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Impact of poverty reduction on oral health outcomes among US adults

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Abstract:	Poor oral health is a public health issue in the United States (US), disproportionately affecting people in poverty. This cross-sectional study investigates the impact of reducing absolute and relative poverty on the prevalence of periodontitis, caries, and dental pain among US adults. Data from 13,139 adults aged 30-70 years who completed dental examinations in the 2011-2018 National Health and Nutrition Examination Surveys (NHANES) were used. Periodontitis and dental caries outcomes were assessed only using 2011-2014 NHANES surveys (N=6,563). Absolute and relative poverty were assessed based on the poverty income ratio established by the US Census Bureau. Hypothetical counterfactual scenarios were emulated to assess the impact of poverty reductions (10%, 25%, and 50%) on periodontitis, dental caries, and dental pain. A targeted minimum loss-based estimator was used to estimate the outcomes under each scenario adjusted for age, sex, race, comorbidity, and marital status. Reductions in both absolute and relative poverty were associated with lower prevalence of oral disease. A 50% reduction in absolute poverty would avert 1.1 million cases of periodontitis, 0.4 million individuals with dental caries, and 0.6 million dental pain cases. A similar reduction in relative poverty would avert 5.4 million cases of periodontitis, 3.8 million individuals with caries, and 2 million cases of dental pain. The greatest impact was seen with a 50% relative poverty reduction: 12% reduction in periodontitis (Prevalence Ratio(PR)=0.88, 95%CI: 0.85-0.92), 13% reduction in caries (PR=0.87, 95%CI: 0.81-0.92), and 18% reduction in frequent dental pain (PR=0.82, 95%CI: 0.73-0.91). These findings highlight the potential of poverty reduction, especially relative poverty, to significantly lower the

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Impact of poverty reduction on oral health outcomes among US adults

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Abstract

Poor oral health is a public health issue in the United States (US), disproportionately affecting people in poverty. This cross-sectional study investigates the impact of reducing absolute and relative poverty on the prevalence of periodontitis, caries, and dental pain among US adults. Data from 13,139 adults aged 30-70 years who completed dental examinations in the 2011-2018 National Health and Nutrition Examination Surveys (NHANES) were used. Periodontitis and dental caries outcomes were assessed only using 2011-2014 NHANES surveys (N=6,563). Absolute and relative poverty were assessed based on the poverty income ratio established by the US Census Bureau. Hypothetical counterfactual scenarios were emulated to assess the impact of poverty reductions (10%, 25%, and 50%) on periodontitis, dental caries, and dental pain. A targeted minimum loss-based estimator was used to estimate the outcomes under each scenario adjusted for age, sex, race, comorbidity, and marital status. Reductions in both absolute and relative poverty were associated with lower prevalence of oral disease. A 50% reduction in absolute poverty would avert 1.1 million cases of periodontitis, 0.4 million individuals with dental caries, and 0.6 million dental pain cases. A similar reduction in relative poverty would avert 5.4 million cases of periodontitis, 3.8 million individuals with caries, and 2 million cases of dental pain. The greatest impact was seen with a 50% relative poverty reduction: 12% reduction in periodontitis (Prevalence Ratio(PR)=0.88, 95%CI: 0.85-0.92), 13% reduction in caries (PR=0.87, 95%CI: 0.81-0.92), and 18% reduction in frequent dental pain (PR=0.82, 95%CI: 0.73-0.91). These findings highlight the potential of poverty reduction, especially relative poverty, to significantly lower the US oral disease burden and

emphasize policy importance for reducing income inequality to achieve equitable oral health.

MESH Keywords: Public Policy, Social Determinants of Health, Oral Health, Nonparametric Statistics, Causation, NHANES

Introduction

In 2022, over 700 million people lived globally in extreme poverty causing deprivation, hardship, and negative health outcomes (World Bank 2022). Despite being a high-income country, the United States of America (US) had 37.9 million individuals (11.5%) living below absolute poverty in 2022 (US Census Bureau 2023). Living below the absolute poverty line indicates that a household's income is less than the minimum threshold required for basic survival in that country. In high-income countries such as the US, absolute poverty captures a small fraction of the population in severe deprivation. Therefore, relative poverty—typically measured as having less than 40%, 50%, or 60% of the population's median income—is also relevant in the US context, as it reveals the pattern and magnitude of socioeconomic inequalities in a wider population bracket (Wilkinson 1997). Both absolute and relative poverty are important social determinants of health, negatively affecting health outcomes, with evidence from high-income countries suggesting that relative poverty is more strongly associated with negative health consequences than absolute poverty (Wagstaff and van Doorslaer 2000; Ram 2005).

The relationship between poverty and poor oral health has been well established (Ghorbani et al. 2017; Tiwari and Franstve-Hawley 2021). Poverty amplifies a lack of material resources that predispose individuals and households to causes of poor oral health and limited access to essential dental care (Singh et al. 2019). Periodontitis and dental caries are the most common oral diseases, and dental pain is a debilitating common symptom that arises due to untreated or delayed treatment of common preventable oral diseases (Aldosari et al. 2021). Oral diseases are a significant public health problem in the US, impacting individuals and society on multiple levels (Vujicic et al. 2016). The Center for Disease Control and Prevention (CDC) estimated that nearly half of adults aged 30 years and older exhibit some form of periodontal disease, while approximately 91% of adults have experienced dental caries in their permanent teeth. Furthermore, over 40% of adults felt pain in their mouth at some time over the past year (CDC 2024). At the individual level, oral diseases can disrupt sleep, concentration, diet, and daily activities and cause excruciating pain, leading to anxiety, depression, and work absenteeism (Cohen et al., 2007). On a societal level, the ramifications of frequent oral diseases are equally concerning. Pain due to oral diseases is the most common dental emergency and leads to work absenteeism and decreased workforce productivity placing additional strain on economies (Currie et al. 2017). The economic impact of oral disease is substantial to the US economy; on average, more than $45 billion in productivity is lost each year due to complications of untreated decay or periodontal disease (Righolt et al. 2018).

Even though the relationship between poverty and oral diseases is intuitively understood, assessing the population-level impact of interventions aimed at reducing absolute and relative poverty remains challenging. This must be quantified for understanding the avoidable burden of oral diseases due to poverty. Recent advances in statistical inference frameworks provide useful tools to intercept such causal questions using observational data (Dang et al., 2023). Given the magnitude of the problem and its cost to the US society, knowing whether and to what extent macro-level interventions to address absolute and relative poverty would potentially reduce the prevalence of common oral disease experiences is a population health priority. This study aimed to estimate the impact of hypothetically reduced household poverty levels on periodontal disease, untreated caries, and frequent dental pain experience among adults in the US.

Methods

Data

Cross-sectional data from 2011-2012 to 2017-2018 National Health and Nutrition Examination Survey (NHANES) cycles were used. NHANES uses a complex, multistage sampling design to select participants nationally representative of the US population (Zipf et al. 2013). Out of four NHANES cycles used, only 2011-2012 & 2013-2014 contained complete data from periodontal and dental caries examinations. All four waves contained dental pain data. Thus, 13,139 participants were included in the analysis of dental pain while only 6,563 participants were included in the analysis of periodontitis and dental caries. Only adult participants ages 30 to 70 who completed dental examinations and were not edentate were included in the analysis. The selection of analytical samples for the study is shown in Figure 1.

Exposure

First, absolute poverty based on the proportion of individuals living below the official poverty line, as established by the US Census Bureau, was used. This official poverty measure is based on the poverty income ratio (PIR), which is calculated by dividing the total annual household income by the inflation-adjusted poverty threshold for the specific year.

PIR= total household income/inflation-adjusted poverty threshold for the year

Individuals with a PIR of less than one, are considered to be in absolute poverty. Second, relative poverty was measured as having less than 60% of the median PIR. We used 60% as it represents the most conservative measure of relative poverty (Garroway and de Laiglesia 2012).

The aforementioned absolute and relative poverty threshold references were used to dynamically shift the observed PIR distribution of our study population (Figure 2).

Outcome variables

Periodontitis, untreated dental caries, and frequent dental pain were the oral disease outcomes of interest. Periodontitis and dental caries were assessed using oral health examination performed by dentists with a dental license in at least one US jurisdiction and trained in NHANES survey methods (Dye et al. 2019). A binary indicator was used to identify periodontitis adapting 2018 periodontal status classification for epidemiological survey data (ACES). Participants with more than one interdental site with ≥1 mm clinical attachment loss (CAL) in non-adjacent teeth and at least one ≥5mm CAL site were categorized as a periodontitis case (Holtfreter et al. 2024). Untreated decay was directly reported by dental examiners. Frequent dental pain was measured using self-report (having fairly often painful aching mouth during the last 12 months).

Confounders

Potential confounders were selected on the basis that influences both the exposure and outcome, causing a spurious association (VanderWeele and Shpitser 2013). Age (range 30-70), sex (Male/Female), race (non-Hispanic white/non-Hispanic black/ Hispanic/Mixed or other), having a comorbidity (congestive heart failure, chronic heart disease, myocardial infarction, stroke, COPD, or cancer), and marital status (married/ divorced/ widowed/never married/with partner/separated) were used. A directed cyclic graph showing the hypothesized associations between variables is shown in Supplementary Figure 1.

Statistical analysis

A descriptive analysis was performed to identify the characteristics of participants stratified by absolute and relative poverty levels. In the main analysis, the following alternate "what if" absolute and relative poverty counterfactual scenarios were emulated.

Scenario 1: What if the level of absolute poverty is reduced by 10%?

Scenario 2: What if the level of absolute poverty is reduced by 25%?

Scenario 3: What if the level of absolute poverty is reduced by 50%?

Scenario 4: What if the level of relative poverty is reduced by 10%?

Scenario 5: What if the level of relative poverty is reduced by 25%?

Scenario 6: What if the level of relative poverty is reduced by 50%?

The maximum poverty reduction was set at 50% following Lippold (2015) (a simulation study to support a policy package by the Urban Institute in the USA), but additional incremental poverty reduction targets (10% and 25%) were added to check for a potential dose response effect. Figure 2 shows the changes in PIR distribution in the study population with each emulated scenario.

Then, a targeted minimum loss-based estimator (TMLE) was used to estimate outcomes under each of the emulated counterfactual scenarios. TMLE is doubly robust as it relies on two models (i.e., outcome model and exposure model) to estimate the g-computation formula (Van Der Laan and Rose 2018). TMLE also allows the use of machine learning to flexibly fit treatment and outcome regressions without relying on parametric assumptions (Schuler and Rose 2017). Generalized linear models, generalized additive models, and extreme gradient boosting models were used within the Superlearner when estimating TMLE models. All estimates were adjusted for confounding variables, weighted to account for the NHANES sampling design, and cross-validated using 5-fold cross-validation.

Then, TMLE outcome estimates for each of the emulated PIR distribution scenarios were contrasted against the outcome estimate under the observed PIR to calculate the prevalence ratio (PR) and 95% confidence intervals (95% CI) for each scenario. In addition, outcome prevalence difference between each of the emulated scenarios and observed PIR was estimated to extrapolate the estimates to the US population. Finally, E values were calculated to report the potential impact of unmeasured confounding on the effect estimates (VanderWeele and Ding 2017).

The *lmtp* R package (within *R version 4.3.2* for *aarch64-apple-darwin20*) was used to compute TMLE estimates and to contrast estimates (Díaz et al. 2021). R codes used in the analysis can be found at *https://github.com/upulcooray/dental-pain-PIR*. The reporting of this study follows the STROBE guidelines.

Handling missing data

Random forest-based multivariate imputation by chained equations (MICE) was used to impute missing data (Shah et al. 2014). Analyses were performed using five imputed datasets, and the estimates were pooled using Rubin's rules (Rubin 2004). The distribution of study variables' missingness is shown in Supplementary Figures 2 and 3.

Results

Table 1 presents characteristics of the study participants stratified by absolute and relative poverty levels. The prevalence of all disease outcomes was higher among those living below both absolute and relative poverty lines. For individuals in absolute poverty, the prevalence of periodontitis was 35.8%, dental caries was 35.2%, and dental pain was 19.9%. For those in relative poverty, the prevalence was 33% for periodontitis, 30.7% for dental caries, and 13.5% for dental pain.

Table 2 provides the prevalence ratios, absolute prevalence difference, and prevalence difference attributable to the US population related to hypothetically shifted PIR scenarios. Interventions on relative poverty appeared to have a greater influence on reducing population-level frequent dental pain prevalence than interventions on absolute poverty.

After adjusting for age, sex, race, comorbidity, and marital status as confounders and accounted for NHANES survey design and weights, a hypothetical 50% reduction in absolute poverty resulted in a 4% decrease in periodontitis (PR=0.96, 95%CI: 0.94-1.00), a 3% decrease in dental caries (PR=0.97, 95%CI: 0.93-1.01), and a 6% decrease in frequent dental pain (PR = 0.95, 95% CI: 0.89-1.00). This translates to 1,139,255 fewer periodontitis cases, 399,249 fewer dental caries cases, and 592,434 fewer dental pain cases at the US population level. A hypothetical 50% reduction in relative poverty led to an 12% decrease in periodontitis (PR=0.88, 95%CI: 0.85-0.92), a 13% decrease in dental caries (PR=0.87, 95%CI: 0.81-0.92), and a 18% decrease in frequent dental pain (PR=0.82, 95%CI: 0.73-0.91). This equates to 5,428,276 fewer periodontitis cases, 3,822,145 fewer dental caries cases, and 2,086,398 fewer frequent dental pain cases.

Discussion

Using nationally representative data from US adults, our findings showed that a 50% reduction in absolute poverty at the population level would potentially result in approximately 1.1 million fewer prevalent cases of periodontitis, 0.4 million fewer cases of untreated dental caries, and 0.6 million fewer cases of frequent dental pain. While a 50% reduction in relative poverty would translate to approximately 5.4 million fewer prevalent cases of periodontitis, 3.8 million fewer individuals with untreated dental caries, and 2 million fewer dental pain cases. The reduction of oral diseases prevalence in response to absolute poverty reductions appeared to be fairly modest (i.e; 50% absolute poverty reduction associated with 4%, 3%, and 6% reductions in periodontitis, caries, and dental pain, respectively). In comparison, relative poverty interventions yielded better reductions in oral disease prevalence (i.e.; 50% relative poverty reduction associated with 12%, 13%, and 18% reductions in periodontitis, caries, and dental pain, respectively). These findings align with the existing evidence on the importance of relative income inequalities when trying to improve health outcomes in high-income countries (Pickett and Wilkinson 2015).

While the prevalence of oral diseases is higher among individuals living in absolute poverty, the majority of the population falls above this threshold. As such, addressing only this smaller subset of individuals may be insufficient to achieve significant reduction in oral disease burden across the US population. The relatively more modest improvements of interventions focused solely on those living in absolute poverty suggest this. Conversely, targeting a broader population range, including those living below the relative poverty line, could yield more improvements in oral health at the population level. This may be because relative poverty better reflects the socioeconomic hierarchy of the whole of the population while engaging a larger segment of the population. In fact, our findings conform with Geoffrey Rose's population strategy for prevention, which seeks to move the distribution of a risk factor, including its low tail, in a favourable direction as emulated in this study (see Figure 2) (Rose et al. 2008).

The distinction between absolute and relative poverty reduction outcomes may be partially attributed to variations in individuals' priorities for healthcare, particularly oral health, across diverse levels of material deprivation. Individuals living in absolute poverty often face extreme material deprivation, making the provision of basic necessities like food and shelter rather challenging. Oral health may not be a primary concern in such situations, as immediate survival needs take precedence (Lynch et al. 1997). Therefore, the additional income threshold needed for individuals in such situations to prioritize oral health would be much higher than what was emulated in this study. Conversely, individuals living in relative poverty might have access to basic necessities but still experience deprivation compared to average living standards in the US. With additional resources, these individuals could potentially gain greater control over their decisions concerning oral health and access to care.

To effectively address oral health inequalities, especially in a high-income country such as the US, policy measures should extend beyond solely targeting those in absolute poverty (Tsakos et al. 2023). More nuanced definitions of income and material deprivations with consideration of social determinants of oral health could be crucial to achieving substantial improvements in oral health outcomes (Patrick et al. 2006). In the US context, race and ethnicity might also interact with the expected health gains due to poverty reduction (Anderson et al. 2004). Furthermore, the intersection between socioeconomic position and ethnicity might also play an important role in this context. Our analysis was not designed to investigate those complex intersectional effects. Future studies with a robust analytic framework and sufficient sample sizes to look at the interaction between poverty and race/ethnicity are needed to gain insights into the heterogeneity of effects of poverty reduction on oral health among various racial and ethnic groups.

This study leverages several strengths to provide insights into the relationship between poverty and common oral conditions. Firstly, utilizing nationally representative data from NHANES ensures generalizability of findings to the broader US adult population (Zipf et al. 2013). Additionally, the large sample size improves the robustness of parameter estimates and reliable inferences. Moreover, our study employs a novel advanced statistical methodology, the modified treatment policy approach. This approach enables us to estimate counterfactual outcomes under different poverty reduction scenarios, offering unique insights into potential consequences of various poverty reduction policy interventions (Cooray et al. 2023). The 50% reduction of poverty was explored by previous research in different contexts not focusing on broader health outcomes or oral health as a result of poverty reduction (Lippold 2015). This study went beyond and explored incremental poverty reductions related to both absolute and relative poverty.

It is essential to acknowledge certain limitations inherent to our study design. The cross-sectional nature of the NHANES data limits the ability to specify the temporality between the study variables absolutely. Hence, reverse causation cannot be completely ruled out. In fact, studies have shown the possibility of catastrophic impacts on individuals' income due to factors such as treatment expenditures and work absenteeism (Bernabé et al. 2017). However, when making inferences at the population level, reverse causation is conceptually less plausible than the temporal order of exposure (poverty) and outcome (oral diseases) hypothesized in the analysis, as socioeconomic measures tend to be established earlier in adult life (Letelier et al. 2022). This assumption related to temporality is further supported by consistent macro level empirical evidence related to poverty, lower socioeconomic status, and material disadvantage associated with higher burden of oral disease (Watt and Sheiham 1999; Foley and Akers 2019; Singh et al. 2019). Furthermore, our analyses facilitated causal inferences as we hypothetically intervened in the observed exposure and estimated the outcomes related to shifted exposure levels. The MTP approach naturally prevents a violation of the positivity assumption (Díaz et al. 2021). However, the conditional exchangeability assumption (i.e., no unmeasured confounding) could not be fully addressed in the analysis. Therefore, the robustness of our effect estimates was assessed using E values. Dental pain experiences over the past 12 months were self-reported and, therefore, susceptible to potential differential misclassification. Furthermore, the specific etiology of the dental pain was not captured. However, this analysis includes periodontitis and dental caries as independent outcomes, and they are the most common causes of dental pain. The similar direction of effects across all outcomes suggests the robustness of these estimates, regardless of the specific oral disease measure used. Even though we used a robust methodology, our claim that poverty reduction led to a decrease in pain experience is a cautious one. Hence, further research employing longitudinal data is needed to establish causality with clear temporal ordering between variables. Furthermore, it would be beneficial to investigate other outcomes such as dental caries and periodontal disease changes at population level in response to poverty reduction as poverty is likely to cause these outcomes through different psychosocial and material pathways. The findings of this study and the effect estimates of poverty reduction are specific to the US context. However, association between poverty and poor oral health outcomes can be considered a global phenomenon (Ghorbani et al. 2017; Tiwari & Franstve-Hawley 2021).

The significance of this study lies in its exploration of a critical social justice issue within a high-income nation like the US. While resources are not inherently scarce in the US, poverty persists due to political reasons (Brady 2023), leading to preventable inequalities in oral health. Our findings suggest that addressing poverty is not just a moral imperative but also a potential pathway towards gaining beneficial oral health outcomes for the US population. In fact, poverty reduction would lead to many potential health benefits beyond oral health. Hence, this research provides important insight for policymakers and advocates working to alleviate poverty and its related health issues. Essentially, our findings fit well with the broader public health agenda advocating for health in all policies.

Conclusion

This study underscores the importance of addressing absolute and relative poverty to considerably improve population oral health and achieve equitable oral health outcomes.

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Author contributions

U. Cooray, contributed to conception, design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; A. Singh, contributed to conception, design, interpretation, critically revised the manuscript; J. Aida, contributed to data interpretation, critically revised the manuscript; G. Tsakos, contributed to design, data interpretation, and critically revised the manuscript; M.A.

Peres, contributed to conception and design, critically revised the manuscript. All authors gave their final approval and agreed to be accountable for all aspects of the work.

Data availability

Software codes and data used in this study are publicly available at *https://github.com/upulcooray/dental_pain_income_index*.

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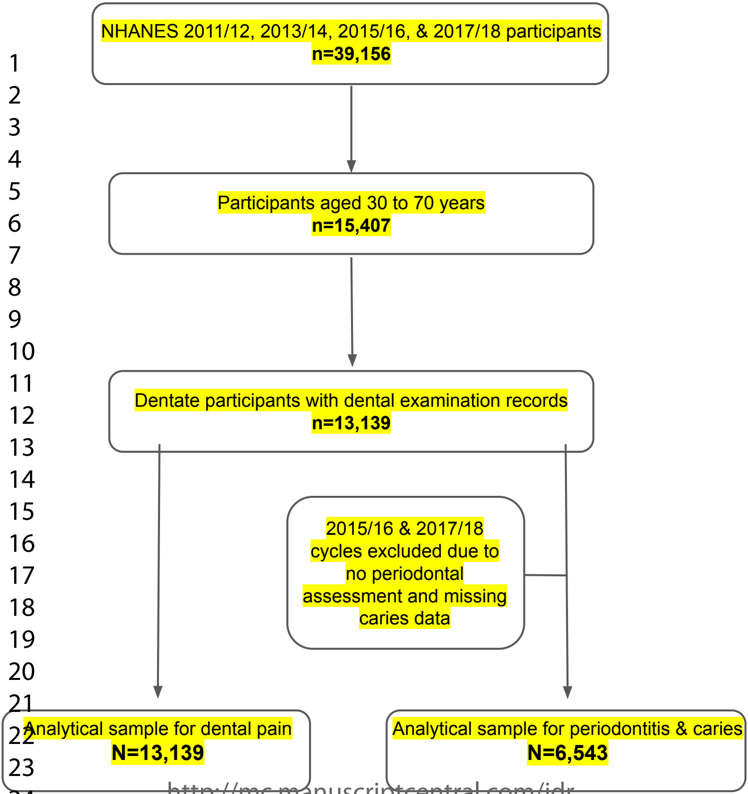
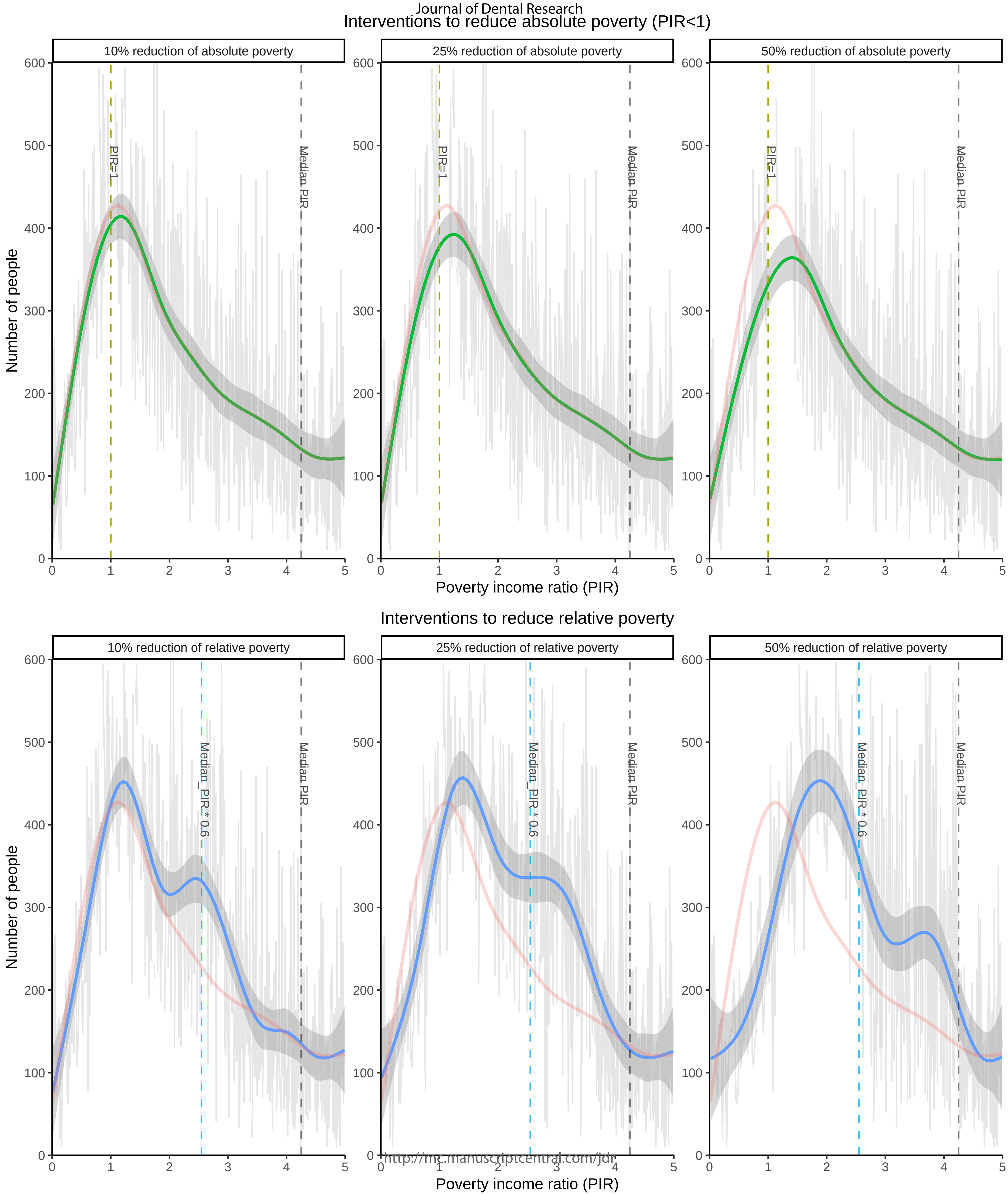
List of table and figure legends


NHANES 2011/12, 2013/14, 2015/16, & 2017/18 participants
n=39,156
Participants aged 30 to 70 years
n=15,407
Dentate participants with dental examination records
n=13,139
2015/16 & 2017/18 cycles excluded due to no periodontal assessment and missing caries data
Analytical sample for dental pain
N=13,139
Analytical sample for periodontitis & caries
N=6,543


Interventions to reduce absolute poverty (PIR<1)
10% reduction of absolute poverty
25% reduction of absolute poverty
50% reduction of absolute poverty
PIR=1
Median PIR
Number of people
Poverty income ratio (PIR)
Interventions to reduce relative poverty
10% reduction of relative poverty
25% reduction of relative poverty
50% reduction of relative poverty
Median_PIR * 0.6
Median PIR
Number of people
Poverty income ratio (PIR)

Characteristics	Periodontitis & Dental Caries (N= 6543)				Frequent Dental Pain (N=13139)			
	Absolute poverty		Relative poverty		Absolute poverty		Relative poverty	
	Above (n=5187)	Below (n=1356)	Above (n=3624)	Below (n=2919)	Above (n=10488)	Below (n=2651)	Above (n=7110)	Below (n= 6029)
Outcome Prevalences								
Periodontitis	20.2	35.8	17.3	33.0	-	-	-	-
Dental caries	13.6	35.2	9.9	30.7	-	-	-	-
Dental Pain	-	-	-	-	5.9	16.9	4.5	13.5
Mean Age- Yrs (SD)	49.1(11.2)	46.0(10.9)	49.4(11.1)	46.9(11.3)	49.3(11.4)	46.6(11.2)	49.7(11.3)	47.3(11.4)
Sex (Female)	49.1	46.4	49.8	46.3	49.2	44.1	49.6	46.1
Having a comorbidity	14.9	13.4	14.9	14.2	15.3	17.0	15.3	16.0
Current smoker	14.0	30.1	11.8	25.4	12.8	29.8	10.6	24.4
Alcohol consumption	82.0	72.2	83.6	74.4	81.1	70.9	82.7	73.6
Race								
Non-hispanic white	70.8	40.8	74.9	49.3	68.6	39.6	73.3	46.8
Non-hispanic black	9.7	21.4	8.3	17.8	9.9	20.7	8.5	17.3
Hispanic	11.7	30.9	8.9	25.8	12.5	30.9	9.6	26.4
Other/ Mixed	7.8	6.9	7.9	7.1	9.0	8.9	8.7	9.5
Marital status								
Divorced	12.4	17.0	11.2	16.9	11.6	16.3	10.1	16.8
Married	67.0	37.4	71.1	45.6	66.9	36.2	71.4	44.6
Never married	10.0	22.1	9.3	16.7	10.1	21.9	9.0	17.3
Seperated	2.1	6.5	1.5	5.3	2.2	7.0	1.6	5.6
Widowed	2.7	4.2	2.0	5.0	2.8	4.4	2.2	4.6
With partner	5.7	12.8	4.8	10.5	6.4	14.2	5.7	11.0

SD = Standard Deviation;
Periodontitis and dental caries outcomes are from NHANES cycles 2011-2012 & 2013-2014;
Dental pain outcome is from NHANES cycles 2011-2012, 2013-2014, 2015-2016, & 2017-2018;
All numbers are percentages (%) unless otherwise noted;
All reported statistics are appropriately accounted for NAHNES survey design & weights

Emulated hypothetical scenario	Oral disease outcome measure	Prevalence ratio [95% CI]	Absolute prevalence difference (per 10000)	Population level prevalence difference	E value
10% reduction in absolute poverty	Periodontitis	0.99 [0.97-1.01]	40	512413	1.12
	Dental caries	0.99 [0.97-1.03]	18	231822	1.14
	Dental pain	0.98 [0.93-1.02]	20	257580	1.18
25% reduction in absolute poverty	Periodontitis	0.97 [0.95-1.00]	50	645912	1.23
	Dental caries	0.99 [0.96-1.02]	25	321975	1.15
	Dental pain	0.96 [0.91-1.01]	34	437886	1.25
50% reduction in absolute poverty	Periodontitis	0.96 [0.93-1.00]	88	1139255	1.27
	Dental caries	0.97 [0.93-1.01]	31	399249	1.21
	Dental pain	0.94 [0.89-1.00]	46	592434	1.31
10% reduction in relative poverty	Periodontitis	0.99 [0.96-1.02]	23	290920	1.11
	Dental caries	1.01 [0.97-1.05]	NaN	NaN	1.17
	Dental pain	0.99 [0.94-1.05]	12	154548	1.10
25% reduction in relative poverty	Periodontitis	0.95 [0.93-0.98]	185	2381075	1.30
	Dental caries	0.98 [0.93-1.03]	44	566676	1.12
	Dental pain	0.93 [0.85-1.00]	71	914409	1.37
50% reduction in relative poverty	Periodontitis	0.88 [0.85-0.92]	421	5428276	1.52
	Dental caries	0.87 [0.81-0.92]	297	3822145	1.58
	Dental pain	0.82 [0.73-0.91]	162	2086398	1.74

95% CI= 95% Confidence Interval; NaN= not estimated due to >1 point estimate value; All the estimates are adjusted for age, sex, race, comorbidity, and marital status; Population level estimates were based on 135 million for the selected age range of 30-70 yrs in 2015 (statista.gov); Population estimates were adjusted for 4.6% edentate rate observed in the data

Appendix

Impact of poverty reduction on oral health outcomes among US adults

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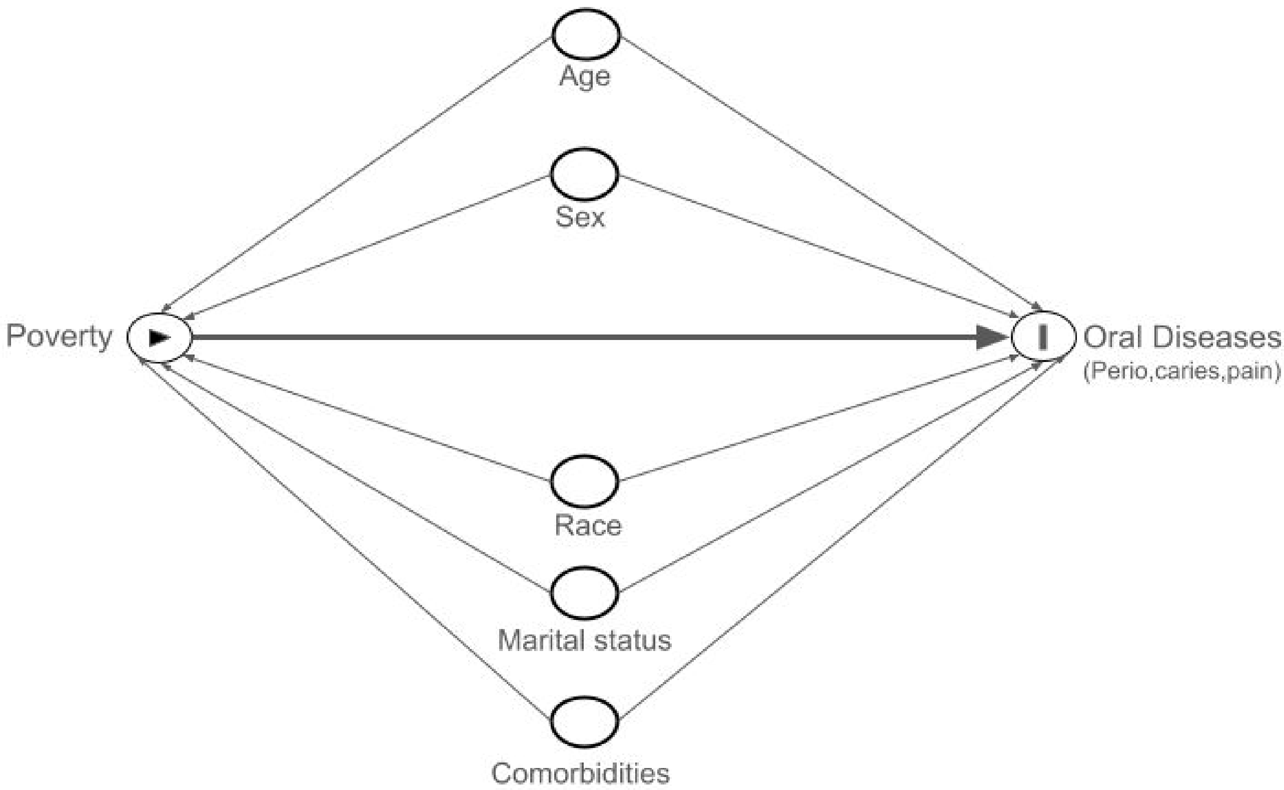
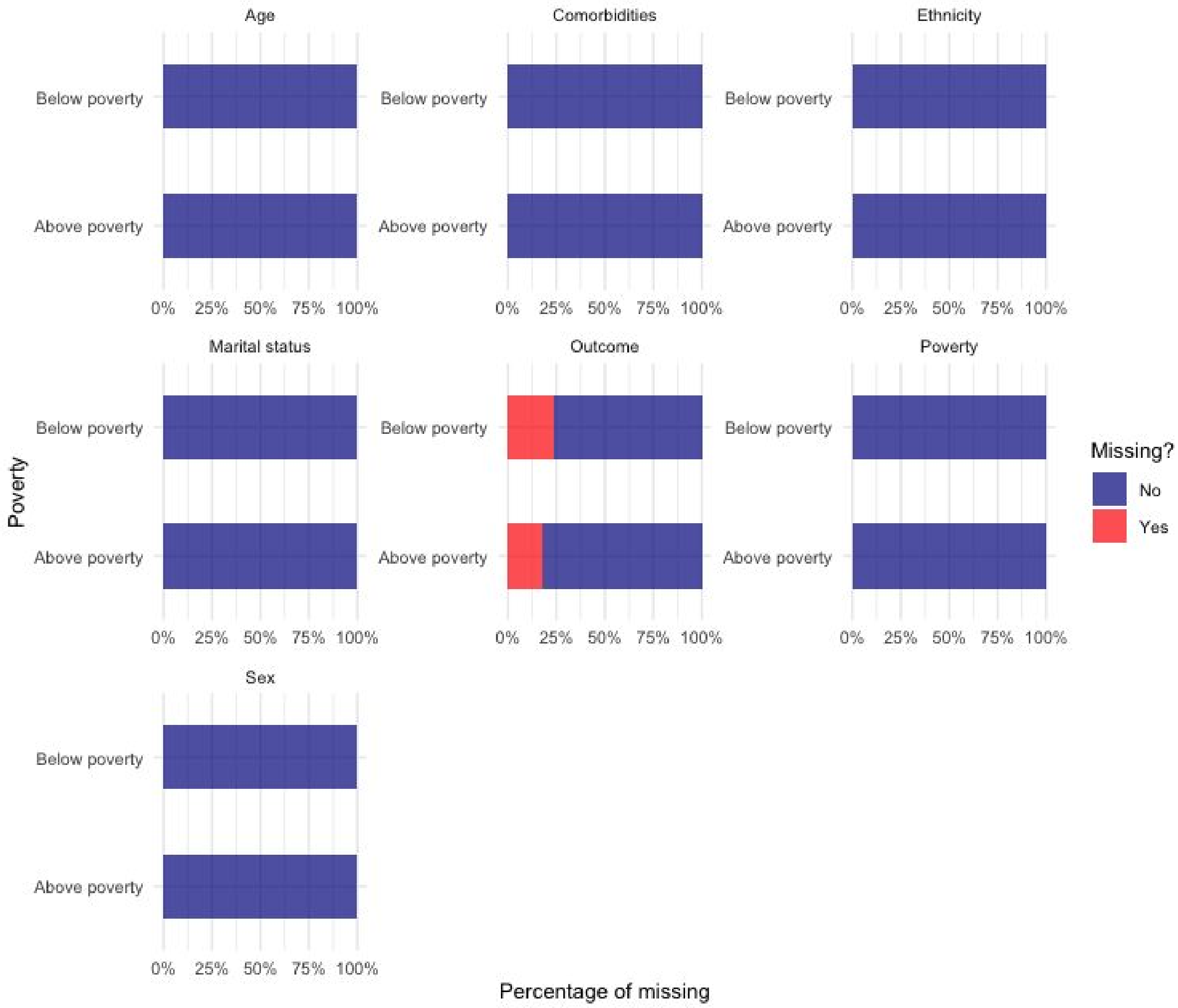
Supplementary Figure 1: Directed Acyclic Graph (DAG) showing the hypothesized associations between study variables

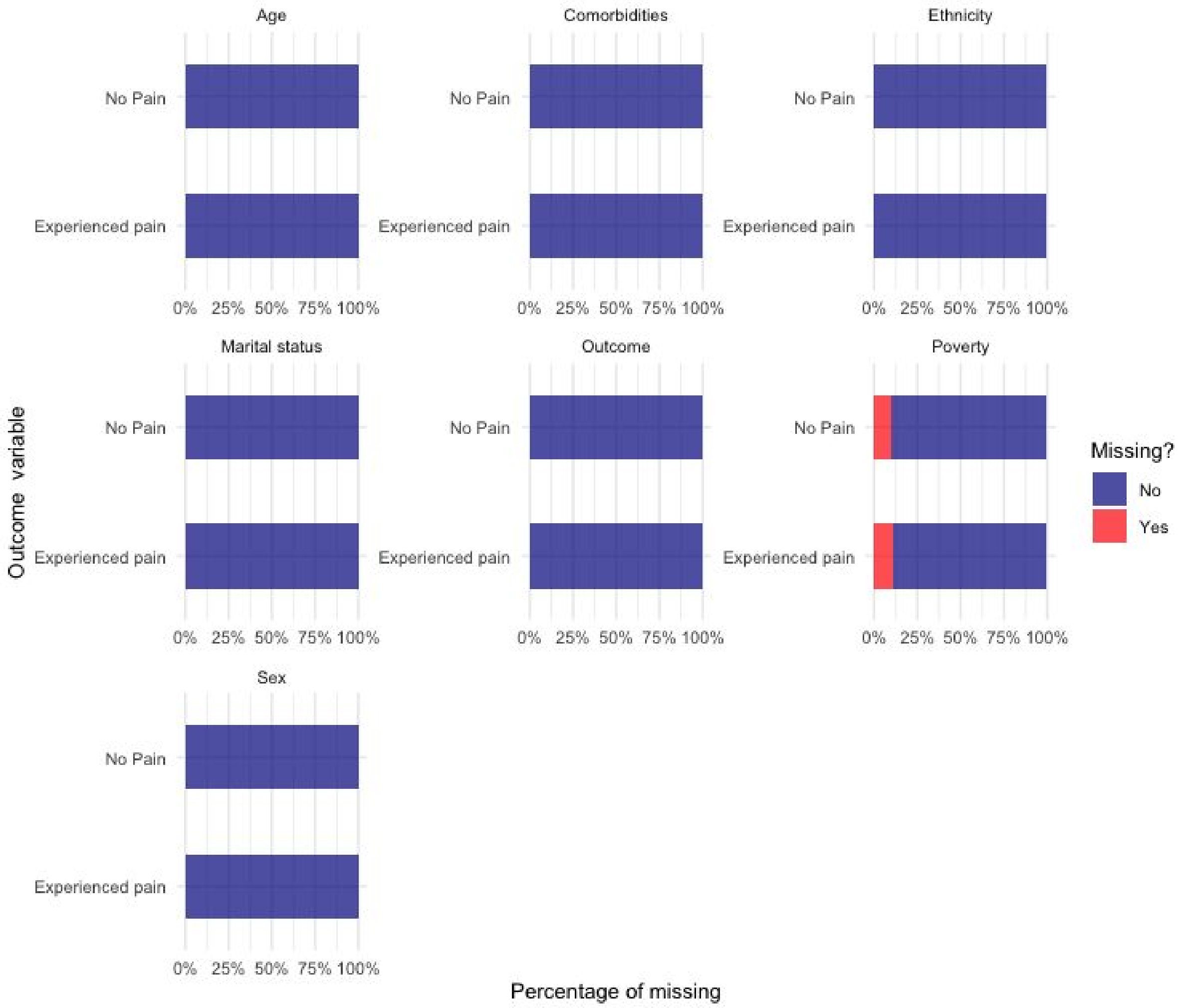


Supplementary Figure 2: Distribution of exposure missingness among study variables



Supplementary Figure 3: Distribution of outcome missingness among study variables

3


Age
Comorbidities
Ethnicity
Marital status
Outcome
Poverty
Sex
No Pain
Experienced pain
0% 25% 50% 75% 100%
Outcome variable
Percentage of missing
Missing?
No
Yes

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Response
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	YES (In abstract)
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	YES
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	YES (Introduction: paragraphs 1-2)
Objectives	3	State specific objectives, including any prespecified hypotheses	YES (Introduction: paragraph 3)
Methods			
Study design	4	Present key elements of study design early in the paper	YES (Page 6)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	YES (Page 6)
Participants	6	*Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	Ref: Selection of participants (Figure 1)
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	NOT APPLICABLE
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	YES (Pages 6-8)
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	YES (Pages 6-8)
Bias	9	Describe any efforts to address potential sources of bias	YES (Page10)
Study size	10	Explain how the study size was arrived at	YES (Figure 1)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	YES (Pages 6-8)
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	YES (Pages 8-10)
		(*b*) Describe any methods used to examine subgroups and interactions	NOT APPLICABLE
		(*c*) Explain how missing data were addressed	YES (Page 10)
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	YES (Page 9)
		(<u>*e*</u>) Describe any sensitivity analyses	YES (Page 10)

Continued on next page

Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	YES (Figure 1)
		(b) Give reasons for non-participation at each stage	NOT APPLICABLE
		(c) Consider use of a flow diagram	YES (Figure 1)
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	YES (Table 1)
		(b) Indicate number of participants with missing data for each variable of interest	YES (Supplementary Figure 2 & 3)
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	NOT APPLICABLE
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	YES (Table 1)
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	YES (Table 1)
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	YES (Table 2)
		(*b*) Report category boundaries when continuous variables were categorized	NOT APPLICABLE
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NOT APPLICABLE
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	YES (Table 2, supplementary table 1)
Discussion			
Key results	18	Summarise key results with reference to study objectives	YES (Discussion paragraph 1)
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	YES (Page 15-16)
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	YES (Page 15)
Generalisability	21	Discuss the generalisability (external validity) of the study results	YES (Page 15-16)
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	NOT APPLICABLE

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.