When Does Statistical Equality Meet Health Equity?

Linying Zhang, MS
Ph.D. Candidate in Dr. George Hripcsak’s Lab
OHDSI Symposium 2022
Washington, D.C.
Oct 14, 2022
Fairness in Clinical Decision-making

- Fairness in clinical decision-making is an important component of health equity.
- Many factors could potentially affect a treatment decision.

Goal: Assess fairness of treatment allocation with EHRs.
Example: Coronary Artery Disease

- Heart disease is the **leading cause of death** in the United States.
- **Coronary heart disease** is the most common type of heart disease, killing 382,820 people in 2020.

Coronary Artery Disease (CAD)  
Myocardial infarction (MI)
Women, racial and ethnic minorities, patients without health insurance, and those who live in low-income neighborhoods may have inadequate access to revascularization procedures.
Women, racial and ethnic minorities, patients without health insurance, and those who live in low-income neighborhoods may have inadequate access to revascularization procedures.

Example: Coronary Artery Disease

Research Question:
Is there sex discrimination in allocating revascularization to CAD patients?

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sensitive Attribute</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary Artery Bypass Graft (CABG)</td>
<td>Biological sex</td>
<td>Myocardial infarction (MI)</td>
</tr>
</tbody>
</table>
**Statistical Parity**

**Question**: Is the treatment assigned at equal rate between men and women?

\[
p(\text{treatment} | \text{male}) = p(\text{treatment} | \text{female})
\]

**Result**: Male patients were more likely to receive revascularization treatment than female patients. Bias against women.
Many Definitions of Fairness are Available

**Associational Fairness**
- Statistical Parity
- Calibration
- Accuracy

**Causal Fairness**
- Principal Fairness
- Counterfactual Fairness
- Path-Specific Fairness

Input: Data

Input: Data + Causal Knowledge

Do they lead to same conclusions? If not, which one to believe?
Question: Does heart attack happen at equal rate between men and women, given their treatment status?

\[ p(\heartsuit | \leftarrow, \bigcirc) = p(\heartsuit | \leftarrow, \bigcirc) \]

and

\[ p(\heartsuit | \bigotimes, \bigcirc) = p(\heartsuit | \bigotimes, \bigcirc) \]
**Result:** Heart attack happened more frequently for male patients than for female patients in the control group. Maybe bias against men?
**Question**: Is the treatment assigned at equal rate between men and women, given their (observed) outcome?

\[
p(\n\|\heartsuit, \text{♀}) = p(\n\|\heartsuit, \text{♀})
\]

and

\[
p(\n\|\heartsuit, \text{♀}) = p(\n\|\heartsuit, \text{♀})
\]
Result: Male patients are more likely to receive the treatment than female patients, regardless of their outcome status. Bias against women.
Limitations of Associational Definitions

• **Conclusions about fairness differ** depending on which metric we use.
• Which metric to use potentially depends on:
  o Is there a **baseline difference** between men and women?
  o Does the treatment **work equally well** for men and women?
  o Does the **physiological mechanism** of the disease depend on sex?
So, what’s next?

- Fairness can be more rigorously defined using **causal reasoning**.
- Population-level fairness might be too “rough” for health care.
  - Consider **individual-level** or **subpopulation-level** fairness.

Assess fairness among similar patients.

How to define “similar patients”?
Principal Fairness: A Causal Fairness

- Patient similarity can be defined by their response to treatments, known as potential outcomes.

Principal Fairness: A Causal Fairness

- Patients in the same principal stratum are considered to be able to benefit equally from a treatment.

$$\begin{align*}
(\text{\large \ding{226} N}, \text{\large \ding{225} O}) &= \\
&\begin{cases} 
(\text{\ding{226} }, \text{\ding{226} }) & \text{Stable} \\
(\text{\ding{226} }, \text{\ding{224} }) & \text{Treatable} \\
(\text{\ding{212} }, \text{\ding{226} }) & \text{Better-Without} \\
(\text{\ding{212} }, \text{\ding{212} }) & \text{Severe}
\end{cases}
\end{align*}$$
Principal Fairness: A Causal Fairness

- A treatment satisfies principal fairness if the treatment is assigned at equal rate between men and women who would benefit equally from the treatment (i.e., patients in the same principal stratum).

\[ p(\text{\knife} | \text{\heart}(\text{\man}), \text{\heart}(\text{\woman}), \text{\female} ) = p(\text{\knife} | \text{\heart}(\text{\man}), \text{\heart}(\text{\woman}), \text{\male} ) \]
A Fundamental Problem in Causal Inference

- Only half of the potential outcomes are observed.
A Bayesian Principal Fairness Assessment Algorithm

**Algorithm 1:** Bayesian Principal Fairness Assessment Algorithm

**Input:** \( \mathcal{D} = \{D_i, A_i, X_i, Y_i\}_{i=1}^{n} \)

**Output:** \( \Delta(h) \ \forall h \)

1. Estimate \( q_\phi(\theta_{y_0}) \) with VI
2. Estimate \( q_\phi(\theta_{y_1}) \) with VI

**for** \( s \leftarrow 1 \text{ to } S \) **do**

- \( \theta_{y_0} \sim q(\theta_{y_0}) \)
- \( \theta_{y_1} \sim q(\theta_{y_1}) \)
- \( Y_i(0) \sim \text{Bern}\left(p(Y_i(0) \mid X_i, A_i, \theta_{y_0})\right), i \in I_1 \)
- \( Y_i(1) \sim \text{Bern}\left(p(Y_i(1) \mid X_i, A_i, \theta_{y_1})\right), i \in I_0 \)

**end**

- Assign \( H_i = (Y_i(0), Y_i(1)) \)
- Compute \( \Delta(h) \ \forall h \)

*Estimate functions of potential outcomes*

*Sample parameters from the posteriors*

*Estimate potential outcomes*

*Estimate principal strata and principal fairness*
Principal Fairness (Sex)

No significant difference in principal strata distribution.

Treatment probability is highest in the severe group.

Bias against women.
Bias in the health care process

EHR database

Symptoms Med history

Measurements

Diagnosis

Treatment

Outcome

Health problem

Hospital? Yes

Testing? Yes

Diagnosis? Yes

Treatment? Yes

Follow-up? Yes

Selection bias

Testing bias

Diagnosis bias

Treatment bias

Censoring bias

Focus of this work
Causal Reasoning and Causal Inference for Fairness Evaluation

Social determinants of health (SDoH) include
1) education access and quality,
2) health care access and quality,
3) neighborhood and built environment,
4) social and community context,
5) economic stability. (Health People 2030)

Society-level impact
Biological impact on health
Environmental impact on health
Clinical decision-making process

Race
\( D_i \)
Migration
Phenotype
Genetics
\( Y_i \)
Conclusions and Future Directions

Statistical Equality ≠ Health Equity

Causality is important in fairness assessment.

Accounting for bias from multiple stages and multiple sources is important in health care.
Acknowledgments

George Hripcsak  David Blei  Noemie Elhadad  Anna Ostropolets  Lauren Richter  Yixin Wang

Poster #117
Sun 10/16 3-5pm health equity WG