Undetected and Undertreated

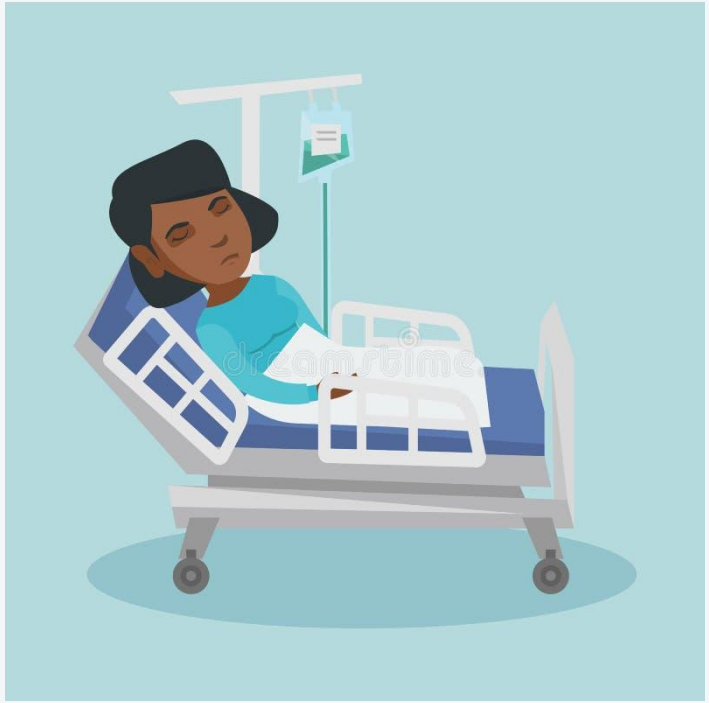
Racial and Gender Disparities in Hidden Hypoxemia and Their Economic Consequences

Nayla Trigueros Ortiz · Patricia Escobar Contreras · William Acosta Lora

COMP/STAT 212 · Macalester College · Spring 2026

Sally's Case: Hidden Hypoxemia

Patients with high melanin are 2× more likely to have hidden hypoxemia



What is Hidden Hypoxemia?

Pulse oximeters clip to your fingertip and estimate blood oxygen saturation (SpO_2) using light absorption through the skin.

Hidden hypoxemia occurs when the device reads $SpO_2 \geq 88\%$ (appearing normal) while true arterial oxygen (SaO_2) is below 88% — the patient is **genuinely hypoxic but the device says otherwise.**

This causes clinicians to withhold oxygen therapy and delay critical interventions — from patients who need them.

WHY DARKER SKIN TONES?

Melanin absorption

Darker skin contains more melanin, absorbing the same near-infrared wavelengths the device uses — inflating the reading.

Device training bias

FDA-cleared oximeters were validated primarily on lighter-skinned subjects, building the bias into their calibration.

Clinical consequence

Black and Hispanic patients are significantly more likely to experience undetected hypoxemia, delaying treatment eligibility.

Two Complementary Datasets

DATASET 1 · OPENOXIMETRY

UCSF Hypoxia Lab

- Paired SpO_2 (pulse ox) and SaO_2 (arterial blood gas) measurements
- Fitzpatrick + Monk skin tone scores from spectrophotometry
- Self-reported race and ethnicity
- Key outcomes: bias ($SpO_2 - SaO_2$) and occult hypoxemia flag
- Access: Data Use Agreement via PhysioNet

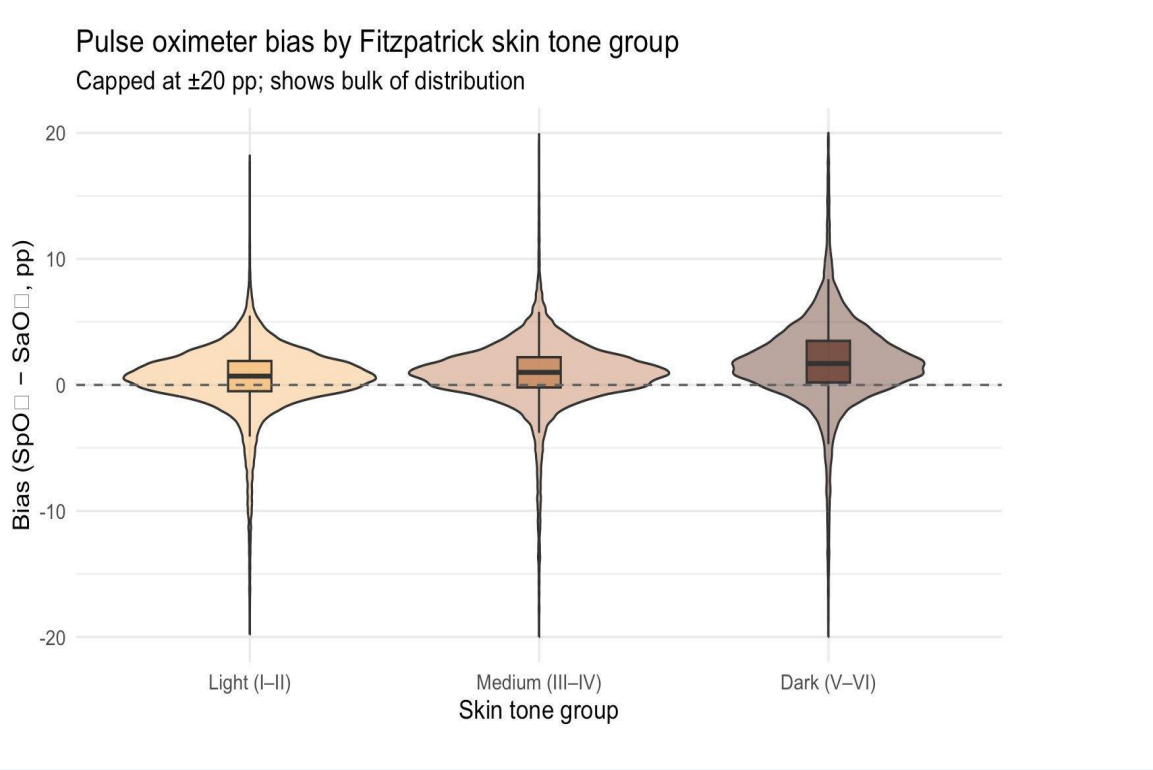
DATASET 2 · NY SPARCS

NY Dept of Health · 2021 Inpatient Discharges

- 103,907 respiratory discharge records (API — no download needed)
- Race, ethnicity, gender, age group
- Total charges, total costs, length of stay
- Insurance type, APR severity score, mortality outcome
- Free / public domain — NY Health Data portal

The two datasets do not share patients — the connection is made at the group level by joining race-stratified summaries from each.

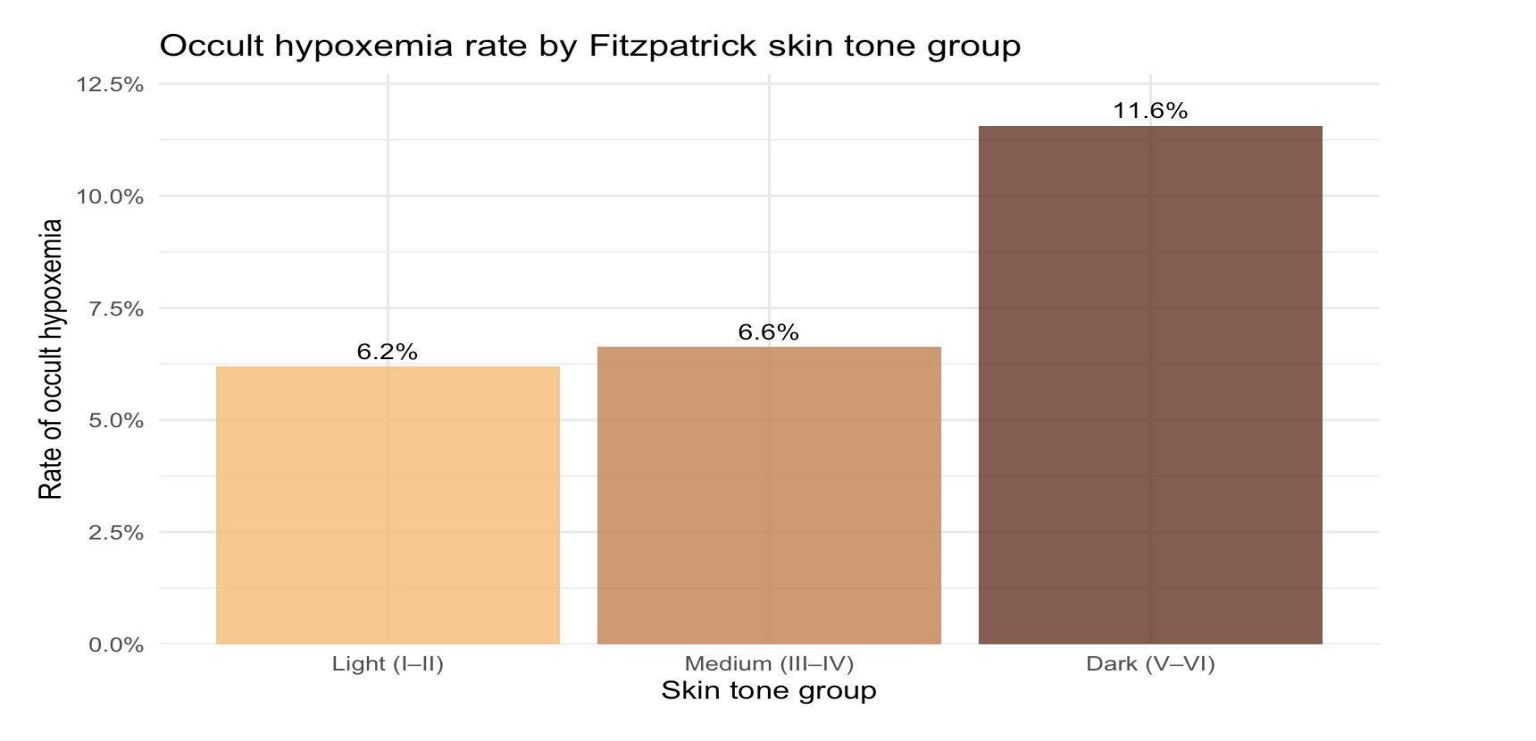
Pulse Oximeter Bias Increases with Skin Tone



What this means

- The bulk of readings cluster near zero for all groups — but the right tail extends further for darker skin.
- Even a 1–2 pp overestimate shifts clinical decisions: patients near the treatment cutoff may be denied oxygen.
- The bias is a gradient across all Fitzpatrick scores, not a threshold between two groups.
- The device flatters the reading for everyone, but darker-skinned patients are flattered most.

Dark Skin Tone -> Nearly Double the Rate of Hidden Hypoxemia

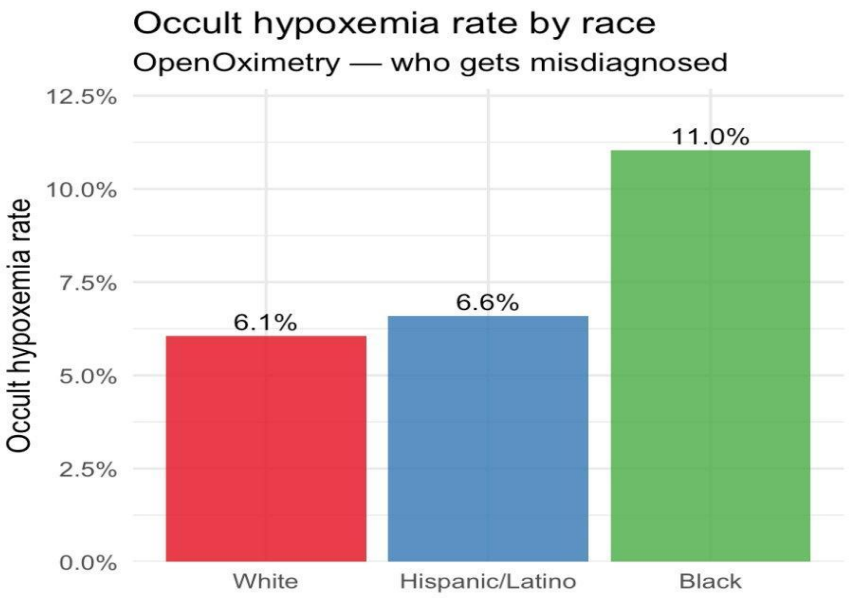


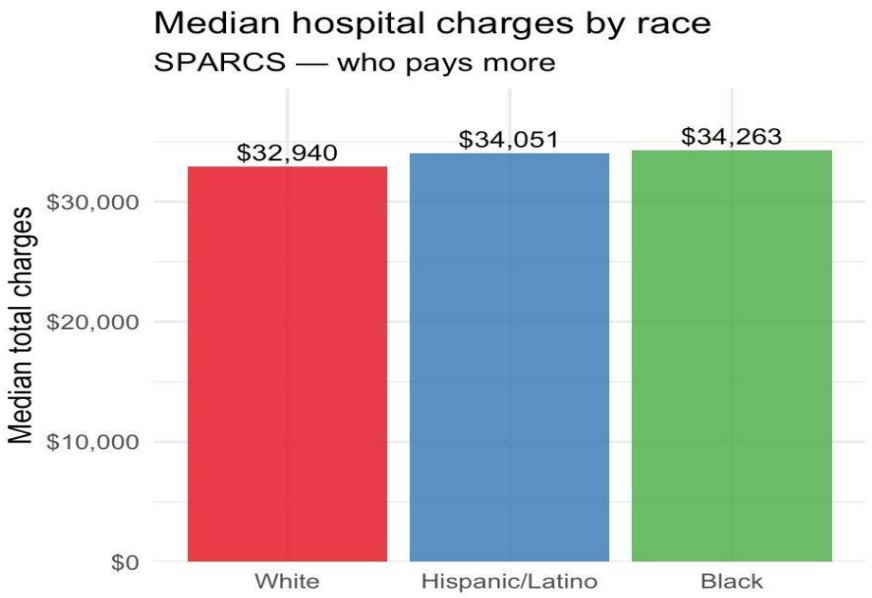
Patients with Fitzpatrick V–VI have an 11.6% occult hypoxemia rate vs. 6.2% for Fitzpatrick I–II — nearly double. This disparity exists regardless of actual oxygen need.

The Racial Ordering in Misdiagnosis Matches the Ordering in Costs

The same racial ordering appears in both misdiagnosis rates and hospital charges

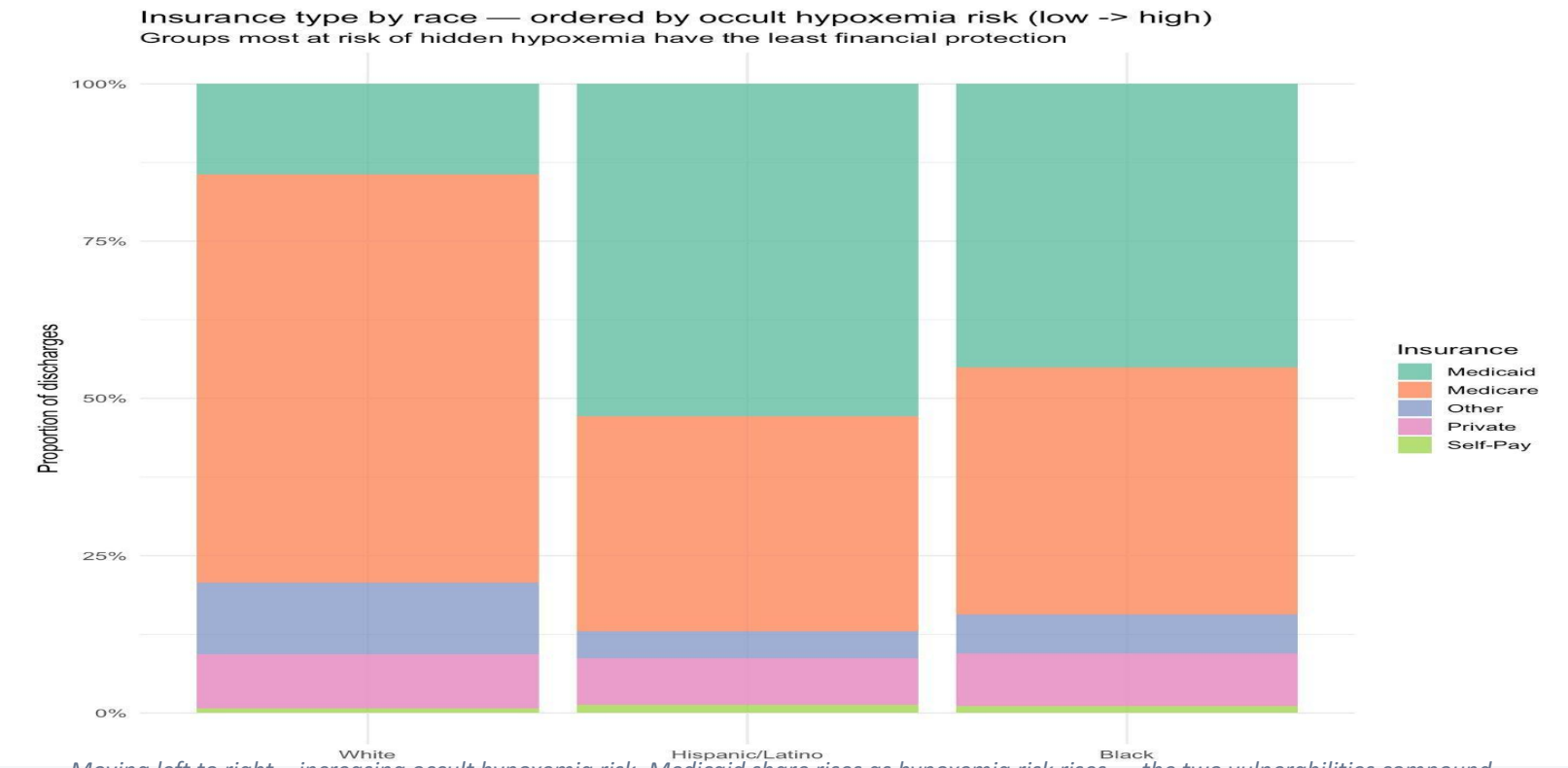
Black patients: highest occult hypoxemia rate and highest median charges





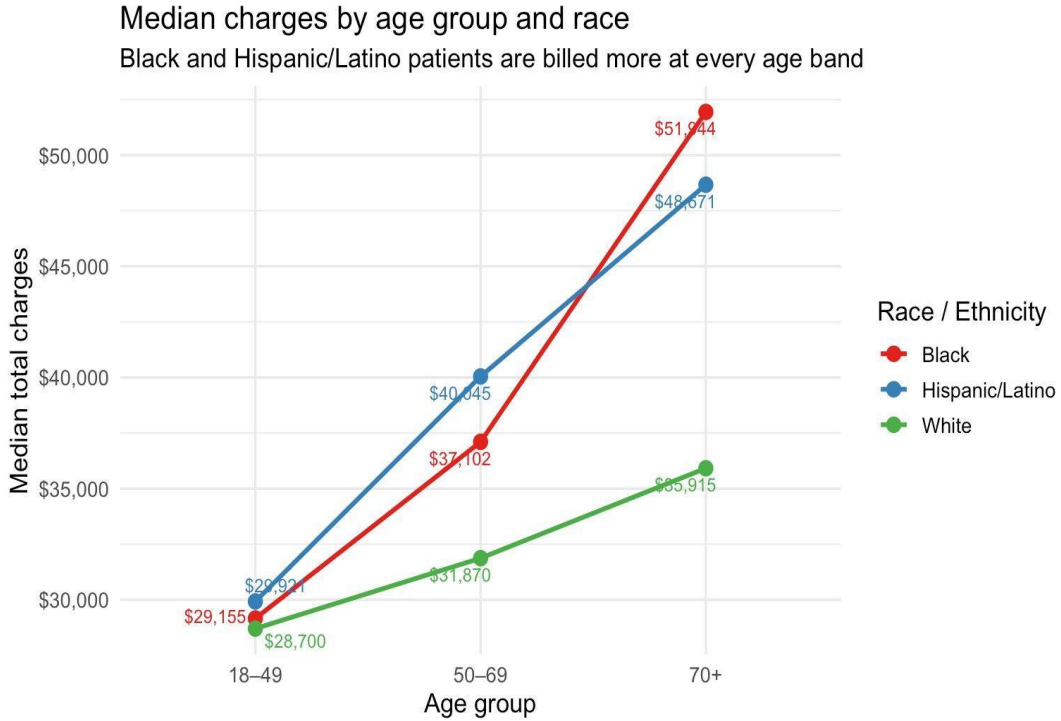
Different populations, different cities — yet the direction is consistent: Black patients face the highest misdiagnosis rate and the highest charges.

Groups Most at Risk of Hidden Hypoxemia Have the Least Financial Protection



Moving left to right = increasing occult hypoxemia risk. Medicaid share rises as hypoxemia risk rises — the two vulnerabilities compound.

Black and Hispanic/Latino Patients Pay More at Every Age



BY AGE BAND

18–49

Gap is small (~$1500). All groups relatively healthy at this age.

50–69

Gap opens. Hispanic/Latino people ~$8K more, Black people ~$5K more than White people.

70+

Gap is largest. Black people pays ~$16K more

At 70+, It is clear that undiagnosed patients are being charged more, and who pays that? Us! This issue is easily solvable if we paid more attention

INSURANCE CONVERGES

1% / 4% / 10%

White / Black / Hispanic on Medicaid at 70+

CHARGE GAP WIDENS

$16K more

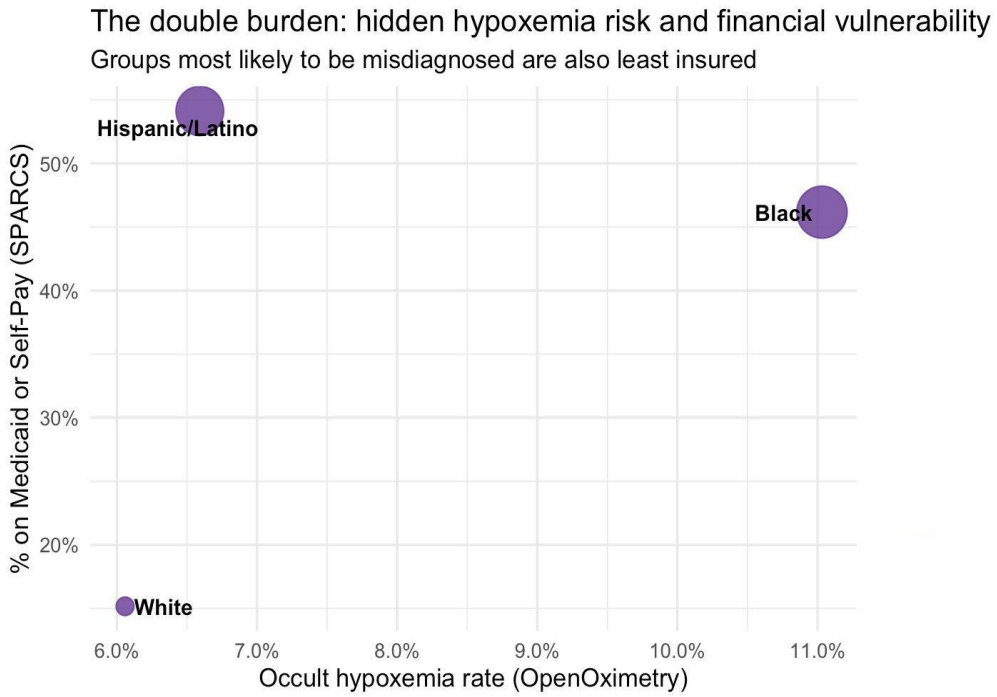
Black patients billed above White patients at 70+
- after holding all other variables in our datasets constant

Pulse Oximeter Bias is Prevalent in Individuals Assigned-Female at Birth

What this means

- While racial bias is a primary driver of device failure, being **female** often compounds this risk, particularly for **Black, Hispanic, Asian, and even White** patients, potentially leading to systemic delays in care for these specific groups.

The Double Burden: Who Is Most Exposed?



Black patients

Both elevated hypoxemia risk (~11%) and significant Medicaid exposure (~45%). Both vulnerabilities compound.

Hispanic/Latino

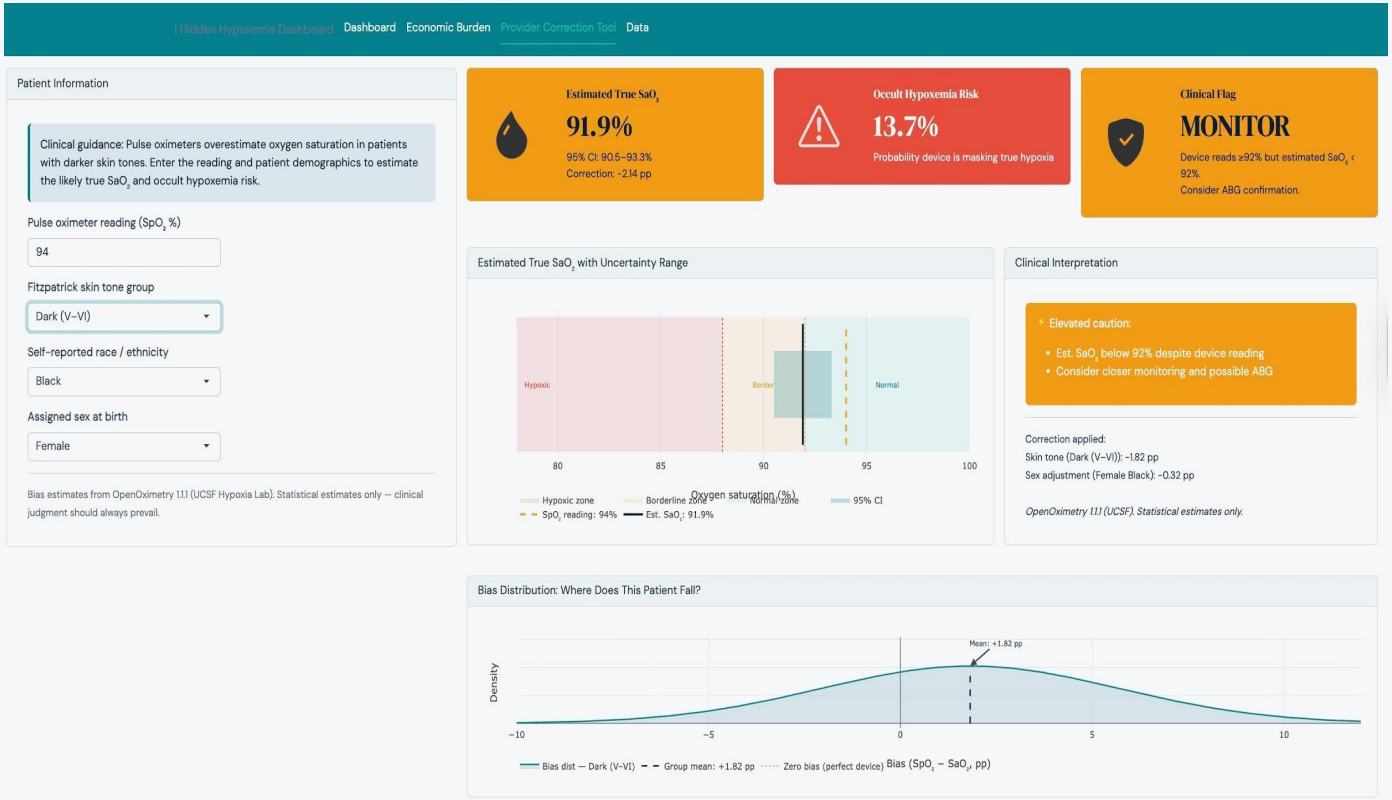
Extreme financial vulnerability (~55% Medicaid) with moderate hypoxemia risk (~6.6%) — additional drivers beyond device bias.

White patients

Lower on both dimensions; predominantly Medicare or Private insurance.

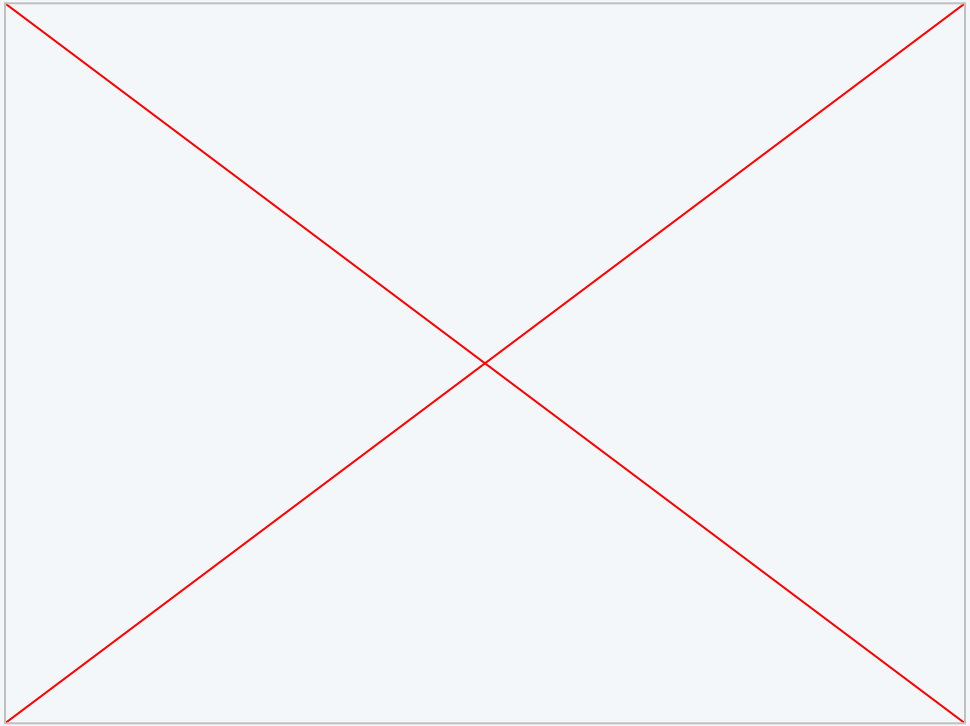
Live Bias Correction Tool for Clinical Use

Shiny App



Demo- Live Bias Correction Tool for Clinical Use

Shiny App



How the Bias Correction Tool Works

Bias Correction

1 Measure the gap

Using 5,000+ paired readings from OpenOximetry, we know exactly how much each skin tone group's device reading differs from true blood oxygen on average.

2 Subtract the bias

```
Estimated SaO2  =  SpO2  -  Mean bias  -  Sex adj.
```

```
Example — Black female, Dark skin, reads 94%:
94 - 1.82 - 0.32  =  91.9% true SaO2
```

3 Flag the risk

If the corrected estimate falls below 88% or 92% — clinical treatment thresholds — the tool raises an alert so the provider can order a blood draw confirmation.

Bias parameters from OpenOximetry (n = 5,421 readings)

Skin group	Mean bias	Occult rate	Std dev
Light skin (I–II)	+0.62 pp	6.2%	±3.21
Medium skin (III–IV)	+1.08 pp	6.6%	±3.45
Dark skin (V–VI)	+1.82 pp	11.6%	±3.89

Clinical Flags

MASKED
Patient may need O_2

MONITOR
Consider blood draw

WITHIN RANGE
Continue monitoring

Formula: Estimated SaO_2 = Device SpO_2 − Group mean bias − Sex adjustment | *95% CI = ±1.96 × SD / √30*

Consequences for Patients, Providers, and Payers

CLINICAL IMPACT

- Delayed oxygen therapy increases risk of organ damage and mortality
- Patients denied treatment eligibility based on a flawed device reading
- Black patients show higher in-hospital mortality

ECONOMIC IMPACT ON PATIENTS

- Black patients billed ~$16K more than White at 70+ for equivalent care
- 70% of Hispanic/Latino and 64% of Black working-age patients are on Medicaid — least protected when costs are highest
- Longer stays → higher out-of-pocket exposure for underinsured patients

IMPACT ON PROVIDERS & PAYERS

- Delayed treatment converts manageable cases into costly interventions
- Medicaid reimbursement shortfalls compound when stays are longer
- Systemic device bias creates legal and regulatory liability for health systems

Limitations

01

We are joining datasets based on race

The two datasets do not share patients. Race-level summaries are joined across two different populations. Directional consistency is evidence — not proof of causation.

02

No Asian Patients category in SPARCS

Asian patients are absorbed into 'Other Race' with no way to separate them, limiting the bridge to three racial groups.

03

SPARCS is New York only

New York's insurance landscape may not generalize to states with different demographics and payer mixes.

Next Steps & Future Work

Geographic variation

Use hospital_county in SPARCS to test whether disparities are concentrated in specific regions or distributed across NY State.

Monk scale analysis

Test whether Monk skin tone scores, where available, capture additional variance in bias beyond the Fitzpatrick score.

Policy implications

Quantify what it would take for FDA oximeter standards to require validation across all Fitzpatrick scores before device clearance.

Thank You

The question this project asks is simple:
When a medical device fails one group of patients more than another, who pays — clinically and economically?

GitHub: mac-stat212-s26 / project-healthcare-william-patricia-nayla
Site: mac-stat212-s26.github.io/project-healthcare-william-patricia-nayla
Data: OpenOximetry (PhysioNet) · NY SPARCS (NY Health Data)

Questions & Feedback Welcome