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.

Example: Coronary Artery Disease

- **Treatment**: Revascularization
- **Sensitive Attribute**: Biological sex
- **Outcome**: Myocardial infarction (MI)
Example: Coronary Artery Disease

- Women, racial and ethnic minorities, patients without health insurance, and those who live in low-income neighborhoods may have inadequate access to revascularization procedures.

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

**Revascularization** | **Biological sex** | **Myocardial infarction (MI)**
**Question:** Is the treatment assigned at equal rate between men and women?

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

**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

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?

\[
p(\text{Heart attack} | \text{Treatment}, \text{Female}) = p(\text{Heart attack} | \text{Treatment}, \text{Male})
\]

and

\[
p(\text{Heart attack} | \text{No Treatment}, \text{Female}) = p(\text{Heart attack} | \text{No Treatment}, \text{Male})
\]

**Calibration**
Result: Heart attack happened more frequently for male patients than for female patients in the control group. Maybe bias against men?
**Accuracy**

**Question:** Is the treatment assigned at equal rate between men and women, given their (observed) outcome?

\[
p(\text{sad} | \text{sad}, \text{♀}) = p(\text{sad} | \text{happy}, \text{♀})
\]

and

\[
p(\text{sad} | \text{happy}, \text{♀}) = p(\text{happy} | \text{sad}, \text{♀})
\]
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:
    - Is there a **baseline difference** between men and women?
    - Does the **treatment work equally well** for men and women?
    - Does the **physiological mechanism** of the disease depend on sex?
From Associational to Causal Fairness

- Fairness can be more rigorously defined using causal reasoning.
- Patient similarity can be defined by their response to treatments, known as potential outcomes.

Assess fairness among similar patients.

Causality

Principal fairness
Principal Fairness: A Causal Fairness

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

Principal Fairness: A Causal Fairness

Joint of Potential Outcomes

Principal Strata

- Stable
- Treatable
- Better-Without
- Severe
Principal Fairness: A Causal Fairness

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

\[ p(\text{\checkmark} | \text{\heartsuit}\{\checkmark\}, \text{\heartsuit}\{\bigcirc\}, \text{\top}) = p(\text{\checkmark} | \text{\heartsuit}\{\checkmark\}, \text{\heartsuit}\{\bigcirc\}, \text{\top}) \]
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:** $\Delta(h) \forall h$

Estimate $q_\phi(\theta_{y_0})$ with VI  
Estimate $q_\phi(\theta_{y_1})$ with VI

for $s \leftarrow 1$ to $S$ do

\begin{align*}
\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 \mathcal{I}_1 \\
Y_i(1) &\sim \text{Bern}\left(p(Y_i(1) \mid X_i, A_i, \theta_{y_1})\right), \ i \in \mathcal{I}_0
\end{align*}

end

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?

Testing?

Diagnosis?

Treatment?

Follow-up?

Selection bias

Testing bias

Diagnosis bias

Treatment bias

Censoring bias

Yes

Yes

Yes

Yes

Yes

No

No

No

No

No

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)
Conclusions and Future Directions

Statistical Equality $\neq$ 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

linking.zhang@columbia.edu