How (not) to Integrate Blood Subtyping Technology to Kidney Exchange?

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NBER Market Design Meeting, Cambridge, MA, October 23-24, 2015

Kidney Exchange and Market Design

- Kidney exchange, originally proposed by Rapaport (1986), has become a major source of kidney transplantations with the introduction of optimization/market design techniques to kidney exchange by Roth, Sönmez, & Ünver (2004, 2005, 2007).

- A handful of transplants from kidney exchanges in the US prior to 2004, increased to 93 in 2006 and to 553 in 2010.
- Currently transplants from kidney exchanges in the US accounts for about 10% of all living donor kidney transplants.

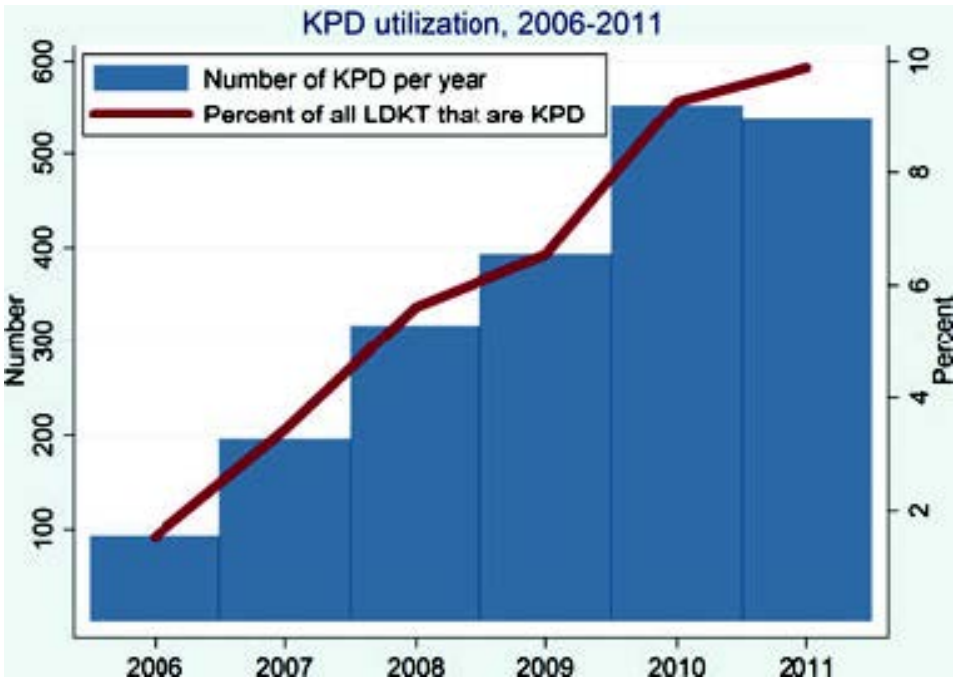


Figure from Massie et al AJT 2013

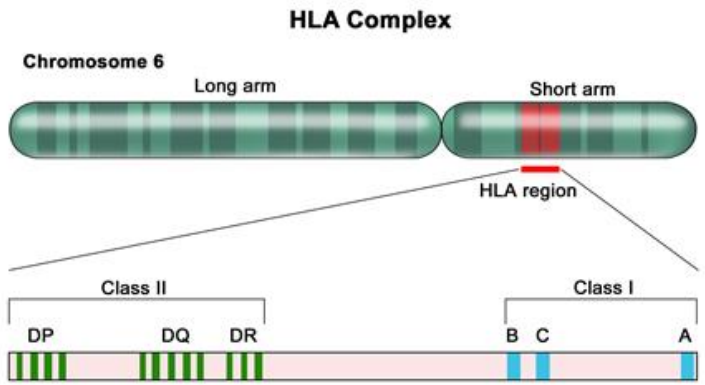
Deceased Donation Policies & Kidney Exchange

- Analysis of policies and procedures that could increase the contribution of kidney exchange to the number of kidney transplants became an active area of research in market design, computer science, and medicine.
- This paper: Analysis of the effects of a 2014 policy change in allocation of deceased donor kidneys on the number of transplants from living donors (including from kidney exchanges).

Traditional Criterion: Tissue Type Compatibility

- Tissue type or Human Leukocyte Antigen (HLA) type: Combination of several pairs of antigens on Chromosome 6.

  For kidney donation, HLA proteins A, B, and DR are especially important.



- Prior to transplantation, the potential recipient is tested for the presence of preformed antibodies against donor HLA.

  If the level of antibodies is above a threshold (positive crossmatch), then the transplant cannot be carried out.

Traditional Criterion: ABO Blood Type Compatibility

- There are two types of red blood cell antigens: A, B.
- Human body produces antibody anti-A in the absence of antigen A and antibody anti-B in the absence of antigen B.
- The combination of red cell antigens determines ABO blood-types:
  - A (antigen A and antibody anti-B)
  - B (antigen B and antibody anti-A)
  - AB (antigens A and B)
  - O (antibodies anti-A and anti-B)
- Hence, based on ABO blood type compatibility:
  - Type O organs can be transplanted into any patient;
  - type A organs can be transplanted into type A or type AB patients;
  - type B organs can be transplanted into type B or type AB patients;
  - type AB organs can only be transplanted into type AB patients.

Biologically Disadvantaged Groups for Transplantation

- Blood type O patients: Disadvantaged because of the "natural injustice" induced by ABO blood type compatibility.
- Blood type B patients: More likely to be ethnic minorities who are more likely to suffer from kidney disease.

	Blood Type Frequency for US Races				
	White	**Black**	**Asian**	**Amer. Indian**	**Pacific Island.**
Blood Type					
O	48.98	49.89	38.31	62.96	48.67
A	37.18	25.28	25.06	28.78	36.00
B	10.55	20.63	29.22	6.84	10.00
AB	3.29	4.19	6.41	1.43	5.33

New Criterion: Blood Subtype Compatibility

- Red blood antigen A has two major subtypes A1 and A2 with different immunologic properties.
- About 80% of US blood type A population is of subtype A1, and 20% is of subtype A2.
- When donated to type B or O patients, subtype A2 kidneys result in significantly weaker antibody response than subtype A1 kidneys.
- The resulting distribution of antibody response in patient population is such that,
  - A2 kidneys can be safely transplanted to more than 80% of type B patients, and
  - to approximately 30-40% of type O patients.
- To mitigate the adverse effects of biological challenges to blood type B patients, blood type A subtyping started to play an important role in allocation of deceased donor kidneys in the US since 2014.

Blood Type A Subtyping & Eligibility for A2 Kidneys

- Transplanting a subtype A2 kidney to a blood type B or blood type O patient requires two sets of tests, one set for the patient and another set for the kidney.
- Antibody Anti-A Titer Value Tests for Patients: Patient antibody Anti-A(IgG) titer value should be consistently below a certain threshold over a period, often over the last 6 months.

  Unless a patient hospital provides the documentation for consistently low antibody Anti-A (IgG) titer value, the patient is ineligible for subtype A2 kidneys.
- Subtyping Tests for Type A Kidneys:
  1. Preliminary subtyping test: Not completely reliable. There is 3.5% odds that an A1 kidney will be tested as A2 (Bryan et al 2006).
  2. Confirmatory subtyping test: Reduces the frequency of mistakenly identifying an A1 kidney as A2 to 0.032%.

2014 US Reform on Deceased Donor Kidney Allocation

- Under the new deceased donor kidney allocation system, subtype A2 kidneys are preferentially allocated to blood type B patients.
- To benefit from increased access to kidneys, antibody Anti-A titer value tests are periodically conducted for blood type B patients.
- Importantly, there is no "apparent" reason to conduct these tests for blood type O patients (unless they have a blood type A living donor).
- We analyze the potential spillovers of this preferential allocation policy on the number of living donor kidney transplants.

Rationale for Preferential Allocation: Equity in Access

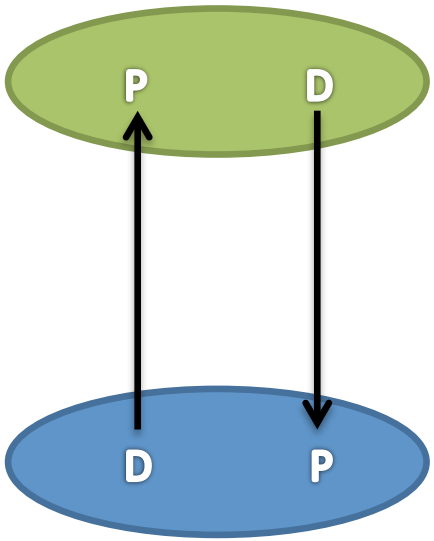
- The Federal Final Rule, adopted in March 2000, provides a regulatory framework for the structure and operation of the OPTN:

  "The primary goal of the OPTN is to increase and ensure the effectiveness, efficiency, and equity of organ sharing in the national system of organ allocation, and to increase the supply of donated organs available for transplantation."
- While types B/O are both biologically disadvantaged, a type B patient is more likely to be a minority than a type O patient.
- The preferential allocation system is especially beneficial for the African American patient population which historically has the lowest access for transplant kidneys.

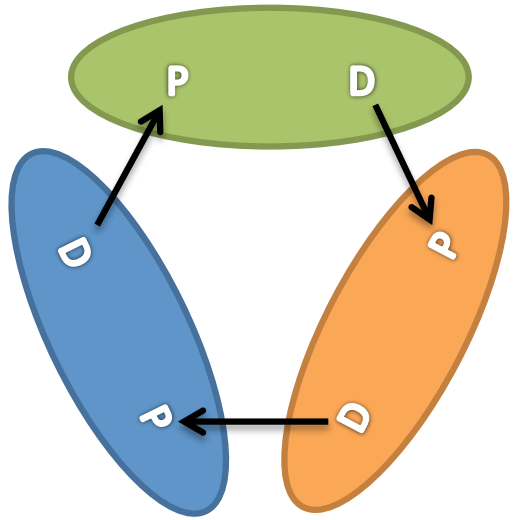
Rationale for Preferential Allocation: Practicality

- For a patient to be eligible for a subtype A2 kidney, his antibody Anti-A titer value should be consistently below a certain threshold over a period.
- Based on this medical criteria, more than 80 percent of type B patients are eligible to receive subtype A2 kidneys.
- In contrast, only 30-40 percent of type O patients are eligible for subtype A2 kidneys.

Kidney Exchange



2-way Kidney Exchange



3-way Kidney Exchange

- First proposed by Rapaport (1986).
- The first kidney exchanges were carried out in S. Korea in early 1990s.
- The first kidney exchange in the US was carried out in Rhode Island in 2000.
- Prior to formal organized kidney exchange clearinghouses, very rare: 5 paired exchanges in New England between 2000-2004.

Notation

- Type $X - Y$: Patient-donor pairs with X blood type patient and Y blood (sub)type donor
- $\{X - Y\}$: Set of pairs of type $X - Y$
- $\{X - Y\}_c$: Set of tissue-type compatible pairs of type $X - Y$
- $\{X - Y\}_i$: Set of tissue-type incompatible pairs of type $X - Y$
- $\#S$: Cardinality of set S
- $\text{odd}_S = \begin{cases} 1 & \text{if } \#S \text{ is odd} \\ 0 & \text{if } \#S \text{ is even} \end{cases}$

Blood Subtyping Technologies

- ABO Compatibility: Baseline technology with no subtyping
- A2-to-B Compatibility: Subtype A2 and A2B kidneys can be transplanted to blood type B patients
- A2-to-O Compatibility: Subtype A2 kidneys can be transplanted to blood type O patients
- Full Compatibility: A2-to-B Compatibility + A2-to-O Compatibility

Timing of Antibody Titer Value Tests & Subtyping Tests

- Antibody Titer Value Tests: Since a patient needs a history of antibody titer value tests to be eligible for an A2/A2B kidney transplant, these tests will be assumed to be carried out at the patient hospital before a potential recipient participates in kidney exchange.
- Subtyping Tests (for A2/A2B) Living Donors: Two scenarios are considered.
  1. Before Joining Kidney Exchange: Carried out at the hospital of the paired-patient of the type A paired-donor before the pair potentially participates in kidney exchange.
  2. After Joining Kidney Exchange: Carried by the kidney exchange program (ex. by UNOS) once a pair joins the kidney exchange pool.

Formation of the Kidney Exchange Pool

- A patient with a paired living donor arrives to a hospital.
- If the pair is deemed (tissue, blood, and subtype) compatible given the available testing technology, the patient receives a transplant from his paired-donor.
- Otherwise the pair is transferred to the kidney exchange program.

Assumptions on the Structure of the Kidney Exchange Pool

- The following assumptions (or their basic variants) are introduced by Roth, Sönmez, & Ünver (2007).
- Definition: A patient-donor type $X - Y$ is on the long side of exchange if regardless of the matching technology (i.e. 2-way exchange alone, 2&3-way exchange, etc.) at least one pair of type $X - Y$ remains unmatched in every feasible matching.
- The following assumption is justified due to the asymmetric structure of blood type donation relation.

  Large Population Assumption (LP): Given a subtyping technology, the following types are on the long side of exchange.

  (i) ABO O-A, O-B, O-AB, A-AB, B-AB
  (ii) A2-to-B O-A, O-B, O-AB, A-AB, B-A1B
  (iii) A2-to-O O-A1, O-B, O-AB, A-AB, B-AB
  (iv) Full O-A1, O-B, O-AB, A-AB, B-A1B

Assumptions on the Structure of the Kidney Exchange Pool

- The next assumption is based on the following empirical observation for the US: The frequency of types $A-B$ and $B-A$ are 0.05 and 0.03 respectively (Terasaki, Gjertson, & Cecka 1998).

  Type Frequencies Assumption (TF): $\#\{A-B\} > \#\{B-A\}$

- The last assumption is justified by Erdös-Rényi (1960) Random Graph Convergence Result for large kidney exchange pools:

  Upper Bound Assumption (UB):

  (i) No patient is tissue-type incompatible with another patient's paired-donor.

  (ii) Each B and O patient in the kidney exchange pool has an antibody Anti-A titer value less than 1:8 (i.e. the critical level for the US).

A2-to-B with Subtyping Before Kidney Exchange

Proposition 1: Assume LP(i), LP(ii), TF, UB. Consider the 2-way exchange technology and suppose subtyping tests are conducted at hospitals before patients are transferred to kidney exchange pool.
If the subtyping technology changes from the baseline ABO Compatibility to A2-to-B Compatibility, then

(i) the number of transplants via direct donation increases by

$$\#\{B-A2\}_c + \#\{B-A2B\}_c,$$

(ii) the number of transplants via exchange decreases by

$$2\#\{B-A2\}_c - \#\{AB-A2B\} - \#\{B-A2B\}_i - \Lambda,$$

(iii) the total number of transplants decreases by

$$\#\{B-A2\}_c - \#\{AB-A2B\} - \#\{B-A2B\} - \Lambda,$$

where
$\Lambda = (\text{odd}_{\{AB-AB\}} - \text{odd}_{\{AB-A1B\}}) + (\text{odd}_{\{B-B\}} - \text{odd}_{\{B-A2B\}_i \cup \{B-B\}})$.

A2-to-O with Subtyping Before Kidney Exchange

Proposition 2: Assume LP(i), LP(iii), UB. Consider the 2-way exchange technology and suppose subtyping tests are conducted at hospitals before patients are transferred to kidney exchange pool.
If the subtyping technology changes from the baseline ABO Compatibility to A2-to-O Compatibility, then

(i) the number of transplants via direct donation increases by

$$\#\{O - A2\}_c,$$

(ii) the number of transplants via exchange increases by

$$\#\{O - A2\}_i + \#\{A - A2\} + \Theta,$$

(iii) the total number of transplants increases by

$$\#\{O - A2\} + \#\{A - A2\} + \Theta,$$

where
$\Theta = (\text{odd}_{\{O-O\}} - \text{odd}_{\{O-O\}\cup\{O-A2\}_i}) + (\text{odd}_{\{A-A\}} - \text{odd}_{\{A-A1\}})$.

Full Compatibility with Subtyping Before Kidney Exchange

Proposition 3: Assume LP(i), LP(iv), TF, UB. Consider the 2-way exchange technology and suppose subtyping tests are conducted at hospitals before patients are transferred to kidney exchange pool.
If the subtyping technology changes from the baseline ABO Compatibility to Full Compatibility, then

(i) the number of transplants via direct donation increases by

$$\#\{O-A2\}_c+\#\{B-A2\}_c+\#\{B-A2B\}_c,$$

(ii) the number of transplants via exchange changes by

$$\#\{O-A2\}_i+\#\{A-A2\}-2\#\{B-A2\}_c \\ +\#\{AB-A2B\}+\#\{B-A2B\}_i+\Theta+\Lambda,$$

(iii) the total number of transplants changes by

$$\#\{O-A2\}+\#\{A-A2\}-\#\{B-A2\}_c \\ +\#\{AB-A2B\}+\#\{B-A2B\}+\Theta+\Lambda,$$

where Θ and Λ are defined as before.

A2-to-B with Subtyping at Kidney Exchange Pool

Proposition 4: Assume LP(i), LP(ii), TF, UB. Consider the 2-way exchange technology and suppose subtyping tests are conducted at the kidney exchange program. If the subtyping technology changes from the baseline ABO Compatibility to A2-to-B Compatibility, then

(i) the number of transplants via direct donation increases by

$$\max\left\{0, \#\{B-A2B\}_c - \text{odd}_{\{B-A2B\}_i \cup \{B-B\}}\right\},$$

(ii) the number of transplants via exchange increases by

$$\#\{AB-A2B\} + \#\{B-A2B\}_i + \min\left\{\#\{B-A2B\}_c, \text{odd}_{\{B-A2B\}_i \cup \{B-B\}}\right\} + \Lambda',$$

(iii) the total number of transplants increases by

$$\#\{B-A2B\} + \#\{AB-A2B\} + \Lambda',$$

where $\Lambda' = (\text{odd}_{\{AB-AB\}} - \text{odd}_{\{AB-A1B\}}) + \left(\text{odd}_{\{B-B\}} - \left(1 - \min\left\{1, \#\{B-A2B\}_c\right\}\right)\text{odd}_{\{B-A2B\}_i \cup \{B-B\}}\right).$

A2-to-O with Subtyping at Kidney Exchange Pool

Proposition 5: Assume LP(i), LP(iii), UB. Consider the 2-way exchange technology and suppose subtyping tests are conducted at the kidney exchange program. If the subtyping technology changes from the baseline ABO Compatibility to A2-to-O Compatibility, then

(i) the number of transplants via direct donation increases by

$$\max\left\{0, \#\{O-A2\}_c - \text{odd}_{\{O-O\}\cup\{O-A2\}_i}\right\},$$

(ii) the number of transplants via exchange increases by

$$\#\{A-A2\}+\#\{O-A2\}_i + \min\left\{\#\{O-A2\}_c, \text{odd}_{\{O-A2\}_i\cup\{O-O\}}\right\} + \Theta',$$

(iii) the total number of transplants increases by

$$\#\{O-A2\} + \#\{A-A2\} + \Theta',$$

where $\Theta' = (\text{odd}_{\{A-A\}} - \text{odd}_{\{A-A1\}}) + \left(\text{odd}_{\{O-O\}} - \left(1 - \min\left\{1, \#\{O-A2\}_c\right\}\right)\text{odd}_{\{O-A2\}_i\cup\{O-O\}}\right).$

Full Compatibility with Subtyping at Kidney Exchange Pool

Proposition 6: Assume LP(i), LP(iv), TF, UB. Consider the 2-way exchange technology and suppose subtyping tests are conducted at the kidney exchange program. If the subtyping technology changes from the baseline ABO Compatibility to Full Compatibility, then

(i) the number of transplants via direct donation increases by

$$\max\left\{0,\#\{B-A2B\}_c - \text{odd}_{\{B-A2B\}_i \cup \{B-B\}}\right\} + \max\left\{0, \#\{O-A2\}_c - \text{odd}_{\{O-O\}\cup\{O-A2\}_i}\right\},$$

(ii) the number of transplants via exchange increases by

$$\#\{AB-A2B\}+\#\{B-A2B\}_i + \#\{A-A2\} + \#\{O-A2\}_i + \min\left\{\#\{B-A2B\}_c, \text{odd}_{\{B-A2B\}_i\cup\{B-B\}}\right\} + \min\left\{\#\{O-A2\}_c, \text{odd}_{\{O-A2\}_i\cup\{O-O\}}\right\} + \Lambda' + \Theta',$$

(iii) the total number of transplants increases by

$$\#\{B-A2B\}+\#\{AB-A2B\}+\#\{O-A2\}+\#\{A-A2\}+\Lambda'+\Theta',$$

where Λ' and Θ' are defined as before.

Summary of 2-way Kidney Exchange Analytical Results

- If subtyping tests are conducted at hospitals, the introduction of A2-to-B Compatibility technology decreases the total number of (living donor) transplants, whereas the introduction of A2-to-O Compatibility technology increases it.

  For this timing of subtyping tests, the maximum number of transplants is obtained by the introduction of A2-to-O Compatibility.
- Carrying out the subtyping tests at kidney exchange programs increases the number of transplants for each of the subtyping technologies.
- The best case scenario is carrying out the subtyping tests at kidney exchange programs with the Full Compatibility technology.
- The worst case scenario is carrying out the subtyping tests at hospitals with A2-to-B technology.

Simulation Setup

- We randomly generate n non-blood related patient-donor pairs.
- Each patient is represented by the following set of characteristics: Race, blood type, A2 subtype compatibility status (for type O/B patients), and PRA status.
- Each kidney patient is assumed to arrive to a hospital paired with a non-biologically related donor.
- The donor can be a spouse or another non-biologically related donor.

  If the donor is a spouse, then she is assumed to be of the same race with the patient. Otherwise, her race is randomly generated using the US adult population race statistics.
- Based on the donor race, her other characteristics (blood type, A2 status, etc.) are randomly and independently generated.

Simulation Setup

- Upon generating a patient-donor pair, the donor is assumed to directly donate to her paired-patient if she is deemed compatible with the patient with the given technology.
  Otherwise the pair is assumed to be transferred to the kidney exchange pool.
- All assumptions used for the analytical analysis are dropped.

Patient-Donor Characteristics

	US Races				
	White	**Black**	**Asian**	**Amer. Indian**	**Pacific Island.**
A. Patient → (Freq. %)	81.46	12.78	5.15	0.40	0.22
B. Other Donor → (Freq. %)	78.00	13.69	5.96	1.94	0.42
C. Blood Type ↓	Frequency (%)				
O	48.98	49.89	38.31	62.96	48.67
A	37.18	25.28	25.06	28.78	36.00
B	10.55	20.63	29.22	6.84	10.00
AB	3.29	4.19	6.41	1.43	5.33
D. Donor Relation	Frequency (%)				
Spouse	34.44	40.12	43.76	32.61	41.18
E. PRA Distribution ↓	Frequency (%)				
Low PRA	70.19				
Medium PRA	20.00				
High PRA	9.81				
F. A2 Subtype Comp.	Frequency (%)				
F.1. For O Patients	30				
F.2. For B Patients	80				

2-way Maximum Cardinality Kidney Exchange

Simulation Averages and Sample Standard Errors of $S = 500$ Simulations with $n = 2000$ Pairs						
	Two-way Exchange					
	1. Without A Subtype Matching	2. With A Subtype Matching				
		Subtype Test Timing		$A2$ Transplant Protocol		
Incomp. Pairs				i. $A2/A2B \to B$ only	ii. $A2 \to O$ only	iii. $A2/A2B \to B$ and $A2 \to O$
984.800 (23.2186)	**376.700 (22.3124)**	**(a) Before** Exchange Participation Decision	**Total Transplants**	**374.616 (23.1654)**	**424.852 (25.9950)**	**416.260 (25.4372)**
			B's receiving from own comp. $A2/A2B$ donors	12.180 (3.391)	-	12.180 (3.391)
			O's receiving from own comp. $A2$ donors	-	15.708 (3.833)	15.708 (3.833)
		(b) After Exchange Participation Decision	**Total Transplants**	**384.238 (23.1129)**	**425.374 (25.9735)**	**428.012 (26.1527)**
			B's receiving from own comp. $A2/A2B$ donors	1.022 (1.4034)	-	0.682 (0.7836)
			O's receiving from own comp. $A2$ donors	-	3.558 (2.2254)	3.882 (3.2902)

2-way Maximum Cardinality Exchange: Racial Breakdown

Races	Total Number of Pairs		Number of Patients of Each Race Matched in Two-way Exchange out of $n = 2000$ Pairs						
			1. Without A subtype matching	2. With A subtype matching					
				(a) A subtype test done **before** participation decision in exchange			(b) A subtype test done **after** participation decision in exchange		
	Comp. (w/o A subtype matching)	Inc. (w/o A subtype matching)		i. $A2/A2B \to B$ only	ii. $A2 \to O$ only	iii. $A2/A2B \to B$ and $A2 \to O$	i. $A2/A2B \to B$ only	ii. $A2 \to O$ only	iii. $A2/A2B \to B$ and $A2 \to O$
White	**833.1060** (23.3396)	**795.1440** (23.0033)	**299.6800** (19.3555)	**297.7780** (19.7659)	**339.3600** (22.2173)	**332.3660** (21.8758)	**305.9440** (19.7554)	**340.0200** (22.2719)	**341.9880** (22.6046)
Black	**126.3580** (10.5689)	**130.5120** (11.1098)	**51.5260** (7.3608)	**51.4080** (7.2456)	**57.6660** (7.4497)	**56.5180** (7.3210)	**52.3240** (7.3320)	**57.4220** (7.7379)	**57.9120** (7.4857)
Asian	**49.5580** (7.2818)	**53.0260** (7.1113)	**23.3540** (5.0095)	**23.2900** (4.8918)	**25.3700** (5.1945)	**24.9720** (5.1886)	**23.8200** (5.0138)	**25.5380** (5.2026)	**25.6700** (5.1160)
American Indian	**4.0420** (2.0564)	**3.9020** (1.9452)	**1.3000** (1.1852)	**1.3080** (1.1558)	**1.5140** (1.2510)	**1.5020** (1.2430)	**1.2980** (1.1747)	**1.4380** (1.2382)	**1.4940** (1.2382)
Pacific Islander	**2.1780** (1.5083)	**2.1740** (1.3621)	**0.8400** (0.8740)	**0.8320** (0.8997)	**0.9420** (0.9531)	**0.9020** (0.9392)	**0.8520** (0.9032)	**0.9560** (0.9633)	**0.9480** (0.9397)
TOTAL	**1015.200** (23.2186)	**984.800** (23.2186)	**376.700** (22.3124)	**374.6160** (23.1654)	**424.852** (25.9950)	**416.260** (25.4372)	**384.238** (23.1129)	**425.374** (25.9735)	**428.012** (26.1527)

2&3-way Maximum Cardinality Kidney Exchange

Averages and Standard Errors of $S = 500$ Simulations with $n = 500$ Pairs						
	Two&Three-way Exchange					
	1. Without A Subtype Matching	2. With A Subtype Matching				
		Subtype Test Timing		$A2$ Transplant Protocol		
Incomp. Pairs				i. $A2/A2B \to B$ only	ii. $A2 \to O$ only	iii. $A2/A2B \to B$ and $A2 \to O$
246.430 (23.2186)	**96.956 (11.6453)**	(a) Before Exchange Participation Decision	**Total Transplants**	**97.240 (12.0308)**	**117.292 (12.9746)**	**114.878 (13.1884)**
			B's receiving from own comp. $A2/A2B$ donors	12.180 (3.391)	-	12.180 (3.391)
			O's receiving from own comp. $A2$ donors	-	15.708 (3.833)	15.708 (3.833)
		(b) After Exchange Participation Decision	**Total Transplants**	**98.358 (11.6661)**	**117.292 (12.9746)**	**118.596 (13.0767)**
			B's receiving from own comp. $A2/A2B$ donors	1.022 (1.4034)	-	0.682 (0.7836)
			O's receiving from own comp. $A2$ donors	-	3.558 (2.2254)	3.882 (3.2902)

2&3-way Maximum Card. Exchange: Racial Breakdown

Races	Total Number of Pairs		Number of Patients of Each Race Matched in Two&three-way Exchange out of $n = 500$ Pairs							
			1. Without	2. With A subtype matching						
				(a) A subtype test done **before** participation decision in exchange			(b) A subtype test done **after** participation decision in exchange			
	Comp.	Inc.	A subtype							
	(w/o A subtype matching)		matching	i. $A2/A2B \to B$ only	ii. $A2 \to O$ only	iii. $A2/A2B \to B$ and $A2 \to O$	i. $A2/A2B \to B$ only	ii. $A2 \to O$ only	iii. $A2/A2B \to B$ and $A2 \to O$
White	**207.8560** (11.8609)	**198.8320** (11.3236)	**76.9180** (9.9465)	**77.2800** (10.3015)	**93.9140** (11.0920)	**92.0640** (11.4244)	**78.2440** (9.9796)	**93.9760** (11.1348)	**95.0840** (11.2439)
Black	**31.5340** (5.4129)	**32.7300** (5.4398)	**13.3880** (3.7924)	**13.3560** (3.7381)	**15.8100** (4.2040)	**15.4240** (4.0449)	**13.4940** (3.7596)	**15.7840** (4.1795)	**15.9480** (4.1795)
Asian	**12.5540** (3.3295)	**13.2520** (3.6572)	**6.0740** (2.4990)	**6.0480** (2.4604)	**6.8340** (2.6526)	**6.7000** (2.5906)	**6.0640** (2.5292)	**6.8040** (2.6075)	**6.8740** (2.6759)
American Indian	**1.0680** (1.0685)	**1.0200** (1.0206)	**0.3400** (0.6428)	**0.3360** (0.6260)	**0.4280** (0.6524)	**0.4060** (0.6679)	**0.3420** (0.6307)	**0.4240** (0.6731)	**0.4040** (0.6706)
Pacific Islander	**0.5580** (0.7535)	**0.5960** (0.7307)	**0.2360** (0.4866)	**0.2200** (0.4605)	**0.3060** (0.5486)	**0.2840** (0.5440)	**0.2140** (0.4697)	**0.3040** (0.5515)	**0.2860** (0.5336)
TOTAL	**253.570** (23.2186)	**246.430** (23.2186)	**96.956** (11.6453)	**97.240** (12.0308)	**117.292** (12.9746)	**114.878** (13.1884)	**98.358** (11.6661)	**117.292** (12.9746)	**118.596** (13.0767)

Policy Implications & Conclusion

- It is important to understand the interaction between policies on various sources of transplant organs (eg. deceased donor transplants, living donor transplants, transplants via exchange, etc.)
- Introduction of blood type A subtyping technology can reduce the number of living donor transplantations, including to disadvantaged groups, if it is restricted to blood type B patients only.
- It is important not to exclude blood type O patients from kidney exchanges that involve subtype A2 kidneys.

  This would mean, type O patients should have a history of antibody Anti-A titer value tests when they join a kidney exchange pool.
- Conducting blood type A subtyping tests at kidney exchange programs can significantly increase the number of transplants from living donors (including those from kidney exchanges).

  This favorable timing of subtyping tests can be encouraged by the Health Insurance system.