Investigation of Racial Bias in Modern Pulse Oximeters During the COVID-19 Pandemic

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

The COVID-19 pandemic has underscored the severe impacts of SARS-CoV-2, which specifically attacks the respiratory system, reducing the body's oxygen-carrying capacity (SpO_2). During the pandemic's peak, the number of patients far exceeded the available number of ventilators, and managing primary assessments of oxygen levels became a daunting challenge (Badgujar et al., 2020). As a result, the use of a small, non-invasive device called a pulse oximeter proved to be a game-changer in primary clinical care. By providing a quick and easy way to detect oxygen requirements in patients, pulse oximeters became a crucial tool for triaging patients (Wiles et al., 2022). Consequently, pulse oximetry became an integral part of monitoring and managing both quarantined and hospitalized patients during the pandemic, influencing treatment decisions for people with COVID-19. Medical professionals used SpO_2 thresholds to decide whether to initiate hospital-based treatments such as supplemental oxygen or intravenous dexamethasone, making pulse oximeters indispensable for patient care during the pandemic (Michard et al., 2021; Sudat et al., 2022).

However, a recent influential report by Sjoding et al. (2020) emerged that detailed the potential racial bias in pulse oximetry, with less accurate data reported for Asian, Black, and Hispanic populations. The data showed that in patients with darker skin, there was a higher risk of occult hypoxemia, a situation where the patient’s oxygen levels are low but the device says the saturation is normal. Despite the warning and increased media attention to the questions surrounding pulse oximetry, it was still used to guide decision making for patients with COVID-19. Coincidentally, COVID-19 mortality rates were disproportionately high in the same racial and ethnic minority groups pulse oximeters fail in (Gross et al., 2020).

Many health professionals and scholars have recognized the link between the racial bias in pulse oximeters and the differential COVID-19 treatments based on race. However, they do

not focus on the politics embedded in pulse oximetry itself and the broader implications beyond misdiagnosis or treatment delays. If we continue to assume that pulse oximeters are universally accurate in measuring oxygen saturation, we risk overlooking how this technology can perpetuate power imbalances between racial groups during the pandemic.

Drawing on the concept of technological politics, which analyzes how relations of power and privilege are expressed and shaped, I argue that pulse oximeters used in hospitals during the COVID-19 pandemic performed social and political work by privileging patients with lighter skin tones and marginalizing patients with darker skin tones (Winner, 1980). I will illustrate pulse oximetry's historical and modern neglect of racial and ethnic minorities up until the pandemic, missed diagnoses and treatment eligibility for different races, and the exacerbation of racial inequalities in healthcare. To support my argument, I will analyze evidence from news articles covering the pulse oximeter controversy, press releases and statistics from health organizations such as the FDA, and journal articles and studies investigating the frequency and magnitude of pulse oximeter bias for COVID-19 patients.

Background

As demonstrated in Figure 1, pulse oximeters work by shining two different wavelengths of light, typically red and infrared, through the skin, usually in the fingertip. The red and infrared light passes through the skin and blood vessels and is absorbed by the oxygenated and deoxygenated hemoglobin in the blood. Oxygenated hemoglobin absorbs more

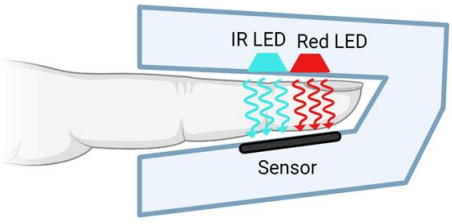

Figure 1. Inner mechanisms of finger pulse oximetry

of the infrared light and less of the red light, while deoxygenated hemoglobin absorbs more of the red light and less of the infrared light. The pulse oximeter sensor detects the amount of light that is absorbed by each and calculates the percentage of oxygen saturation in the blood based on the difference in absorption of the two wavelengths of light (Lopez, 2011).

The reason why pulse oximeters can be less accurate is because darker skin contains more melanin, a pigment that gives skin its color. Melanin absorbs light, which can interfere with the accuracy of pulse oximeters in individuals with darker skin tones. Specifically, the absorption of light by melanin can cause the pulse oximeter to overestimate the amount of deoxygenated hemoglobin in the blood, leading to lower oxygen saturation readings. This is because the pulse oximeter may have difficulty distinguishing between the light absorbed by melanin and the light absorbed by deoxygenated hemoglobin (Cabanas et al., 2022).

Literature Review

As the COVID-19 pandemic and the recent attention regarding racial bias in pulse oximeters has only occurred within the last few years, there is a lack of in-depth, abundant research regarding the subject matter. However, there still exists an adequate amount of literature that acknowledges the connection between racial inaccuracies in pulse oximeter devices and COVID-19 treatment courses. Typically, these analyses are narrow in scope, concentrating on retrospective cohort studies within a specific healthcare system and overlooking the politics involved in pulse oximetry. Furthermore, there is a lack of detailed examination of the many different ways in which White people were advantaged and Black people were disadvantaged through the reliance on pulse oximetry, with the focus instead placed on the raw data demonstrating that certain health outcomes are inferior for individuals with darker skin.

Fawzy et al. (2022) introduced key principle findings after comparing patients' oxygen saturation levels measured both by pulse oximetry and the gold standard arterial blood gas method. The study revealed that when pulse oximetry readings were compared with the gold standard, around one-third of patients from various racial or ethnic minority groups had at least one instance of occult hypoxia that went undetected, compared to less than one-fifth of White patients. Fawzy et al. (2022) also discovered a systematic failure to identify Black and Hispanic patients who should have received COVID-19 therapy and a significant delay in recognizing the guideline-recommended threshold for starting therapy among Black patients when compared to White patients (p. 730). Although the authors provide compelling evidence of pulse oximetry's racial bias, they concentrate primarily on the delayed recognition of treatment eligibility as a single outcome using only SpO_2 statistics and neglect to recognize other outcomes. Sudat et al. (2022) follow a similar structure and echo similar results, including more variables such as treatment with dexamethasone which is a drug treatment for COVID-19, supplemental oxygen, return admissions and discharges, and exact minutes to admit decision for African American patients (p. 7). However, the broader implications of mortality rates, health disparities, and racial biases remain untouched. Plaisime (2023) contextualizes clinical studies on pulse oximeters during COVID-19 within the broader history of racial bias in medical devices, highlighting their contribution to inadequate health outcomes and health disparities in Black patients. However, the author assesses various medical technologies and chooses to emphasize the underrepresentation of minorities in clinical trials instead of focusing solely on the pulse oximeter technology itself.

Although retrospective studies on hospital data offer critical evidence of differential treatment pathways, it is necessary to consider the broader context and implications to fully examine the extent and impact of pulse oximeter reliance during the pandemic in exacerbating

racial health disparities. Furthermore, adopting a technological politics framework to analyze the pulse oximeter will enable the clear identification of various ways in which individuals with darker skin were disproportionately disadvantaged during the COVID-19 pandemic.

Conceptual Framework

To frame my analysis on the racial biases in pulse oximetry during the COVID-19 pandemic, I will draw upon Langdon Winner's theory of technological politics to explore how reliance on pulse oximeters has shaped social relations of power among patient populations. Technological politics seeks to address how technological designs can be judged not only for their efficiency, productivity, and effects, but also for the ways in which they embody power and authority (Winner, 1980). These politics, or power dynamics, serve to empower and provide advantages to certain groups while excluding and harming others who use the technological artifacts either intentionally or as an unintended consequence.

According to Winner (1980), "technology" refers to "smaller or larger pieces or systems of hardware of a specific kind" and "politics" as "arrangements of power and authority in human associations as well as the activities that take place within those arrangements" (p. 123). In this analysis, the "technology" analyzed is a pulse oximeter, which includes the lights, sensors, and SpO_2 calculation algorithm. The "politics" surrounding the technology involve the power relations and social structures that shape the racial outcomes that benefit individuals with lighter skin tones. It also entails consideration of the implications of relying on a technology that disproportionately disadvantages certain groups. Winner expresses how certain technologies in themselves have political properties, and stresses the importance that technical artifacts must be

taken seriously, paying attention to the characteristics of technical objects and the meaning of those characteristics.

In the theory of technological politics, intentional or unintentional biases can arise from the design and implementation of technology, potentially leading to implicit bias. According to Winner (1980), in some cases, technology can transcend categories and favor certain social interests, which can result in compounded or multiple advantages for some groups that have been favored for a long time. Drawing on these aspects of the theory of technological politics, in the analysis that follows I will begin by providing a brief background history and establishing the intentionality behind the pulse oximeter that eventually led to empower individuals with lighter skin tones and disadvantage those with darker skin tones. Through a focus on the pulse oximeter, I will demonstrate the neglect and the lack of concern for the health outcomes of racial and ethnic minorities up until the pandemic, overlooked diagnosis and treatment eligibility for different races, and the exacerbation of racial inequalities in healthcare through morbidity rates and costs.

Analysis

In order to understand how pulse oximetry marginalized people with darker skin tones, it is important to grasp the inner technologies and algorithms that pulse oximeters were historically built and run on. The pulse oximeter uses the Beer-Lambert Law to relate the light transmitted through the finger at both red and infrared (IR) wavelengths to determine SpO_2 concentration. Absorbance of pulsating arterial blood (AC) and tissue, venous, and nonpulsating arterial blood (DC) are taken into account. Signal processing algorithms in the device identify the peaks and troughs of light transmittance to calculate the amplitudes of the signal and the modulation ratio:

$R = (AC_{red}/DC_{red})/(AC_{IR}/DC_{IR})$. However, pulse oximeter manufacturers determine the correlation between R and arterial oxygen saturation (SaO_2) based on data collected from test subjects since there is no direct mathematical relationship between the two. This is usually accomplished by measuring R in healthy volunteers with altered saturations and assuming that the relationship between R and SaO_2 remains consistent among the general population (Sjoding et al., 2023). Therefore, the diminished accuracy of pulse oximeters for individuals with dark skin tones may stem from inadequate control for increased melanin absorption of red light during device development and insufficient representation of dark-skinned individuals during device calibration (Jamali et al., 2022).

Historical and Modern Neglect

The long-standing issue of differential pulse oximetry accuracy for non-White patients during the pandemic can be attributed to the historical neglect and lack of concern for the health outcomes of racial and ethnic minorities, perpetuated by the use of White patients as the standard in biomedical design, economic considerations, and the inertia of innovation (Valbuena et al., 2022). As Winner's theory of technological politics calls to examine the original intentionality of the device so that the outcomes are clearer and easier to identify, the racialized historical neglect surrounding the pulse oximeter will be described and analyzed.

Pulse oximetry was invented by Takuo Aoyagi in the 1970's in order to monitor oxygen saturation (SpO_2) during anesthesia (Michard et al., 2021). The original intentions of the inventor and the oversights of the companies that produced the pulse oximeters are likely a case of unintentional or implicit and unconscious bias. However, the social standards of using White bodies as the standard impacted the politics of the technology. Due to historical exclusion of

minority individuals from data collection, the creation of pulse oximeter algorithms put anyone who is not White at a disadvantage right from the start. Additionally, assuming a consistent relationship between R and SaO_2 by pulse oximeter developers was a flawed assumption that only worked to advantage those who the device was originally calibrated for, which was a predominantly white population. Despite the homogenous data used to create the technology, it soon became a ubiquitous clinical tool to estimate SpO_2 for anesthesia, recovery, and critical care purposes (Jamali et al., 2022).

Questions regarding the differences in pulse oximeters based on race are not a surprise and nothing new. Studies by Bickler et al. (2005), Feiner et al. (2007), and Jubran & Tobin (1990) all demonstrated that pulse oximeters overestimated arterial oxygen levels in individuals with darker skin tones. Despite multiple studies showing that pulse oximeters may not accurately measure arterial oxygen levels in Black individuals, no significant action was taken to address the issue until recent societal movements and the COVID-19 pandemic brought attention to its adverse effects. The lack of action surrounding the pulse oximeter can be seen as performing political work in the form of perpetual political marginalization and institutional racism.

Then, at the start of the COVID-19 pandemic, use of personal and clinical pulse oximeters spiked. According to market research, sales of pulse oximeters have increased by 500% since the onset of the coronavirus pandemic in the U.S. (Smith, 2021). The seminal study by Sjoding et al. (2020) suggested that devices may be less accurate in people with dark skin pigmentation, causing a departure from ignorance as journals and media outlets started to report on the flawed devices.

Finally, on February 19, 2021 in response to the study, the U.S. Food and Drug Administration released an announcement titled, “Pulse Oximeter Accuracy and Limitations:

FDA Safety Communication" providing recommendations to patients, caregivers, and health providers on the interpretation and limitations of pulse oximeters during the COVID-19 pandemic. Since the pulse oximeter's creation in the 1970s to acknowledgement by the FDA in 2021, almost 50 years passed before widespread attention was drawn to pulse oximeter's racial bias. After ignoring the evidence for years, which could have affected countless Black patients, attention was finally turned towards efforts to acknowledge and redesign the pulse oximeter as a result of increased use during the pandemic. However, the consequence was half a century of the Black community being excluded in healthcare in relation to pulse oximeter technology.

Langdon Winner's theory of technological politics highlights the importance of examining the original intentionality of a technology and the social standards that impact its development. In the case of pulse oximetry, the historical neglect and lack of concern for the health outcomes of racial and ethnic minorities perpetuated the use of White patients as the standard in biomedical design, leading to differential pulse oximetry accuracy for non-White patients. Although unintentional or implicit bias likely played a role, the inertia of innovation and economic considerations also contributed to the neglect. Studies showing the accuracy differences of pulse oximeters based on race were largely ignored until the COVID-19 pandemic sparked a surge in sales and media attention. Only then did the FDA release recommendations on pulse oximeter accuracy and limitations. The neglect of the issue for so long could have affected countless Black patients, highlighting the need for a critical examination of the intentionality of technologies to ensure equitable outcomes.

Misdiagnosis and Treatment Outcomes

During the COVID-19 pandemic, pulse oximeters utilized in hospitals had a social and political impact that favored patients with lighter skin tones and disadvantaged those with darker skin tones in regards to missed diagnoses and treatment eligibility. Hypoxia refers to a condition where the body or a part of the body is deprived of an adequate supply of oxygen. It is a medical emergency that requires prompt treatment, especially in patients with COVID-19. In a study at the University of Michigan Hospital, it was found that Black patients had almost three times the rate of undetected hypoxemia by pulse oximetry compared to White patients (Sjoding et al., 2020). These findings were particularly important during the COVID-19 pandemic since pulse oximetry was widely used for medical decision making. As suggested by the results, dependence on pulse oximetry to triage patients and adjust oxygen levels put Black patients at a higher risk for hypoxemia and eventual adverse outcomes. By using pulse oximetry to influence decision making, the Black community was further marginalized in healthcare.

As pulse oximeters missed critical diagnoses based on racial patterns, treatment outcomes were also impacted. Not only did pulse oximetry miss key diagnosis for Black patients, but a study by Fawzy et al. (2022) revealed that Black patients also had a median treatment delay of one hour longer than White patients. Beyond the inconvenience of waiting an extra hour, delayed treatment can lead to more severe health implications, especially in the cases of hypoxemia in COVID-19 patients. Furthermore, longer treatment times can also have significant economic consequences for those requiring longer hospital stays and more intensive treatment. Therefore, pulse oximeters not only cause detriments to direct health, but also contribute to the lack of inclusive and equitable healthcare for Black individuals. Overall, the data suggests that the use of pulse oximetry has disproportionately impacted Black patients, resulting in missed critical

diagnoses and delayed treatment. The findings of these studies reveal a systematic neglect of Black patients, highlighting the ways in which technological tools can be designed and implemented in ways that advantage certain groups over others.

As I have argued, the utilization of pulse oximeters themselves during the COVID-19 pandemic had a social and political impact that favored patients with lighter skin tones and disadvantaged those with darker skin tones in terms of missed diagnoses and treatment eligibility. One argument against the idea that pulse oximeters are racially biased as a measurement for diagnosis is that there could be other factors at play that affect the accuracy of pulse oximetry readings, not just skin color. For example, some medical conditions, such as anemia, can affect the accuracy of pulse oximetry readings and may be more prevalent in certain racial or ethnic groups. Additionally, factors such as age, tobacco use, body temperature, and patient movement can influence readings (Cabanas et al., 2022). While it is true that there are medical conditions and lifestyle factors that can impact pulse oximetry readings, it is important to recognize that these factors do not fully explain the significant racial disparities observed in the accuracy and effectiveness of pulse oximeters. The studies cited in the previous discussion have taken into account these factors and have still found a clear racial bias in the accuracy of pulse oximetry readings, as well as in treatment eligibility and timing. Furthermore, while anemia and other medical conditions may affect pulse oximetry readings, it is also important to recognize that these conditions may themselves be a result of systemic racial biases in healthcare and social determinants of health. Therefore, while it is important to consider other factors that may affect pulse oximetry accuracy, it is not sufficient to discount the racial disparities observed in the use of pulse oximeters during the COVID-19 pandemic.

Exacerbation of Racial Disparities

Along with misdiagnosis and treatment outcomes, pulse oximetry reliance also contributed to worsening racial health disparities in terms of hospitalization and morbidity rates from COVID-19. According to the Centers for Disease Control and Prevention (CDC), Black or African American individuals were 2.1x more likely to get hospitalized and 1.6x more likely to die from COVID-19 than White individuals. Tobin & Jubran (2022) suggest that this may be due in part to racial disparities in the accuracy of pulse oximetry readings and subsequent treatment decisions. Therefore, not only do pulse oximeters marginalize darker skinned individuals through diagnosis, but it also impacts survival outcomes. By using pulse oximeters, White patients are given an advantage over Black patients in every aspect of COVID-19 healthcare including diagnosis, treatment, and effectiveness.

Mitigation strategies for pulse oximeter racial bias can also prove to worsen racial disparities in healthcare. Suggestions to increase pulse oximetry targets can prelude dangerous racial correction strategies, while also failing to address the fundamental errors of the technology itself (Fawzy et al., 2023). The potential strategy could also prolong hospitalization and increase demands, ultimately raising costs that would put further strain on an already marginalized racial demographic struggling with healthcare bills (Moore et al., 2022). As many different companies look towards developing a pulse oximeter that eliminates racial bias, the factor of costs is important. If the racial dimension of skin coloration is fixed, but higher prices prevent the widespread adoption and access of the device, then racial disparities will just be transferred in the form of cost.

Conclusion

The technology of pulse oximeters used in hospitals during the pandemic worked to privilege patients with lighter skin tones and disadvantage patients with darker skin tones as clearly demonstrated by the technological politics framework. Lack of diversity in initial training data, methods embedded in pulse oximeter technologies, and historical disregard for racial and ethnic minorities manifested themselves directly in pulse oximeters. As a result, the reliance on pulse oximetry for COVID-19 diagnostic guidance led to mistreatment of ethnic minorities and ultimately exacerbated the racial inequalities in healthcare. By considering the intentions behind the design, history of flaws, and catastrophic differential racial outcomes during a major health crisis, the argument for solutions and alternatives to the technology is strengthened. As outlined thus far, increased awareness brought to all aspects of the technology in general is essential for reparations moving forward. The importance of redesigning the pulse oximeter and widespread adoption of new racially equalizing technologies in all parts of the healthcare system cannot be understated so that no unnecessary deaths occur based on use of a single, fixable technology. Instead of exacerbating healthcare inequalities, pulse oximeter technology can alleviate the barriers that marginalized communities face.

References

Badgujar, K. C., Badgujar, A. B., Dhangar, D. V., & Badgujar, V. C. (2020). Importance and use of pulse oximeter in COVID-19 pandemic: General factors affecting the sensitivity of pulse oximeter. *Indian Chemical Engineer*, *62*(4), 374–384. https://doi.org/10.1080/00194506.2020.1845988

Bickler, P. E., Feiner, J. R., & Severinghaus, J. W. (2005). Effects of skin pigmentation on pulse oximeter accuracy at low saturation. *Anesthesiology*, *102*(4), 715–719. https://doi.org/10.1097/00000542-200504000-00004

Cabanas, A. M., Fuentes-Guajardo, M., Latorre, K., León, D., & Martín-Escudero, P. (2022). Skin pigmentation influence on pulse oximetry accuracy: A systematic review and bibliometric analysis. *Sensors (Basel, Switzerland)*, *22*(9), 3402. https://doi.org/10.3390/s22093402

Fawzy, A., Valbuena, V. S. M., Chesley, C. F., Wu, T. D., & Iwashyna, T. J. (2023). Dynamic errors in pulse oximetry preclude use of correction factor. *Annals of the American Thoracic Society*, *20*(2), 338–339. https://doi.org/10.1513/AnnalsATS.202210-872LE

Fawzy, A., Wu, T. D., Wang, K., Robinson, M. L., Farha, J., Bradke, A., Golden, S. H., Xu, Y., & Garibaldi, B. T. (2022). Racial and ethnic discrepancy in pulse oximetry and delayed identification of treatment eligibility among patients with COVID-19. *JAMA Internal Medicine*, *182*(7), 730–738. https://doi.org/10.1001/jamainternmed.2022.1906

Feiner, J. R., Severinghaus, J. W., & Bickler, P. E. (2007). Dark skin decreases the accuracy of pulse oximeters at low oxygen saturation: The effects of oximeter probe type and gender. *Anesthesia & Analgesia*, *105*(6), S18. https://doi.org/10.1213/01.ane.0000285988.35174.d9

Gross, C. P., Essien, U. R., Pasha, S., Gross, J. R., Wang, S., & Nunez-Smith, M. (2020). Racial and ethnic disparities in population-level Covid-19 mortality. *Journal of General Internal Medicine*, *35*(10), 3097–3099. https://doi.org/10.1007/s11606-020-06081-w

Jamali, H., Castillo, L. T., Morgan, C. C., Coult, J., Muhammad, J. L., Osobamiro, O. O., Parsons, E. C., & Adamson, R. (2022). Racial disparity in oxygen saturation measurements by pulse oximetry: Evidence and implications. *Annals of the American Thoracic Society*, *19*(12), 1951–1964. https://doi.org/10.1513/AnnalsATS.202203-270CME

Jubran, A., & Tobin, M. J. (1990). Reliability of pulse oximetry in titrating supplemental oxygen therapy in ventilator-dependent patients. *Chest*, *97*(6), 1420–1425. https://doi.org/10.1378/chest.97.6.1420

Lopez, S. (2011). *Pulse oximeter fundamentals and design*. Freescale Semiconductor. https://www.fer.unizg.hr/_download/repository/Pulse_Oximeter_Fundamentals.pdf

Michard, F., Shelley, K., & L'Her, E. (2021). COVID-19: Pulse oximeters in the spotlight. *Journal of Clinical Monitoring and Computing*, *35*(1), 11–14. https://doi.org/10.1007/s10877-020-00550-7

Moore, K. L., Gudelunas, K., Lipnick, M. S., Bickler, P. E., & Hendrickson, C. M. (2022). pulse oximeter bias and inequities in retrospective studies—Now what? *Respiratory Care*, *67*(12), 1633–1636. https://doi.org/10.4187/respcare.10654

Plaisime, M. V. (2023). Undiagnosed and undertreated: The suffocating consequences of racially-biased medical devices during the COVID-19 pandemic. *American Journal of Epidemiology*, kwad019. https://doi.org/10.1093/aje/kwad019

Sjoding, M. W., Ansari, S., & Valley, T. S. (2023). Origins of racial and ethnic bias in

pulmonary technologies. *Annual Review of Medicine*, *74*(1), 401–412. https://doi.org/10.1146/annurev-med-043021-024004

Sjoding, M. W., Dickson, R. P., Iwashyna, T. J., Gay, S. E., & Valley, T. S. (2020). Racial bias in pulse oximetry measurement. *New England Journal of Medicine*, *383*(25), 2477–2478. https://doi.org/10.1056/NEJMc2029240

Smith, J. (2021, February 20). This device is crucial in the fight against Covid. It may not work on dark skin. *CNN*. https://www.cnn.com/2021/02/20/health/pulse-oximeters-dark-skin-covid/index.html

Sudat, S. E. K., Wesson, P., Rhoads, K. F., Brown, S., Aboelata, N., Pressman, A. R., Mani, A., & Azar, K. M. J. (2022). Racial disparities in pulse oximeter device inaccuracy and estimated clinical impact on COVID-19 treatment course. *American Journal of Epidemiology*, kwac164. https://doi.org/10.1093/aje/kwac164

Tobin, M. J., & Jubran, A. (2022). Pulse oximetry, racial bias and statistical bias. *Annals of Intensive Care*, *12*(1), 2. https://doi.org/10.1186/s13613-021-00974-7

Valbuena, V. S. M., Merchant, R. M., & Hough, C. L. (2022). Racial and ethnic bias in pulse oximetry and clinical outcomes. *JAMA Internal Medicine*, *182*(7), 699–700. https://doi.org/10.1001/jamainternmed.2022.1903

Wiles, M. D., El-Nayal, A., Elton, G., Malaj, M., Winterbottom, J., Gillies, C., Moppett, I. K., & Bauchmuller, K. (2022). The effect of patient ethnicity on the accuracy of peripheral pulse oximetry in patients with COVID-19 pneumonitis: A single-centre, retrospective analysis. *Anaesthesia*, *77*(2), 143–152. https://doi.org/10.1111/anae.15581

Winner, L. (1980). Do artifacts have politics? *Daedalus*, *109*(1), 121–136.