99%/AB. Category A4: 80% ≤ PRA < 99%/O, PRA ≥ 99%/A or B, PRA ≥ 99%/O.

^a(1/sHR – 1) × median waiting time of reference group.

7 points to the intermediate PRA group (80% ≤ PRA < 99%), and 17 points to the high PRA group (PRA ≥ 99%) (Table 4).

Discussion

The results of this nationwide study demonstrated that groups disadvantaged in DDKT opportunities, such as sensitized patients with blood type O, have similar post-transplant outcomes to those of other groups. We also observed no significant differences in graft failure or mortality rates according to the PRA status, ABO blood type, or their combination. Based on these results, we developed a new scoring system for deceased-donor kidney allocation to provide additional points to compensate for the low DDKT accessibility of the disadvantaged group despite comparable posttransplant outcomes.

An efficient and equitable allocation system for limited organ resources is not only essential but is also implemented in various forms across different countries. However, even with established principles, a single universal organ allocation system cannot be applied because of the distinct socioeconomic circumstances and organ demand-supply

dynamics in each country or region [16]. Medical ethics have developed several principles to guide the decision-making process. The principle of utility focuses on ensuring that organ allocation results in the greatest benefit to most people. This may involve strategies that prioritize recipients who are likely to have a significant survival benefit or improved quality of life after transplantation [17,18]. Therefore, an allocation system grounded in utility emphasizes the maximization of overall societal benefit. However, the principle of equity treats individuals fairly and provides all patients with equal access to transplantation [19]. This includes “random allocation” or a “first-come, first-serve” approach, ensuring a fair chance for all individuals in need of transplantation. This principle attempts to balance the system by counteracting the disparities in organ allocation and fostering equal opportunities. Priority for vulnerable patients is another guiding principle that advocates for the preferential treatment of certain patient groups. For example, children or individuals with life-threatening conditions who lack alternative treatment options are considered vulnerable populations [18]. Systems that incorporate this principle believe in the moral obligation to allocate re-

sources to those in dire need. Finally, the principle of social usefulness emphasizes the societal contributions of potential recipients.

Navigating these principles and developing an organ allocation system that balances utility, equity, the needs of the vulnerable, and societal usefulness poses a complex challenge, which is further exacerbated by the unique socioeconomic circumstances and organ demand/supply situation of each country. The new kidney allocation system (KAS) introduced in the United States in 2014 proposes “longevity matching” to enhance organ utility [20]. This method prioritizes allocating the highest-quality kidneys to patients expected to have the longest posttransplant survival based on the KDPI, an index of donor kidney quality, and estimated posttransplant survival, an index of recipient prognosis [21,22]. Furthermore, the new KAS provides additional points to sensitized patients, for example, from 4 to 202 points in the highest cPRA group, to address inequity in DDKT opportunities [20]. The KAS is an example of balancing the utility and equity in organ allocation.

To address the inequity experienced by sensitized patients, many countries, including the United Kingdom, countries under the Eurotransplant system, Australia, and New Zealand, have implemented strategies that assign additional points to those with higher PRA [23–26]. This approach aims to increase opportunities for DDKT in highly sensitized patients.

Efforts have been made to address the disparities associated with ABO blood types, with a particular focus on the A2 subtype of blood type A [27–29]. Given the lower antigen expression of A2 subtype compared with A1, A2 bears functional similarities to blood type O, and A2B is akin to blood type B in terms of ABO antigen expression [30]. To enhance equity, the US has implemented measures to improve transplant accessibility for patients with blood type B, who typically face extended waiting periods. The new KAS prioritizes the allocation of A2 and A2B kidneys to B candidates without additional treatment [29,31,32]. This modification has led to increased utilization of A2 kidneys for blood type B candidates, while graft and patient outcomes have remained comparable to those observed in traditional ABO-compatible DDKT despite increased anti-A titers [33–36]. Moreover, a recent Canadian study proposed an innovative approach to address the disparity in kidney allocation for blood types B and O by introducing

a novel ABO-adjusted cPRA. This method adjusts the ABO sensitization to the same scale as the HLA sensitization. Similar to the cPRA computation based on HLA sensitization, ABO-adjusted cPRA is determined by the frequency of ABO blood types in the donor pools. Through this system, candidates with blood types B and O, who traditionally have fewer opportunities for DDKT, are awarded additional points in the kidney allocation process, thereby enhancing their chances of DDKT [37,38].

We previously demonstrated the serious inequities in DDKT opportunities according to PRA and ABO blood types in Korea [11]. An integrated categorization system using a combination of PRA status and ABO blood type successfully provided relative DDKT opportunities for each category. These data suggest that additional points should be provided according to the DDKT opportunity to compensate for the disadvantages of sensitization and ABO blood types. However, equity and utility must be balanced to change the allocation policy. Therefore, we need to check whether posttransplant outcomes in this disadvantaged group were comparable to those in the reference group after providing more benefits and DDKT opportunities to this group to enhance equity. This study confirmed that graft failure rates and mortality were similar across PRA groups, ABO blood groups, and combination categories, suggesting that the enhancement of equity concerning PRA and ABO blood types would not compromise utility in Korea.

An equitable revision of the KAS in Korea requires the appropriate allocation of points based on biological factors, including sensitization and ABO blood types. Based on the adjusted HR of the disadvantaged group compared with the reference group with the highest DDKT opportunity, we created an equation to award additional points to compensate for disadvantages in DDKT opportunity. Using this equation, we can provide additional points to various categories according to the combination of PRA status and ABO blood type to enhance equity in DDKT accessibility. We also proposed another scoring system based on the PRA status alone by allocating kidneys to waitlisted patients with the same blood types, excluding patients with compatible blood types in cases of full HLA matching. Taken together, this new scoring system could improve the KAS in Korea by mitigating disparities related to sensitization and ABO blood types, which were previously overlooked.

Considering the comparable posttransplant outcomes according to PRA status, ABO blood types, and integrated categories the new scoring system would enhance equity without sacrificing utility. However, in the context of Korea with a lower organ donation rate, the introduction of a new scoring system may require a more extended period for disadvantaged candidates to experience its benefits, compared to Western countries, where the introduction of new allocation systems had immediately increased DDKT rates in disadvantaged candidates [39].

This study has several limitations. First, cPRA was not implemented in our cohorts; instead, we utilized max PRA%, defined as the highest PRA values across PRA classes I and II. This could potentially overestimate actual PRA values, making direct comparisons with other kidney allocation systems based on cPRA difficult. We hope to use cPRA in future studies because an increasing number of Korean centers have introduced single-antigen PRA assays. Second, the influence of PRA% was exclusively examined within the hospital cohort, possibly limiting the representativeness of our findings to the entire Korean DDKT population because the national cohort supplied only PRA positivity data. Future studies could establish a more refined allocation model through precise mathematical modeling, utilizing a larger dataset of cPRA values. Third, we could not adjust immunosuppressive regimens and posttransplant complications in the multivariate analysis due to a lack of detailed information. Further studies to fully adjust these factors are needed to confirm our findings.

Nevertheless, this study, together with our previous study, demonstrated the impact of sensitization and ABO blood types on posttransplant outcomes, as well as DDKT opportunities in Korea, where the DDKT program is the most active in Asia, but still remarkably less active than that in Western countries [11]. These results contribute to an increased understanding of inequity in DDKT opportunities in Asia, with longer wait times and different environments from Western countries as most research has studied this issue in Western countries. Furthermore, we propose a new scoring system for kidney allocation in Korea to enhance equity related to sensitization and ABO blood types without sacrificing posttransplant outcomes. This study could serve as a model for other Asian countries to develop DDKT allocation systems. Future studies are needed to further refine the proposed allocation model based on more

precise PRA measures (cPRA) to more efficiently and fairly allocate limited organ resources in Korea and other Asian countries facing severe shortages.

In conclusion, despite considerable differences in DDKT opportunities based on PRA and ABO blood types, graft and patient outcomes did not differ significantly according to PRA and ABO blood types. A new scoring system to compensate for the disadvantages of DDKT opportunity could ensure the fair and efficient allocation of scarce kidneys.

Conflicts of interest

All authors have no conflicts of interest to declare.

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Data sharing statement

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Authors' contributions

Conceptualization, Methodology: JHL, JY

Investigation: JHL, JHS, TYK, JHC, KPK, JEL, KHO

Data curation: JHL, JHS, BSK, JY

Formal analysis: JHL, JHS

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References

1. Abecassis M, Bartlett ST, Collins AJ, et al. Kidney transplantation as primary therapy for end-stage renal disease: a National Kidney Foundation/Kidney Disease Outcomes Quality Initiative (NKF/KDOQIM) conference. *Clin J Am Soc Nephrol* 2008;3:471-480.
2. International Registry in Organ Donation and Transplantation. Worldwide actual deceased organ donors rate 2021 [Internet]. International Registry in Organ Donation and Transplantation, c2021 [cited 2023 Aug 1]. Available from: https://www.irodat.org/img/database/grafics/2021_01_worldwide-actual-deceased-organ-donors.png
3. United States Renal Data System. Incidence, prevalence, patient characteristics, and treatment modalities. In: End stage renal disease [Internet]. United States Renal Data System, c2022 [cited 2023 Aug 1]. Available from: <https://usrds-adr.niddk.nih.gov/2022/end-stage-renal-disease>
4. Ryu JH, Koo TY, Ha JY, Jung MR, Ha JW, Yang J. Factors associated with waiting time to deceased donor kidney transplantation in transplant candidates. *Transplant Proc* 2018;50:1041-1044.
5. Clark B, Unsworth DJ. HLA and kidney transplantation. *J Clin Pathol* 2010;63:21-25.
6. Ogura K, Terasaki PI, Johnson C, et al. The significance of a positive flow cytometry crossmatch test in primary kidney transplantation. *Transplantation* 1993;56:294-298.
7. Wiwattanathum P, Ingsathit A, Thammanichanond D, Mongkolsuk T, Sumethkul V. Significance of HLA antibody detected by PRA-bead method in kidney transplant outcomes. *Transplant Proc* 2016;48:761-765.
8. Lee H, Lee H, Eum SH, et al. Impact of low-level donor-specific anti-HLA antibody on posttransplant clinical outcomes in kidney transplant recipients. *Ann Lab Med* 2023;43:364-374.
9. Zecher D, Zeman F, Drasch T, et al. Impact of sensitization on waiting time prior to kidney transplantation in Germany. *Transplantation* 2022;106:2448-2455.
10. Roodnat JL, van de Wetering J, Claas FH, Ijzermans J, Weimar W. Persistently low transplantation rate of ABO blood type O and highly sensitised patients despite alternative transplantation programs. *Transpl Int* 2012;25:987-993.
11. Lee JH, Koo TY, Lee JE, Oh KH, Kim BS, Yang J. Impact of sensitization and ABO blood types on the opportunity of deceased-donor kidney transplantation with prolonged waiting time. *Sci Rep* 2024;14:2635.
12. Korean Network for Organ Sharing. 8th edition of guidelines of organ transplantation management [Internet]. The National Institute of Organ, Tissue and Blood Management, c2021 [cited 2023 Aug 1]. Available from: https://www.konos.go.kr/board/boardListPage.do?page=sub4_1_2&boardId=17&depth=2
13. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA* 2013;310:2191-2194.
14. International Summit on Transplant Tourism and Organ Trafficking. The Declaration of Istanbul on organ trafficking and transplant tourism. *Kidney Int* 2008;74:854-859.
15. Noordzij M, Leffondré K, van Stralen KJ, Zoccali C, Dekker FW, Jager KJ. When do we need competing risks methods for survival analysis in nephrology? *Nephrol Dial Transplant* 2013;28:2670-2677.
16. Yeung MY, Coates PT, Li PK. Kidney organ allocation system: how to be fair. *Semin Nephrol* 2022;42:151274.
17. Cookson R, Dolan P. Principles of justice in health care rationing. *J Med Ethics* 2000;26:323-329.
18. Persad G, Wertheimer A, Emanuel EJ. Principles for allocation of scarce medical interventions. *Lancet* 2009;373:423-431.
19. Organ Procurement and Transplantation Network. Ethical principles in the allocation of human organs [Internet]. Organ Procurement and Transplantation Network, c2015 [cited 2023 Aug 1]. Available from: <https://optn.transplant.hrsa.gov/professionals/by-topic/ethical-considerations/ethical-principles-in-the-allocation-of-human-organs/>
20. Israni AK, Salkowski N, Gustafson S, et al. New national allocation policy for deceased donor kidneys in the United States and possible effect on patient outcomes. *J Am Soc Nephrol* 2014;25:1842-1848.
21. Organ Procurement and Transplantation Network. A guide to calculating and interpreting the Kidney Donor Profile Index (KDPI) [Internet]. Organ Procurement and Transplantation Network, c2020 [cited 2023 Aug 1]. Available from: https://optn.transplant.hrsa.gov/media/1512/guide_to_calculating_interpreting_kdpi.pdf
22. Organ Procurement and Transplantation Network. A guide to calculating and interpreting the Estimated Post-Transplant Survival (EPTS) score used in the Kidney Allocation System (KAS) [Internet]. Organ Procurement and Transplantation Network, c2020 [cited 2023 Aug 1]. Available from: https://optn.transplant.hrsa.gov/media/1512/guide_to_calculating_interpreting_epts.pdf

- plant.hrsa.gov/media/1511/guide_to_calculating_interpreting_epts.pdf
23. Mayer G, Persijn GG. Eurotransplant kidney allocation system (ETKAS): rationale and implementation. *Nephrol Dial Transplant* 2006;21:2–3.
 24. Friedewald JJ, Samana CJ, Kasiske BL, et al. The kidney allocation system. *Surg Clin North Am* 2013;93:1395–1406.
 25. Wu DA, Watson CJ, Bradley JA, Johnson RJ, Forsythe JL, Oniscu GC. Global trends and challenges in deceased donor kidney allocation. *Kidney Int* 2017;91:1287–1299.
 26. Mamode N, Bestard O, Claas F, et al. European guideline for the management of kidney transplant patients with HLA antibodies: by the European Society for Organ Transplantation Working Group. *Transpl Int* 2022;35:10511.
 27. Bryan CF, Winkhofer FT, Murillo D, et al. Improving access to kidney transplantation without decreasing graft survival: long-term outcomes of blood group A2/A2B deceased donor kidneys in B recipients. *Transplantation* 2005;80:75–80.
 28. Hurst FP, Sajjad I, Elster EA, et al. Transplantation of A2 kidneys into B and O recipients leads to reduction in waiting time: US-RDS experience. *Transplantation* 2010;89:1396–1402.
 29. Bryan CF, Cherikh WS, Sesok-Pizzini DA. A2 /A2 B to B renal transplantation: past, present, and future directions. *Am J Transplant* 2016;16:11–20.
 30. Garg N, Warnke L, Redfield RR, et al. Discrepant subtyping of blood type A2 living kidney donors: missed opportunities in kidney transplantation. *Clin Transplant* 2021;35:e14422.
 31. Lentine KL, Smith JM, Hart A, et al. OPTN/SRTR 2020 annual data report: kidney. *Am J Transplant* 2022;22 Suppl 2:21–136.
 32. Organ Procurement and Transplantation Network. OPTN policies [Internet]. Organ Procurement and Transplantation Network, c2023 [cited 2023 Aug 1]. Available from: https://optn.transplant.hrsa.gov/media/eavh5bf3/optn_policies.pdf
 33. Martins PN, Mustian MN, MacLennan PA, et al. Impact of the new kidney allocation system A2/A2B → B policy on access to transplantation among minority candidates. *Am J Transplant* 2018;18:1947–1953.
 34. Forbes RC, Feurer ID, Shaffer D. A2 incompatible kidney transplantation does not adversely affect graft or patient survival. *Clin Transplant* 2016;30:589–597.
 35. Williams WW, Cherikh WS, Young CJ, et al. First report on the OPTN national variance: allocation of A2 /A2 B deceased donor kidneys to blood group B increases minority transplantation. *Am J Transplant* 2015;15:3134–3142.
 36. Shaffer D, Feurer ID, Rega SA, Forbes RC. A2 to B kidney transplantation in the post-kidney allocation system era: a 3-year experience with anti-A titers, outcomes, and cost. *J Am Coll Surg* 2019;228:635–641.
 37. Stewart DE, Wilk AR, Toll AE, et al. Measuring and monitoring equity in access to deceased donor kidney transplantation. *Am J Transplant* 2018;18:1924–1935.
 38. Gragert L, Kadatz M, Alcorn J, et al. ABO-adjusted calculated panel reactive antibody (cPRA): a unified metric for immunologic compatibility in kidney transplantation. *Am J Transplant* 2022;22:3093–3100.
 39. Hart A, Gustafson SK, Skeans MA, et al. OPTN/SRTR 2015 annual data report: early effects of the new kidney allocation system. *Am J Transplant* 2017;17 Suppl 1:543–564.