OK Google: Who gets the kidney?

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Participants

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On two occasions I have been asked, “Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?” ... I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a Question.

Charles Babbage (1864)
Translation:

Garbage in, Garbage out.
Outline

Part I: Kidney Transplantation & Exchange

- History of kidney allocation policy
- Intro to kidney exchange

Part II: Artificial Intelligence & Medicine

- Intro to AI
- AI in medicine
- AI in kidney exchange

Part III: AI & Ethics / Building a Better Algorithm

- Challenges of integrating AI & Ethics
- A way forward?
Part I

Kidney Transplantation & Exchange
History: Kidney Transplantation, deceased donors

- Early 60’s: kidneys used locally; policies decided by local transplant center
- 1968: Southeast Organ Procurement Foundation (SEOPF) formed to share kidneys in southeast US
- 1977 First computer-based organ matching system (UNOS)
- 1984 UNOS separates from SEOPF
- 1984 Congress passes NOTA and establishes OPTN
- 1986 Federal contract to operate OPTN awarded to UNOS
- 1999 UNOS launches UNET, secure internet-based database system to manage organ allocation
More history

● 2000 OPTN Final Rule - “Equitable allocation of deceased donor organs”
  ○ Use sound medical judgment
  ○ Achieve best use of donated organs
  ○ Avoid wasting organs
  ○ Avoid futile transplants
  ○ Promote patient access to transplantation

● 2004 OPTN Kidney Transplant Committee
  ○ Charged with developing a “new rule” based on above criteria
  ○ Most allocation was based on waiting time

● 2014 New allocation system implemented
  ○ Yes, it took a decade
Exchanges: Kidney Paired Donations (KPD)

- 2001: First KPD program in US (Hopkins)
- 2009: Hopkins - first 16 patient multicenter Domino Chain
- 2010: UNOS begins “pilot” kidney exchange program
  - Using AI-based algorithm to match patients with donors
- 2014: National Kidney Registry sets new record with 70 participant chain

- National exchanges: South Korea (‘91), Netherlands (‘05), Canada (‘09)
- There are MANY exchanges in the US, and they don’t all work together
  - UNOS, NKR, APD, NCDEC, Private hospitals (ex Johns Hopkins)
Kidney Donation in the US

Patients in Need of an Organ

Transplants

Images: https://optn.transplant.hrsa.gov/
Kidney Exchange

Mother (patient)

Daughter (donor)

Wife (donor)

Husband (patient)
Kidney Exchange

- Mother (patient) incompatible with Daughter (donor)
- Wife (donor) incompatible with Husband (patient)
Kidney Exchange

Mother (patient) → compatible → Daughter (donor)

Wife (donor) → compatible → Husband (patient)

Incompatible

Incompatible

Incompatible
Part II

Artificial Intelligence & Medicine
What is Artificial Intelligence?

In popular culture:

*AI is whatever hasn’t been done yet. (the “AI effect”)*

For us:

*AI is an algorithmic system that makes decisions or takes actions on behalf of a human.*
What is Artificial Intelligence?

Planning & Optimization

Natural Language Processing

Recommender Systems
Also Artificial Intelligence...

Artificial General Intelligence & Machine Consciousness
Algorithms & AI In Medicine

- **Decision support tools**
- Automatic Alerts
- Machine Learning
Algorithms & AI In Medicine

- Decision support tools
- *Automatic Alerts*
- Machine Learning

### Sepsis Alert Algorithm

**If:** Suspected Infection and 2 or more of:
- Temp >38 or <36
- Heart rate >90
- Resp. rate >20
- Systolic BP <90 mmHg
- SaO2 <93% on RA without chronic lung disease
- Glucose >8 mmol/L without diabetes
- Confusion/unresponsiveness

**Then:** Issue Sepsis Alert
Algorithms & AI In Medicine

- Decision support tools
- Automatic Alerts
- Machine Learning

![Diagram](image)

**Medical Imaging Data** → **Machine learning model** → **Diagnosis**

*Clinically applicable deep learning for diagnosis and referral in retinal disease*

Jeffrey De Fauw*, Joseph P. Lueders*, Bernardo Romero-Paredes*, Stanislaw Nikolov*, Ronald Tomaszewski, Sam Mackowell, Henry Ashkenazi, Xavier Giro-i, Brendan O’Donoghue, Danilo Vicenzi, George van den Oord, Raha Baharlou, Clemens Meyer, Faith MacKinder, Simon Bauters, Kewon Ayouba, Beena Chopra†, Dimitri King, Alan Kurtzke, Camilla Tumisz, Corin O. Hughes, Rossen Rashov, Julian Hayhoe, Dennis A. Stiel, Catherine Egger, Adrian Tufail, Hugh Montgomery, Dennis Hoskins, Gerard Ross, Trevor Beck, Paul T. Brown, Martin Sulemoff, Julian Cordeiro‡, Philippe A. Rosso‡ and Olaf Ronneberger‡‡

[Ref: URL]
Algorithms & AI In Medicine

- Algorithms (and AI) are common in medicine

- Usually easy to interpret:
  - Decision support
  - Automatic alerts
  - Diagnosis prediction

- What about kidney exchange?
Kidney Transplant (Without Exchange)
Kidney Transplants (Without Exchange)
Kidney Transplants (Without Exchange)

Without Exchange

Roughly 50% of patients can receive a kidney from their donor.

(The rest are incompatible.)
Paired Kidney Exchange

Two pairs exchange donors.

Roughly 75% of patients can find a donor (from 50%).
Kidney Exchanges: Longer Cycles

Every pair in a cycle donates to the next pair, and so on
Kidney Exchanges: Longer Cycles

Every pair in a cycle donates to the next pair, and so on.
Kidney Exchanges: Longer Cycles

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Kidney Exchanges: Longer Cycles

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Kidney Exchanges: Longer Cycles

Every pair in a cycle donates to the next pair, and so on

Implications

In real exchange pools, long cycles can reach far more patients...

But long cycles have a far higher risk of breaking.

To reduce risk, cycles are often carried out simultaneously, and limited to 2 or 3 transplants.
Kidney Exchanges: Chains

NDDs can increase overall number of transplants (by 5-6%) by donating to an exchange rather than the waiting list.

DPD:
- Often simultaneous
- In practice, limited to 3-4 transplants

NEAD:
- First reported chain had 10 transplants over 8 months
- Unlimited length (in theory)
Q: How do we decide which cycles & chains to use?
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A: Algorithms

1) Exchanges set a *matching policy*.

2) Computer scientists design an algorithm to implement the policy.

The Kidney Exchange Problem
The Kidney Exchange Problem

Q: How do we decide which cycles & chains to use?

A: Algorithms

General Policy Principles

<table>
<thead>
<tr>
<th>Efficiency / Utilitarianism</th>
<th>Donor kidneys should do the most good for the most patients.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prioritarianism</td>
<td>Some patients should be prioritized over others.</td>
</tr>
<tr>
<td>Egalitarianism</td>
<td>All participants should have equal access to donor kidneys.</td>
</tr>
</tbody>
</table>
Policy Examples & Corresponding Principles

Utilitarian Policy:
- Maximize total number of transplants
- Maximize expected life years

Prioritarian Policy:
- Transplant younger patients before older patients
- Transplant sick patients before healthy patients

Egalitarian Policy:
- Lottery (randomly select patients to receive transplants)
- First-come first-served
Policy Example: Priority Points (OPTN/UNOS)

UNOS Matching Policy:

1) Assign a score to each transplant

2) Select the cycles & chains to maximize total score

This is...

- Computationally hard (NP-hard)
- Practically impossible without an algorithm
Policy Example: Priority Points (OPTN/UNOS)

100 “base points” + ...
## Policy Example: Priority Points (OPTN/UNOS)

### Table 13-2: OPTN KPD Prioritization Points

<table>
<thead>
<tr>
<th>If the:</th>
<th>Then the match will receive:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candidate is a 0-ABDR mismatch with the potential donor</td>
<td>200 points</td>
</tr>
<tr>
<td>Candidate has a CPRA greater than or equal to 80%</td>
<td>125 points</td>
</tr>
<tr>
<td>Candidate is a prior living organ donor</td>
<td>150 points</td>
</tr>
<tr>
<td>Candidate was less than 18 years old at the time the candidate was registered in the OPTN KPD program</td>
<td>100 points</td>
</tr>
<tr>
<td>Candidate and potential donor are registered for the OPTN KPD program in the same region</td>
<td>25 points</td>
</tr>
<tr>
<td>Candidate and potential donor are registered for the OPTN KPD program in the same DSA</td>
<td>25 points</td>
</tr>
<tr>
<td>Transplant hospital that registered both the candidate and potential donor in the OPTN KPD program is the same</td>
<td>25 points</td>
</tr>
<tr>
<td>Potential donor has at least one of the other antibody specificities reported for the candidate</td>
<td>-5 points</td>
</tr>
</tbody>
</table>

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**Prioritarianism**

**Utilitarianism**

**Egalitarianism**
Policy Example: Priority Points (OPTN/UNOS)

Egalitarian, Prioritarian, or Utilitarian?

Q: Does maximizing priority points maximize the overall number of transplants?
Egalitarian, Prioritarian, or Utilitarian?

Q: Does maximizing priority points maximize the overall number of transplants?

A: Not necessarily!

Policy Example: Priority Points (OPTN/UNOS)
Policy Example: Priority Points (OPTN/UNOS)

Egalitarian, Prioritarian, or Utilitarian?

Q: If patient X has a higher score than patient Y, will X receive a kidney before Y?
Policy Example: Priority Points (OPTN/UNOS)

Egalitarian, Prioritarian, or Utilitarian?

Q: If patient X has a higher score than patient Y, will X receive a kidney before Y?

A: Not necessarily!
UNOS awards points based on the following criteria (plus 100 “base points”):

- Exact HLA match: 200 points
- Highly sensitized: 125 points
- Prior organ donor: 150 points
- Age < 18: 100 points
- Geographic proximity: 25-75 points
UNOS Policy - Ethical Implications

UNOS awards points based on the following criteria (plus 100 “base points”):

- Exact HLA match: 200 points
- Highly sensitized: 125 points
- Prior organ donor: 150 points
- Age < 18: 100 points
- Geographic proximity: 25-75 points

Consider two patients:

A) 16 y/o patient awaiting his second kidney, highly sensitized due to prior non-compliance with failure of original graft
   (100 + 100 + 125 = 325 points)

B) 30 y/o non-sensitized prior organ donor.
   (100 + 150 = 250 points)

Patient A is prioritized over Patient B
Questions:

Is it fair to maximize priority points?

When, if ever, should we carry out fewer than the maximum possible number of transplants?

Can priority points reflect principles of...

- Utilitarianism?
- Prioritarianism?
- Egalitarianism?
View from the Operating Room

Real people, real stories from the transplant world

- When do I hold out for a better kidney?
- What about gaming the system?
- What risks do I accept?
Part III

AI & Ethics / Building a Better Algorithm
AI & Ethics: Questions

What are the moral implications of an algorithm’s design and use?

How should competing implications/principles be resolved?
Designing a Better Algorithm

(1) Stakeholders
- define moral theories
- define morally-relevant features

(2) Technicians
- create design options
- characterize morally-relevant features

(3) Stakeholders
- select a design option, or
- refine moral theories & return to (1)
Conclusions

- AI & algorithms are prevalent in medicine
- These algorithms often have ethical implications
- One example: kidney exchange
  - relies on AI to match patients and donors
  - unintended consequences
- We can do better
  - Iterative, collaborative process with both technical and ethical experts
Thank you for your attention

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