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Multilevel model to estimate county-level untreated dental caries among US children aged 6–9 years using the National Health and Nutrition Examination Survey

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ABSTRACT

Because conducting population-based oral health screening is resource intensive, oral health data at small-area levels (e.g., county-level) are not commonly available. We applied the multilevel logistic regression and post-stratification method to estimate county-level prevalence of untreated dental caries among children aged 6–9 years in the United States using data from the National Health and Nutrition Examination Survey (NHANES) 2005–2010 linked with various area-level data at census tract, county and state levels. We validated model-based national estimates against direct estimates from NHANES. We also compared model-based estimates with direct estimates from select State Oral Health Surveys (SOHS) at state and county levels. The model with individual-level covariates only and the model with individual-, census tract- and county-level covariates explained 7.2% and 96.3% respectively of overall county-level variation in untreated caries. Model-based county-level prevalence estimates ranged from 4.9% to 65.2% with median of 22.1%. The model-based national estimate (19.9%) matched the NHANES direct estimate (19.8%). We found significantly positive correlations between model-based estimates for 8-year-olds and direct estimates from the third-grade State Oral Health Surveys (SOHS) at state level for 34 states (Pearson coefficient: 0.54, $P = 0.001$) and SOHS estimates at county level for 53 New York counties (Pearson coefficient: 0.38, $P = 0.006$). This methodology could be a useful tool to characterize county-level disparities in untreated dental caries among children aged 6–9 years and complement oral health surveillance to inform public health programs especially when local-level data are not available although the lack of external validation due to data unavailability should be acknowledged.

1. Introduction

Dental caries, if untreated, can lead to pain, infection, and problems in eating, speaking and learning (Griffin et al., 2014; US Department of Health and Human Services, 2000). Although the prevalence of untreated dental caries among US children has declined in the past decade, data from 2011–2012 indicate that 21.5% of children aged 6–9 years have untreated caries in primary or permanent teeth (US Department of Health and Human Services, 2010). Reducing the prevalence of untreated dental caries in the primary and permanent teeth among these children is a Healthy People (HP) 2020 objective (US Department of Health and Human Services, 2010).

As there is strong evidence for the effectiveness of dental sealants (Ahovuo-Saloranta et al., 2013) and topical fluoride in preventing caries (Marinho et al., 2013), increasing access to these interventions could reduce untreated caries. To effectively target these interventions, caries-prevention programs require information on children's caries risk and access to dental care at the local level (e.g., county or school). Local data on children's oral health are rarely available because conducting population-based oral health screening is resource intensive, requiring clinical examination by highly skilled and calibrated examiners and significant material and program support (Centers for Disease Control and Prevention, 2005).

Neither of the two data sources used to monitor caries – the National

Abbreviations: MRP, multilevel regression and poststratification; BRFSS, Behavioral Risk Factor Surveillance System; BSE, Basic Screening Examination; CDC, Centers for Disease Control and Prevention; CHIP, Children's Health Insurance Program; CI, confidence interval; COPD, Chronic Obstructive Pulmonary Disease; HP, Healthy People; NCHS, National Center for Health Statistics; NHANES, National Health and Nutrition Examination Survey; SAE, small area estimation; SOHS, State Oral Health Surveys; RDC, Research Data Center

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Health and Nutrition Examination Survey (NHANES) (Centers for Disease Control and Prevention) tracking national progress in reaching HP objectives (US Department of Health and Human Services, 2010) and the State Oral Health Surveys (SOHS) used to monitor state-level caries status (Centers for Disease Control and Prevention, 2015) – provides county level estimates of caries status across the United States.

Two studies have generated small-area estimates of oral health measures – one estimating county-level caries prevalence among third-grade children using the 1994 Washington SOHS (Leroux et al., 1996), and another estimating census block-level periodontitis prevalence among adults using 2009–2012 NHANES (Eke et al., 2016). These studies were limited by lack of either individual-level data (Leroux et al., 1996) or area-level covariates for their small area estimation (SAE) models (Eke et al., 2016). Recent publications highlight the importance of including individual-level and area-level factors (e.g., dental care use among low-income children and dentist shortage at state and county levels) to assess the complex multilevel influence on oral health measures (Fisher-Owens et al., 2007; Lin et al., 2012).

Recent studies applied a novel methodology known as multilevel regression and poststratification (MRP) to national health survey data to generate SAE of select health indicators (e.g., obesity, smoking) at state, county and census block levels (Zhang et al., 2015; Zhang et al., 2013). MRP has the advantage of allowing use of information from both individual-level data within the survey sample and from various area-level covariates external to the original sample. Therefore, MRP estimates reflect the multilevel influence of various factors on the health outcomes. The poststratification to Census population allows flexibility of SAE generated nationwide at different geographic levels and better accounts for demographic distribution at local levels (Gelman and Little, 1997; Zhang et al., 2014).

The aim of this study to apply the MRP approach to NHANES 2005–2010 linked with various area-level factors to estimate county-level prevalence of untreated dental caries among US children aged 6–9 years, nationwide.

2. Materials and methods

Our MRP approach followed three steps: model construction, model prediction and poststratification, and evaluation of model-based estimates.

Step 1: We used individual-level data from NHANES 2005–2010 linked with census tract-, county- and state-level data to construct and fit multilevel logistic regression models to estimate associations between untreated dental caries and factors at different levels.
Step 2: We applied the estimated model parameters to the Census population at census tract level by age, sex and race/ethnicity as well as their poverty and health insurance status via bootstrapping to estimate individual-level probability of untreated caries. This was then weighted using the population counts at census tract, county, state, or national level to estimate prevalence of untreated dental caries at the corresponding level.
Step 3: We performed internal validation at the national level between direct estimates from NHANES and model-based estimates for 6–9 year olds. We also conducted external comparisons between state- and county-level SAE for 8 year old children and direct estimates from select third-grade SOHS.

2.1. Primary data source

We used geocoded NHANES data 2005–2010 at the Research Data Center (RDC) of the National Center for Health Statistics (NCHS), which allows area-level data to be linked to individual-level NHANES data by census tract, county and state. Details about NHANES are described in Appendix A.

2.2. Study population

We included 2304 children aged 6–9 years with data for untreated caries lesions. The mean age was 7.5 years. The study population was almost equally distributed by sex and single year of age.

2.3. Outcome variable

Untreated dental caries was defined as a dichotomous variable, presence of at least one primary or permanent tooth with cavitated caries lesions (yes/no). NHANES 2005–2010 used the Basic Screening Examination (BSE), a simplified caries examination conducted by health technologists in 2005–2008 and dental hygienists in 2009–2010 (Centers for Disease Control and Prevention, 2005).

2.4. Individual-level covariates

We considered select socio-demographic variables (sex, age, race/ethnicity, poverty status, health insurance status, and survey cycles) from NHANES based on self-report by parents or guardians. Details of these covariates are described in Appendix B.

2.5. Census tract-, county- and state-level variables

We selected characteristics at various area levels based on the factors reported to have potential influence on children's oral health and data availability (Fisher-Owens et al., 2007; Lin et al., 2012). Tract-level percentage of population in poverty was obtained from the 2006–2010 5-year American Community Survey (ACS) (US Census Bureau).

We obtained the following data at both the county and state levels from the Area Health Resources Files (Health Resources and Services Administration): percentage of population in poverty, 2006, 2007–2008, 2009–2010; percentage of population aged 25 + years with high school graduate or higher education, 2005–2010; percentage of children without health insurance, 2008, 2009–2010; percentages of children in individual race/ethnicity groups (Non-Hispanic white, Non-Hispanic black, Hispanic), 2005–2006, 2007–2008, 2009–2010; and dentist population ratio per 10,000 population, 2007, 2009–2010.

We also considered two state-level factors: percentage of children enrolled in Medicaid/Children's Health Insurance Program (CHIP) receiving dental services in the past year (2005–2006, 2007–2008, 2009) from the Centers for Medicare & Medicaid Services' CMS-416 reports (Centers for Medicare & Medicaid Services); percentage of population served by Community Water System receiving fluoridated water (2006, 2008, 2010) from biennial reports of the Centers for Disease Control and Prevention (CDC)'s Water Fluoridation Reporting System (Centers for Disease Control and Prevention, 2015). We categorized these area-level variables by quartiles. We used the 2006 NCHS 6-level urban-rural classification scheme for counties: large central metro, large fringe metro, medium metro, small metro, micropolitan, and non-core (Ingram and Franco, 2012).

2.6. Statistical analyses

First, we used NHANES 2005–2010 data linked with tract-, county- and state-level data to construct and fit multilevel logistic regression models to quantify associations between untreated caries and individual and area-level covariates. Details about the model building are described in Appendix C. The final model included sex, age, race/ethnicity, and insurance status at the individual level; poverty rate at the tract level; poverty rate, percentage of 25 + year olds with education level ≥ high school graduate, percentage of Hispanic children, dentist population ratio, and urban-rural classification at the county level; and percentage of Medicaid/CHIP enrolled children receiving dental services at the state level. We included county-level random effects to