Student Column

WORK-RELATED ASTHMA AMONG ADULTS WITH CURRENT ASTHMA IN 33 STATES AND DC: EVIDENCE FROM THE ASTHMA CALL-BACK SURVEY, 2006–2007

Gretchen E. Knoeller, MPH
Jacek M. Mazurek, MD, MS, PhD
Jeanne E. Moorman, MS

Asthma is associated with a variety of physical, chemical, and biological stimuli[1–4] including those found in the workplace.[5] The term "work-related asthma" (WRA), representing a subset of all asthma, encompasses both occupational asthma (OA), which is asthma that is caused by workplace exposure to a sensitizing or irritant substance, and work-exacerbated asthma (WEA), which is asthma that is worsened by work-related factors.[6]

WRA is a preventable[7–9] and underdiagnosed[10] occupational lung disease associated with adverse social and economic outcomes, disability, and mortality.[11–16] Workers who leave their jobs due to WRA often experience loss in income and/or unemployment.[11,17] A French study followed workers with WRA for an average of 3.1 years after diagnosis. At follow-up, 44% had left their jobs, 25% were unemployed, and 46% had experienced loss in income.[18] Among adults with asthma, those with WRA have a lower quality of life[11,15,19,20] and more frequent emergency department and doctors' visits for worsening asthma.[21] WRA caused by a number of workplace agents may also lead to death.[22]

An estimated 6.7% of adults aged ≥18 years in the United States have current asthma.[2] The American Thoracic Society has cited estimates that 4%–58% (median = 15%) of adults with asthma have WRA.[23] Estimates of the proportion of adults with OA range from 10% to 15%,[6,23] and estimates of WEA range from 14% to 58% (median = 21%).[24] However, few such estimates have been published at the state level.[21,25–27] The Adult Asthma Call-Back Survey (ACBS), part of the Behavioral Risk Factor Surveillance System (BRFSS), offers a unique opportunity to provide this information for a large number of states. To determine the proportion of asthma that is work-related, we analyzed data from the 2006 and 2007 ACBS for each participating state.

METHODS

The BRFSS is a state-based, random-digit-dial telephone survey of U.S. noninstitutionalized adults aged ≥18 years that is conducted annually.[28] The ACBS collects information on asthma, including asthma work-relatedness, from BRFSS participants who have reported health professional-diagnosed asthma.[29] In 2006, 24 states and the District of Columbia (DC) conducted the ACBS; in 2007, those same states plus an additional nine states conducted the ACBS. The BRFSS has a surveillance exemption from Institutional Review Board (IRB) review at the Centers for Disease Control and Prevention (CDC). Participating states are subject to state-specific IRB requirements.

We defined current asthma by "yes" responses to two questions asked during the BRFSS survey: "Have you ever been told by a doctor, nurse, or other health professional that you had asthma?" and "Do you still have asthma?" We defined ACBS respondents as having been ever-employed if they described their current employment status as "employed full-time" or "employed part-time" or answered "yes" to the question, "Have you ever been employed outside the home?" Ever-employed respondents were asked questions about asthma work-relatedness. Health professional-diagnosed WRA was determined on the basis of a "yes" response to the question, "Were you ever told by a doctor or other health professional that your asthma was related to any job you ever had?" Possible WRA was determined using positive responses to any of the following four questions: (1) "Was your asthma caused by chemicals, smoke, fumes, or dust in your current job?" (2) "Was your asthma caused by chemicals, smoke, fumes, or dust in any previous job you ever had?" (3) "Is your asthma

made worse by chemicals, smoke, fumes, or dust in your current job?" and (*4*) "Was your asthma made worse by chemicals, smoke, fumes, or dust in any previous job you ever had?" Possible OA was determined using a positive response to at least one of the first two questions used for possible WRA, and possible WEA was determined using a positive response to at least one of the last two questions used for possible WRA.

We used SAS® software version 9.2[30] and SUDAAN® version 10.0.1[31] for analyses. We combined data for DC and the 24 states participating in the ACBS during both 2006 and 2007 to increase precision of estimates; for the nine states with only 2007 ACBS data, we based estimates on one year of data. We weighted the data to account for nonresponse and unequal sampling probabilities using weights generated by CDC. We used the Rao-Scott Chi-square test to assess associations between groups, and calculated prevalence ratios (PRs) adjusted for age, gender, race/ethnicity, education, income, and health insurance status. All tests were two-sided with $p<0.05$ considered significant.

RESULTS

Overall, 26,047 adults participated in the ACBS (10,802 in 2006 and 15,245 in 2007). Of these, 8,410 were excluded from analysis for the following reasons: 7,150 did not have current asthma, 619 had missing data on asthma status, 509 were never employed, and 132 had missing data on employment. The remaining sample of 17,637 respondents represented an estimated 14.5 million ever-employed adults with current asthma in the participating states and DC. Selected demographic characteristics of the study population are shown in Table 1.

Health professional-diagnosed WRA

An estimated annual 9.7% of ever-employed adults with current asthma had health professional-diagnosed WRA (Table 2). Individual state estimates ranged from 5.0% in Arizona to 13.8% in Florida (Table 3). Adjusted PRs indicated significantly higher proportions of health professional-diagnosed WRA among 45- to 64-year-olds (PR=1.9) compared with 18- to 44-year-olds, and among those with annual household incomes <$50,000 (PR range: 1.5–2.2) compared with those with incomes ≥$50,000 (Table 2).

Possible WRA

An estimated 47.5% of ever-employed adults with current asthma had possible WRA (Table 2). Individual state estimates ranged from 38.1% in Arizona to 62.6% in Oklahoma (Table 3). Adjusted PRs indicated

significantly higher proportions of possible WRA among 45- to 64-year-olds (PR=1.2) compared with 18- to 44-year-olds; among males (PR=1.1) compared with females; among non-Hispanic people of "other" race/ethnicity (PR=1.2) compared with non-Hispanic white (NHW) people; among those with a high school education or less (PR=1.1) compared with those with more than a high school education; among those with lower annual household incomes (PR range: 1.1–1.3) compared with those with annual incomes ≥$50,000; and among those without health insurance (PR=1.2) compared with those with insurance (Table 2).

Possible OA and WEA

An estimated 27.9% of ever-employed adults with current asthma had possible OA and an estimated 44.8% had possible WEA (Table 4). Individual state estimates of possible OA ranged from 15.5% in Massachusetts to 35.6% in Texas, and individual state estimates of possible WEA ranged from 32.4% in DC to 60.9% in Oklahoma (Table 3). Adjusted PRs indicated significantly higher proportions of possible OA among 45- to 64-year-olds (PR=1.2) compared with 18- to 44-year-olds; among males (PR=1.2) compared with females; among Hispanic people (PR=1.3) compared with NHW people; among non-Hispanic people of "other" race/ethnicity (PR=1.5) compared with NHW people; among those with a high school education or less (PR=1.2) compared with those with more than a high school education; and among those with lower annual household incomes (PR range: 1.4–1.6) compared with those with annual incomes ≥$50,000 (Table 4).

Adjusted PRs indicated significantly higher proportions of possible WEA among 45- to 64-year-olds (PR=1.2) compared with 18- to 44-year-olds; among non-Hispanic people of "other" race/ethnicity (PR=1.3) compared with NHW people; among those with a high school education or less (PR=1.1) compared with those with more than a high school education; among those with lower annual household incomes (PR range: 1.1–1.3) compared with those with annual incomes ≥$50,000; and among those without health insurance (PR=1.2) compared with individuals with health insurance (Table 4).

DISCUSSION

An estimated 11 million U.S. workers may be exposed to occupational agents that cause or trigger asthma,[32–34] indicating the need for research on WRA. In this study, we estimated that 9.7% of ever-employed adults with current asthma had health professional-diagnosed WRA and 47.5% had possible WRA. Our estimates are

Table 1. Selected characteristics of ever-employed adults with current asthma—Adult Asthma Call-Back Survey, 33 states[a] and the District of Columbia: BRFSS 2006 and 2007

Characteristics	Sample N[b]	Estimated N[c] (in thousands)	Population estimates Percent[d] (95% CI)
Age group (in years)			
18–44	4,851	7,326	50.6 (48.7, 52.4)
45–64	8,393	5,126	35.4 (33.8, 37.0)
≥65	4,329	2,027	14.0 (13.1, 14.9)
Gender			
Male	4,623	5,473	37.8 (35.8, 39.8)
Female	13,014	9,006	62.2 (60.2, 64.2)
Race/ethnicity			
Non-Hispanic white	14,706	11,120	76.8 (74.9, 78.6)
Non-Hispanic black	839	999	6.9 (6.0, 7.9)
Hispanic	700	1,318	9.1 (7.7, 10.5)
Non-Hispanic other[e]	1,268	1,042	7.2 (6.0, 8.4)
Education level			
≤High school graduate	6,207	4,937	34.1 (32.3, 35.8)
>High school graduate	11,418	9,542	65.9 (64.2, 67.7)
Household income			
<$15,000	2,590	1,969	13.6 (12.3, 15.0)
$15,000–$24,999	2,965	2,244	15.5 (14.0, 17.0)
$25,000–$34,999	1,943	1,491	10.3 (9.1, 11.4)
$35,000–$49,999	2,478	2,085	14.4 (13.1, 15.8)
≥$50,000	5,989	6,689	46.2 (44.3, 48.1)
Health insurance			
No	1,601	2,027	14.0 (12.4, 15.7)
Yes	15,964	12,452	86.0 (84.3, 87.6)

[a]Includes Alaska, Arizona, California, Colorado, Connecticut, Florida, Georgia, Hawaii, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Mexico, New York, Ohio, Oklahoma, Oregon, Pennsylvania, Texas, Utah, Vermont, Washington, West Virginia, and Wisconsin

[b]Unweighted sample size (sample sizes vary due to missing information)

[c]Weighted sample size

[d]Average annual estimate

[e]Includes Asian, Native Hawaiian or other Pacific Islander, American Indian or Alaska Native, those who classified themselves as "other," and those who identified as belonging to multiple racial/ethnic minority groups

BRFSS = Behavioral Risk Factor Surveillance System

CI = confidence interval

consistent with previously reported estimates from six states.[21,25–27] The results reported in this article, however, are representative of adults in 33 states and DC.

During 2001 and 2002, as part of the BRFSS, select states administered the question, "Were you ever told by a doctor or other medical person that your asthma was related to any job you ever had?" Using this 2001 and 2002 BRFSS data, Breton and colleagues estimated that 6.2% of Massachusetts adults with current asthma have WRA.[21] Using 2001 BRFSS data from three states, Flattery et al. produced corresponding estimates of 5.8% for California, 6.1% for Massachusetts, and 5.8% for Michigan.[25] Starting in 2005, a modified WRA question was administered as part of the ACBS: "Were you

ever told by a doctor or other health professional that your asthma was related to any job you ever had?" Using 2005 ACBS data, Lutzker et al. reported the proportions of current asthma that is work-related in Michigan (7.6%), Minnesota (5.6%), and Oregon (9.0%). They also reported the proportions of possible WRA among people with current asthma in Michigan (52.9%), Minnesota (53.3%), and Oregon (52.8%) using the same definition we used in our study.[26] Using 2006 and 2007 ACBS data, Tice and colleagues estimated the proportion of WRA among New York adults with current asthma to be 11.6%.[27]

Consistent with previous studies,[21,25–27] in our study, the proportions of health professional-diagnosed WRA

and possible WRA did not vary largely by state. We only found significant differences in the proportions of health professional-diagnosed and possible WRA by state in states with the highest and lowest proportions of health professional-diagnosed and possible WRA. Such differences may be explained by state variations in industry and occupation, health-care access, health insurance, and prevention programs. Further research is needed to explain the differences in the proportions of health professional-diagnosed and possible WRA by state.

Although estimates from these four studies are

Table 2. Multivariate associations with health professional-diagnosed WRA and possible WRA among ever-employed adults with current asthma—Adult Asthma Call-Back Survey, 33 states[a] and the District of Columbia: BRFSS 2006 and 2007

	Health professional-diagnosed WRA[b]		Possible WRA[b]	
	Percent[c] (95% CI)	Adjusted[d] PR (95% CI)	Percent[c] (95% CI)	Adjusted[d] PR (95% CI)
All	9.7 (8.6, 10.8)		47.5 (45.7, 49.4)	
Age group (in years)				
18–44	7.3 (5.9, 8.9)	Ref.	44.4 (41.2, 47.7)	Ref.
45–64	14.2 (12.2, 16.2)	1.9 (1.5, 2.4)	54.3 (51.9, 56.7)	1.2 (1.1, 1.3)
≥65	7.5 (5.9, 9.1)	0.9 (0.7, 1.3)	41.9 (38.9, 45.0)	0.9 (0.8, 1.0)
Gender				
Male	9.9 (8.0, 11.8)	1.1 (0.9, 1.4)	48.9 (45.2, 52.7)	1.1 (1.0, 1.2)
Female	9.6 (8.3, 10.9)	Ref.	46.7 (44.7, 48.7)	Ref.
Race/ethnicity				
Non-Hispanic white	8.8 (7.8, 9.9)	Ref.	45.5 (43.5, 47.5)	Ref.
Non-Hispanic black	12.2 (8.2, 16.2)	1.1 (0.8, 1.7)	49.4 (42.4, 56.4)	1.0 (0.8, 1.1)
Hispanic	13.8 (8.0, 19.5)	1.4 (0.9, 2.2)	53.4 (45.3, 61.6)	1.1 (0.9, 1.3)
Non-Hispanic other[e]	12.4 (6.4, 18.4)	1.1 (0.6, 1.8)	59.1 (50.9, 67.2)	1.2 (1.1, 1.4)
Education level				
≤High school graduate	11.8 (9.9, 13.7)	1.2 (0.9, 1.5)	53.1 (49.9, 56.3)	1.1 (1.0, 1.2)
>High school graduate	8.7 (7.4, 10.0)	Ref.	44.6 (42.3, 47.0)	Ref.
Household income				
<$15,000	16.4 (12.3, 20.5)	2.2 (1.6, 3.1)	59.5 (54.0, 65.0)	1.3 (1.2, 1.5)
$15,000–$24,999	12.2 (9.2, 15.1)	1.7 (1.2, 2.4)	54.8 (49.5, 60.1)	1.2 (1.1, 1.4)
$25,000–$34,999	13.3 (8.3, 18.4)	1.9 (1.2, 2.9)	49.0 (43.0, 54.9)	1.1 (1.0, 1.3)
$35,000–$49,999	10.3 (7.8, 12.8)	1.5 (1.1, 2.1)	51.7 (46.7, 56.7)	1.2 (1.1, 1.4)
≥$50,000	6.7 (5.4, 8.1)	Ref.	41.3 (38.6, 44.1)	Ref.
Health insurance				
No	13.2 (8.9, 17.5)	1.1 (0.8, 1.6)	60.6 (54.0, 67.2)	1.2 (1.0, 1.4)
Yes	9.2 (8.1, 10.2)	Ref.	45.5 (43.6, 47.4)	Ref.

[a]Includes Alaska, Arizona, California, Colorado, Connecticut, Florida, Georgia, Hawaii, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Mexico, New York, Ohio, Oklahoma, Oregon, Pennsylvania, Texas, Utah, Vermont, Washington, West Virginia, and Wisconsin

[b]Health professional-diagnosed WRA was determined on the basis of a "yes" response to the question, "Were you ever told by a doctor or other health professional that your asthma was related to any job you ever had?" Possible WRA was determined using positive responses to any of the following four questions: (1) "Was your asthma caused by chemicals, smoke, fumes, or dust in your current job?" (2) "Was your asthma caused by chemicals, smoke, fumes, or dust in any previous job you ever had?" (3) "Is your asthma made worse by chemicals, smoke, fumes, or dust in your current job?" and (4) "Was your asthma made worse by chemicals, smoke, fumes, or dust in any previous job you ever had?"

[c]Average annual estimate

[d]Adjusted for age group, gender, race/ethnicity, education level, household income, and health insurance status as appropriate

[e]Includes Asian, Native Hawaiian or other Pacific Islander, American Indian or Alaska Native, those who classified themselves as "other," and those who identified as belonging to multiple racial/ethnic minority groups

WRA = work-related asthma

BRFSS = Behavioral Risk Factor Surveillance System

CI = confidence interval

PR = prevalence ratio

Ref. = reference group

Table 3. Estimated proportion of ever-employed adults with current asthma who report WRA, by state—Adult Asthma Call-Back Survey, 33 states and DC: BRFSS 2006 and 2007

State/area	Health professional-diagnosed WRA[a] Percent (95% CI)	Possible WRA[a] Percent (95% CI)	Possible OA[a] Percent (95% CI)	Possible WEA[a] Percent (95% CI)
Alaska	NR[b]	58.2 (46.8, 69.5)	26.6 (17.6, 35.5)	55.9 (44.6, 67.2)
Arizona	5.0 (2.3, 7.6)	38.1 (28.3, 47.9)	17.8 (11.9, 23.7)	37.0 (27.2, 46.8)
California	11.5 (7.2, 15.9)	46.4 (40.2, 52.6)	27.7 (22.2, 33.2)	43.5 (37.3, 49.7)
Colorado	7.5 (4.7, 10.3)	44.6 (38.7, 50.4)	23.2 (18.2, 28.2)	43.3 (37.4, 49.1)
Connecticut	9.2 (5.8, 12.5)	39.3 (32.6, 46.0)	21.6 (16.7, 26.6)	36.5 (29.8, 43.2)
DC	5.4 (2.3, 8.5)	41.9 (32.1, 51.8)	23.0 (12.8, 33.2)	32.4 (24.3, 40.4)
Florida[c]	13.8 (6.2, 21.4)	45.1 (34.8, 55.4)	24.7 (16.7, 32.7)	42.1 (31.9, 52.4)
Georgia	11.6 (7.1, 16.0)	51.4 (44.8, 58.0)	31.1 (25.0, 37.2)	48.1 (41.5, 54.7)
Hawaii	7.1 (4.3, 9.9)	44.6 (38.2, 51.0)	34.0 (27.8, 40.1)	35.4 (29.5, 41.2)
Illinois[c]	7.0 (3.3, 10.7)	49.2 (40.0, 58.3)	24.9 (16.4, 33.5)	49.2 (40.0, 58.3)
Indiana	10.7 (7.6, 13.7)	51.7 (46.1, 57.4)	30.4 (25.5, 35.4)	49.2 (43.5, 54.8)
Iowa	8.5 (5.3, 11.7)	48.5 (41.8, 55.2)	28.2 (22.0, 34.4)	44.7 (37.9, 51.5)
Kansas	9.4 (6.7, 12.2)	50.3 (44.9, 55.6)	28.8 (24.1, 33.6)	44.8 (39.5, 50.1)
Maine	10.9 (7.4, 14.4)	46.7 (40.4, 52.9)	24.2 (19.4, 29.1)	44.2 (38.0, 50.4)
Maryland	8.7 (5.2, 12.1)	38.7 (33.0, 44.4)	18.6 (14.4, 22.9)	36.8 (31.2, 42.5)
Massachusetts	5.9 (2.9, 9.0)	41.6 (33.0, 50.3)	15.5 (10.7, 20.4)	40.5 (31.8, 49.1)
Michigan	10.8 (7.4, 14.1)	50.6 (45.3, 56.0)	30.5 (25.4, 35.7)	44.4 (39.1, 49.7)
Missouri	8.1 (4.3, 11.8)	55.6 (48.2, 63.0)	34.0 (26.0, 41.9)	51.6 (44.0, 59.1)
Montana	11.7 (7.1, 16.3)	50.6 (43.5, 57.7)	26.9 (20.8, 32.9)	47.0 (39.9, 54.1)
Nebraska	8.1 (5.3, 10.8)	52.1 (43.7, 60.6)	25.2 (17.5, 32.8)	49.7 (41.2, 58.2)
Nevada[c]	11.8 (6.3, 17.4)	50.1 (39.2, 61.0)	27.2 (18.5, 35.9)	47.0 (36.4, 57.7)
New Hampshire	9.1 (5.1, 13.2)	45.7 (39.6, 51.8)	22.2 (17.1, 27.4)	43.3 (37.2, 49.4)
New Mexico[c]	NR[b]	52.2 (42.2, 62.2)	25.9 (18.2, 33.6)	49.4 (39.6, 59.3)
New York	12.1 (8.0, 16.1)	46.4 (40.6, 52.2)	32.2 (26.5, 37.9)	42.8 (37.0, 48.5)
Ohio[c]	8.2 (4.8, 11.6)	51.5 (42.3, 60.8)	26.3 (19.6, 33.1)	47.7 (38.5, 57.0)
Oklahoma[c]	12.4 (6.7, 18.1)	62.6 (54.6, 70.7)	27.4 (20.2, 34.6)	60.9 (52.8, 69.1)
Oregon	7.0 (4.6, 9.4)	47.1 (40.8, 53.3)	25.8 (20.4, 31.2)	42.8 (36.8, 48.8)
Pennsylvania[c]	7.9 (3.8, 12.1)	45.4 (34.8, 56.1)	33.7 (23.7, 43.7)	44.9 (34.2, 55.5)
Texas	9.6 (5.7, 13.4)	49.6 (40.7, 58.5)	35.6 (26.6, 44.6)	47.3 (38.4, 56.1)
Utah[c]	7.0 (3.2, 10.9)	43.0 (34.2, 51.8)	29.1 (20.7, 37.4)	39.5 (30.8, 48.2)
Vermont	10.5 (7.6, 13.3)	40.7 (36.2, 45.3)	23.2 (19.2, 27.2)	37.1 (32.7, 41.5)
Washington	6.5 (5.4, 7.6)	44.8 (41.9, 47.8)	26.9 (24.2, 29.6)	42.3 (39.4, 44.3)
West Virginia[c]	11.9 (7.0, 16.8)	46.6 (37.7, 55.4)	27.0 (19.8, 34.2)	44.8 (36.0, 53.5)
Wisconsin	9.0 (5.3, 12.8)	50.6 (43.3, 57.9)	23.2 (16.8, 29.6)	48.6 (41.3, 56.0)
All 33 states and DC	9.7 (8.6, 10.8)	47.5 (45.7, 49.4)	27.9 (26.2, 29.6)	44.8 (42.9, 46.7)

[a]Health professional-diagnosed WRA was determined on the basis of a "yes" response to the question, "Were you ever told by a doctor or other health professional that your asthma was related to any job you ever had?" Possible WRA was determined using positive responses to any of the following four questions: (1) "Was your asthma caused by chemicals, smoke, fumes, or dust in your current job?" (2) "Was your asthma caused by chemicals, smoke, fumes, or dust in any previous job you ever had?" (3) "Is your asthma made worse by chemicals, smoke, fumes, or dust in your current job?" and (4) "Was your asthma made worse by chemicals, smoke, fumes, or dust in any previous job you ever had?" Possible OA was determined using a positive response to at least one of the first two questions used for possible WRA, and possible WEA was determined using a positive response to at least one of the last two questions used for possible WRA.

[b]Estimate suppressed because the relative standard error was >30%

[c]States for which only one year (2007) of data were analyzed; for all other listed states and DC, two years of data (2006 and 2007) were analyzed.

WRA = work-related asthma

DC = District of Columbia

BRFSS = Behavioral Risk Factor Surveillance System

OA = occupational asthma

WEA = work-exacerbated asthma

CI = confidence interval

NR = not reportable

similar to the corresponding state-specific estimates from this study, there are some methodological differences. The wording of the question on health professional-diagnosed WRA differed slightly: "medical person" was used in the earlier BRFSS surveys and "health professional" was used in the more recent ACBS. However, the effect of this minor difference in wording is not likely substantial. All four of those previous studies included adults with asthma regardless of employment status, but our results were based on analyses restricted to the population at risk, which was ever-employed adults; therefore, our estimates

Table 4. Multivariate associations with possible OA and WEA among ever-employed adults with current asthma—Adult Asthma Call-Back Survey, 33 states[a] and the District of Columbia: BRFSS 2006 and 2007

	Possible OA[b]		Possible WEA[b]	
	Percent[c] (95% CI)	Adjusted[d] PR (95% CI)	Percent[c] (95% CI)	Adjusted[d] PR (95% CI)
All	27.9 (26.2, 29.6)		44.8 (42.9, 46.7)	
Age group (in years)				
18–44	25.7 (22.9, 28.7)	Ref.	41.8 (38.6, 45.0)	Ref.
45–64	31.7 (29.6, 34.0)	1.2 (1.1, 1.4)	51.5 (49.1, 53.9)	1.2 (1.1, 1.3)
≥65	26.1 (23.5, 29.0)	1.0 (0.9, 1.2)	38.9 (35.9, 41.9)	0.9 (0.8, 1.0)
Gender				
Male	30.5 (27.0, 34.0)	1.2 (1.1, 1.4)	45.9 (42.1, 49.6)	1.1 (1.0, 1.2)
Female	26.3 (24.5, 28.0)	Ref.	44.1 (42.1, 46.1)	Ref.
Race/ethnicity				
Non-Hispanic white	25.2 (23.6, 26.8)	Ref.	43.1 (41.1, 45.0)	Ref.
Non-Hispanic black	32.5 (26.5, 38.6)	1.1 (0.9, 1.4)	45.6 (38.8, 52.4)	0.9 (0.8, 1.1)
Hispanic	37.3 (29.3, 45.3)	1.3 (1.0, 1.7)	48.4 (40.2, 56.6)	1.0 (0.8, 1.2)
Non-Hispanic other[e]	39.7 (29.3, 49.3)	1.5 (1.2, 1.9)	56.8 (48.5, 65.2)	1.3 (1.1, 1.5)
Education level				
≤High school graduate	33.0 (30.0, 36.0)	1.2 (1.0, 1.3)	49.0 (45.8, 52.3)	1.1 (1.0, 1.2)
>High school graduate	25.2 (23.1, 27.2)	Ref.	42.5 (40.2, 44.8)	Ref.
Household income				
<$15,000	38.2 (33.1, 43.3)	1.6 (1.3, 1.9)	55.8 (50.3, 61.3)	1.3 (1.2, 1.5)
$15,000–$24,999	32.7 (27.3, 38.1)	1.4 (1.1, 1.7)	51.3 (45.9, 56.7)	1.2 (1.1, 1.4)
$25,000–$34,999	33.3 (27.4, 39.3)	1.5 (1.2, 1.8)	45.8 (39.9, 51.8)	1.1 (1.0, 1.3)
$35,000–$49,999	33.0 (28.1, 37.9)	1.5 (1.3, 1.8)	48.9 (43.9, 53.9)	1.2 (1.1, 1.4)
≥$50,000	20.8 (18.6, 23.0)	Ref.	39.3 (36.5, 42.0)	Ref.
Health insurance				
No	39.3 (32.5, 46.0)	1.2 (1.0, 1.5)	56.4 (49.7, 63.1)	1.2 (1.0, 1.3)
Yes	26.1 (24.4, 27.7)	Ref.	43.0 (41.1, 44.8)	Ref.

[a]Includes Alaska, Arizona, California, Colorado, Connecticut, Florida, Georgia, Hawaii, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Mexico, New York, Ohio, Oklahoma, Oregon, Pennsylvania, Texas, Utah, Vermont, Washington, West Virginia, and Wisconsin

[b]Possible OA was determined using a positive response to at least one of the following two questions: "Was your asthma caused by chemicals, smoke, fumes, or dust in your current job?" and "Was your asthma caused by chemicals, smoke, fumes, or dust in any previous job you ever had?" Possible WEA was determined using a positive response to at least one of the following two questions: "Is your asthma made worse by chemicals, smoke, fumes, or dust in your current job?" and "Was your asthma made worse by chemicals, smoke, fumes, or dust in any previous job you ever had?"

[c]Average annual estimate

[d]Adjusted for age group, gender, race/ethnicity, education level, household income, and health insurance status as appropriate

[e]Includes Asian, Native Hawaiian or other Pacific Islander, American Indian or Alaska Native, those who classified themselves as "other," and those who identified as belonging to multiple racial/ethnic minority groups

OA = occupational asthma

WEA = work-exacerbated asthma

BRFSS = Behavioral Risk Factor Surveillance System

CI = confidence interval

PR = prevalence ratio

Ref. = reference group

were more restrictive. In the studies by Breton et al. and Flattery et al., the WRA question was administered as part of the BRFSS survey, without necessitating a request for additional permission from the respondent for a call-back to obtain asthma information, as is the case in the ACBS.[21,25]

WRA is generally unrecognized and underdiagnosed by health-care providers.[26,35–37] Medical record studies have found documentation of consideration of workplace exposures in relation to asthma in only 7%–15% of incident adult asthma cases.[35,36] Physicians may underrecognize WRA because of difficulties in documenting typical temporal associations between workplace exposure and asthma symptoms. Individuals may increase medication use, experience worsening symptoms at or after work, or experience improvement in asthma symptoms after they spend time away from work.[38] Curwick and colleagues found that the majority of patients with WRA did not receive appropriate objective evaluation of pulmonary function.[39] WRA may also be misclassified as asthma not related to work, particularly if patients infrequently visit their physician for asthma management.[21]

Underdiagnosis may be due to a number of factors including the healthy worker effect, whereby workers self-select themselves out of industries or occupations where exposures worsen asthma symptoms before they see a health professional.[6,40] Consequently, their asthma may not be diagnosed as WRA. This practice may partially explain why such a high proportion of individuals in our analyses believed that their asthma was work-related, while a much lower proportion of workers were told so by a health professional.

It is unclear why, in our analysis, individuals aged 45–64 years had higher proportions of health professional-diagnosed WRA and possible WRA. Such age differences may be due to multiple factors such as WRA diagnosis, communication by physicians, recall bias, and true incidence. Flattery and colleagues found that the proportion of WRA was higher among men than women in all three states, but these differences were not statistically significant.[25] Similarly, we found no evidence for gender differences in the proportion of health professional-diagnosed WRA, but we did find that men were significantly more likely than women to have possible WRA and OA. This gender difference may be associated with differences in workplace exposures.[41] The diagnosis of WRA is related to both occupational-health practices of health professionals and health-care-seeking behavior among people with asthma. The latter may be different in men and women.[25] Schatz and Camargo reported that women are significantly more likely than men to have outpatient visits for their asthma.[42] This difference in outpatient visits, along with the higher proportion of WRA among men, may explain the lack of a statistically significant association between gender and health professional-diagnosed WRA in our study.

Based on our analyses, adults with asthma who had lower incomes were significantly more likely to report all measures of WRA, OA, and WEA. In addition, we found that adults with asthma who did not have health insurance were significantly more likely to have possible WRA than those with health insurance. This finding was contrary to our a priori expectations that, because they may have better access to health professionals, adults with asthma who have health insurance would be more likely to be diagnosed as having WRA than individuals without health insurance. These findings lead us to hypothesize that individuals with possible WRA are more likely to work in jobs that do not offer health insurance. An alternate hypothesis is that individuals without health insurance may not be seeking health professional advice and, as a consequence, are not properly educated about their asthma or are not diagnosed with WRA. However, due to the nature of ACBS data, this hypothesis could not be evaluated.

Limitations

Our findings were subject to several limitations. The BRFSS and ACBS rely on self-reported measures of asthma and WRA that were not validated and, thus, estimates may have been subject to recall bias. It is possible, although unlikely, that respondents did not correctly recall being told by a health professional about asthma work-relatedness. Additional limitations in estimation methods (i.e., measurement, nonresponse, and sampling errors) are described in the "BRFSS Operational and User's Guide."[43]

The Council of American Survey and Research Organizations' median response rates among the 24 participating states and DC in 2006 were 48.6% (range: 36.9%–66.0%) for the BRFSS and 52.1% (range: 37.0%–70.8%) for the ACBS. Among the 33 participating states and DC in 2007, the median response rates were 47.6% (range: 31.4%–65.4%) for the BRFSS and 54.3% (range: 36.5%–72.2%) for the ACBS. The ACBS has the potential to introduce participation bias because respondents who self-selected to participate in the ACBS may differ from those who did not.[44] Also, in 2006 and 2007, the ACBS queried only those with landline telephone access. People residing in households lacking landline telephones and those using only cellular telephones, who tend to have a lower income, be younger, and be members of racial/ethnic minority groups, were not included.[45]

Furthermore, due to the cross-sectional nature of this survey, a temporal sequence could not be established and causal inferences could not be made. For example, it is not clear whether lower income precedes WRA or is a consequence of the disease.

Lastly, estimates were limited to the 33 states and DC that conducted the ACBS in 2006 and 2007 and do not represent nonparticipating states or the entire U.S. population. However, the number of states conducting the ACBS has steadily increased from three states in 2005 to 36 states, DC, and Puerto Rico in 2009, allowing for additional state estimates.

CONCLUSIONS

The ACBS can supplement case-based surveillance by providing population-based information on WRA. Currently, a limited number of states conduct case-based surveillance of WRA[46] and collect information on industry, occupation, and asthma-related exposures that is used to develop various targeted WRA preventive interventions (e.g., development and distribution of educational booklets, brochures, and posters on asthma among construction workers, graffiti-removal workers, and applicators of polyurethane liners for truckbeds).[47–49] Industry and occupation information on WRA cases is important because it allows for prevention of other cases in the same settings and may be used to create safer workplaces. Neither the BRFSS nor the ACBS is designed to collect detailed data on respondents' occupational history or workplace exposures. Such information would further enable states, other government agencies, health professionals, employers, workers, and worker representatives to develop targeted interventions.

Based on population survey data from 33 states and DC, we estimate that only about 10% of ever-employed adults with current asthma have been told by a health professional that their asthma is work-related, though nearly half of ever-employed adults with current asthma report that work exposures have either caused or exacerbated their asthma. Further studies are needed to better understand this apparent discrepancy.

Gretchen Knoeller is an Association of Schools of Public Health/Centers for Disease Control and Prevention (CDC) Public Health Fellow and Jacek Mazurek is a Senior Service Fellow with CDC, National Institute for Occupational Safety and Health (NIOSH), Division of Respiratory Disease Studies in Morgantown, West Virginia. Jeanne Moorman is a Survey Statistician with CDC, National Center for Environmental Health, Division of Environmental Hazards and Health Effects in Atlanta, Georgia.

Address correspondence to: Gretchen E. Knoeller, MPH, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Respiratory Disease Studies, 1095 Willowdale Rd., MS-HG900, Morgantown, WV 26505; tel. 304-285-5838; fax 304-285-6111; e-mail <ipb8@cdc.gov>.

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Student Column

GEOSPATIALLY ILLUSTRATING REGIONAL-BASED ORAL HEALTH DISPARITIES IN KENTUCKY

Daniel M. Saman, MPH
Andrew O. Johnson, PhD
Oscar Arevalo, DDS, ScD, MBA, MS
Agricola Odoi, BVM, MSc, PhD

Oral health conditions in parts of Appalachia—a region of the United States spanning 13 states across the Appalachian Mountains from southern New York to Northern Mississippi and including 24.8 million people—are considered severe.[1–3] In particular, Kentucky, a highly Appalachian state containing the highest proportion of economically distressed counties across all of Appalachia,[4] has some of the worst oral health outcomes in the nation.[5–7] Kentucky ranks seventh nationwide in the number of completely edentulous older adults,[5] ninth in adults with any permanent teeth extracted,[6] and eighth in the prevalence of individuals not having visited a dentist or dental clinic within the past year for any reason.[7] Though Kentucky does have a high rate of water fluoridation,[8] teeth cleanings, and dental sealants as compared with the rest of the nation, it still has a higher rate of caries and untreated caries among children.[9]

In addition, rural inhabitants in the U.S. have been shown to experience worse oral health outcomes compared with urban inhabitants. Vargas et al. found that adults living in rural areas in the U.S. were less likely to visit a dentist in the past year and more likely to be edentulous than their urban counterparts.[10] About 30% of Kentuckians live in Appalachian-designated counties. These counties reflect high levels of rurality and some of the poorest populations in the U.S., contributing to the acute condition of oral health in the region.[1] Further, as reported by their parents, rural Kentucky children are less likely to have teeth in excellent condition and to have dental insurance than their urban counterparts.[11] These indicators seem to suggest the existence of geographic disparities with higher rates of oral health problems and lower use of dental care in Appalachian Kentucky—a predominantly rural region—than in non-Appalachian Kentucky. Unfortunately, tabular presentations of oral health data to policy makers can fail to convey both the relative magnitude and location of disparities.

To clearly illustrate the geographic differences in an oral health outcome in Kentucky, we proposed the use of two geospatial techniques: (*1*) a cartographic construction technique called the bivariate cartogram and (*2*) hot-spot cluster analysis. We chose to present these data with cartograms due to the limitations associated with the more commonly encountered choropleth map and tabular presentation displays. For example, tabular presentations of spatial data do not display data according to the context of space, thereby limiting the results and interpretation. Choropleth maps (i.e., thematic maps in which regions are shaded according to the distribution of data values) can often lead to misinterpretation by displaying larger regions more prominently than smaller ones. Cartograms are maps that proportionally scale the area of a geographic entity (e.g., counties, states, and countries) according to a given (i.e., nonspatial) attribute (e.g., population),[12,13] thereby reducing the effect of the previously mentioned size-prominence limitation of choropleth maps. Bivariate cartograms use one attribute (e.g., county population) to proportionally rescale the area of each county polygon, and a second attribute (e.g., percentage of adults aged 18 years and older with six or more teeth removed because of tooth decay or gum disease) as a traditional choropleth-type thematic map.

A hot-spot cluster analysis is useful for investigating clusters of health events, such as the percentage of adults with six or more teeth removed by county in the Appalachian and non-Appalachian regions of Kentucky. Using hot-spot analysis for geospatial visualization can readily show the locations of significant hot spots or clusters of health events and, hence, help in identifying disparities. Individually, cartograms transform regions relative to an underlying variable, while a hot-spot analysis finds areas with statistical clusters at the county level. When used in conjunction, as performed in this study, the techniques produce a highly informative and visually compelling understanding of oral health disparities in the state.

These geographic techniques have been useful in assessing and investigating clustering patterns for other health events. For example, Mandal et al. found that breast and prostate cancers cluster spatially in the U.S., with clusters of counties with high cancer rates found in the North and clusters with low cancer rates found in the South.[14] Studies with similar methodology have also used hot-spot analysis to identify elevated clusters of mosquito breeding,[15] respiratory infection incidence rates,[16] and typhoid outbreaks from 1906 to 1909.[17] Moreover, cartograms have been used to visualize disparities in obesity prevalence by state,[18] map the global burden of malaria,[19] and map crime rates.[20]

To our knowledge, however, there are no extant examples of the use of these two techniques—bivariate cartograms and hot-spot analysis—in the relevant literature for examining oral health-related disparities. As an example of the intersection between oral health and geographic analysis, this study was intended to bridge that gap in the literature and highlight the use of a geographic information system (GIS) as a novel tool when analyzing regional-based oral health disparities. The findings from this study will be useful in guiding health planning, resource allocation, and policy decisions aimed at reducing oral health disparities and improving oral health for all Kentuckians.

METHODS

Cartogram analysis

We created cartograms using ArcGIS® version 9.3[21] that visualized 2006 population estimates,[22] 2007 dental workforce,[23] and an oral health outcome across Kentucky by county. We calculated the dental workforce by county, defined as dentists per 10,000 population, by geocoding the physical practice addresses of all Kentucky dentists and calculating the rate as a point-in-polygon count of dentists divided by the respective county population. County polygon areas were then transformed by the resulting county populations and dentist-per-10,000 population ratio using the Gastner-Newman diffusion algorithm,[24] available as a downloadable script for ArcGIS.[25] Next, the newly transformed county polygons were shaded as a choropleth map using the percentage, by county, of adults aged 18 years and older with six or more permanent teeth removed because of tooth decay or gum disease. The data for this variable were taken from a 2007 report by the Kentucky Institute of Medicine,[26] which compiled data from the Kentucky Behavioral Risk Factor Surveillance System in the years 1997, 1999, 2002, and 2004.[27] County polygons were shaded by the relative values of the oral health outcome variable as categorized into five classes using the Natural Breaks algorithm,[28] with a monochromatic color scheme provided by ColorBrewer.org.[29,30]

Appalachian county designations were identified from the Appalachian Regional Commission.[1] We downloaded the Kentucky county polygon data from the Kentucky Division of Geographic Information.[31] We also created a table to offer a brief descriptive understanding of the cartograms. We performed student's two-sample t-tests on the variables in the Table comparing Appalachia with non-Appalachia using SAS® version 9.1.[32]

Hot-spot analysis

We performed a hot-spot analysis using the hot-spot analysis tool in ArcGIS, based on the Getis-Ord Gi* statistic,[33] to identify counties with statistically significant ($p<0.05$) clusters of high or low rates of the percentage of adults with six or more teeth removed because of tooth decay or gum disease. Extreme (high or low) values of the Getis-Ord Gi* statistic indicated an increasing intensity of clusters of high or low values (i.e., a nonrandom distribution of the oral health outcome by county). The output statistic of the hot-spot analysis, the Z-score, measures the standard deviation (SD). Counties with statistically significantly higher Z-scores (darker counties) indicate a cluster of counties with a higher percentage of adults with six or more teeth removed because of tooth decay or gum disease, and counties with statistically significantly lower Z-scores (lighter counties) indicate a cluster of counties with a lower percentage of adults with six or more teeth removed because of tooth decay or gum disease (Figure 1).

Table. Descriptive statistics for variables of interest in a study of oral health in Appalachian and non-Appalachian regions in Kentucky

Variables	Regions		State
	Appalachian	Non-Appalachian	
Mean population of counties[a] (SD)	22,080 (16,098)	45,837 (91,946)	35,146 (69,089)
Mean dentists per 10,000 population of counties (SD)	3.10 (1.69)	3.74 (2.22)	3.45 (2.00)
Mean percentage of adults 18 years of age and older[b] with six or more permanent teeth removed because of tooth decay or gum disease (SD)	42.20 (9.40)	33.20 (8.30)	37.30 (8.80)

[a]$p<0.05$; two-sample t-test assuming unequal variances

[b]$p<0.0001$; two-sample t-test assuming equal variances

SD = standard deviation

Figure 1. High[a] and low[b] hot-spot GI* analysis of the percentage of adults 18 years of age and older with six or more permanent teeth removed because of tooth decay or gum disease in Kentucky
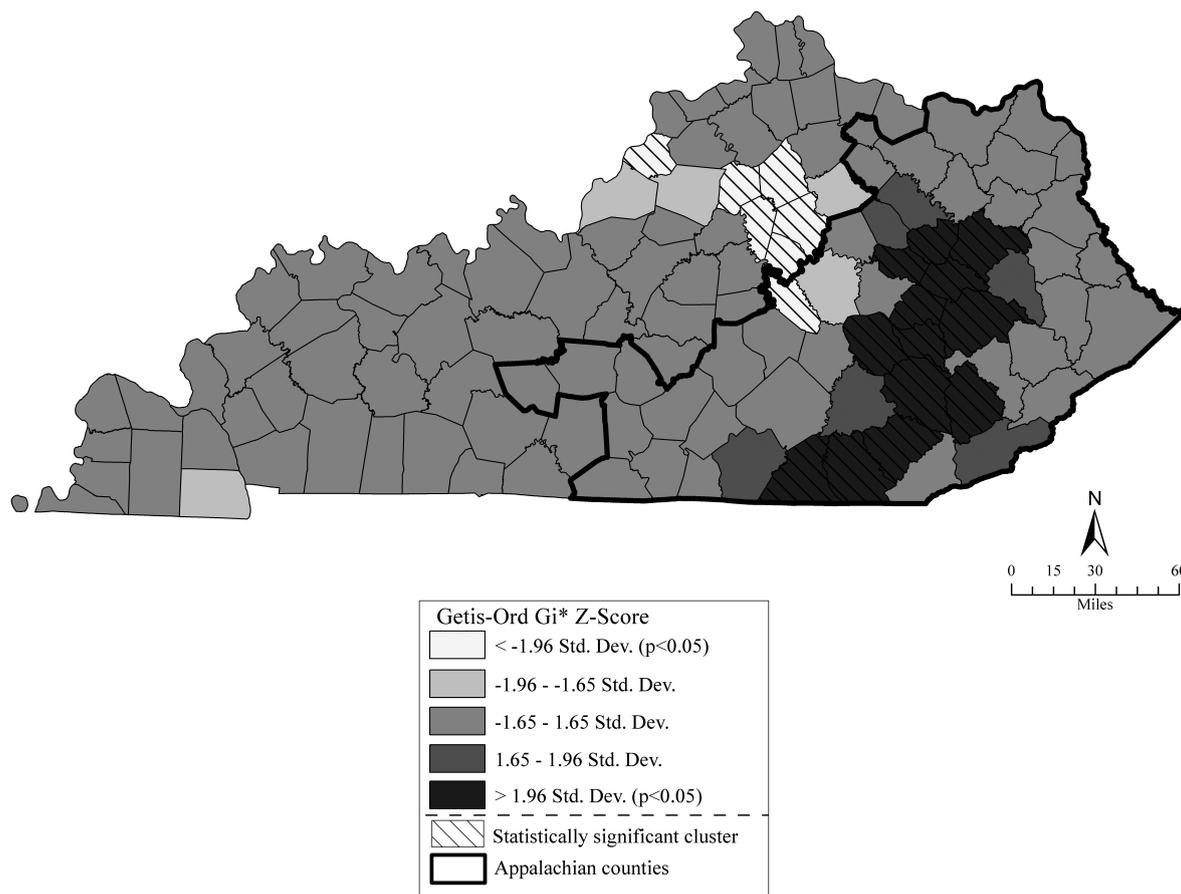
[a]High clusters (darker counties): 13 out of the 54 Appalachian counties were nonrandom clusters ($p<0.05$) with respect to oral health outcome (i.e., higher percentage of adults with teeth removed). One of the 13 Appalachian counties had a low cluster. This county was relatively close to lower Z-score cluster counties and just within the border of the Appalachian region.

[b]Low clusters (lighter counties): six non-Appalachian counties were nonrandom clusters ($p<0.05$) with respect to oral health outcome (i.e., lower percentage of adults with teeth removed).

Std. dev. = standard deviation

RESULTS

As shown in Figure 2a, an untransformed choropleth map of Kentucky highlights the concentration of darker counties—those with a higher percentage of adults with six or more teeth removed—in the Appalachian region. Nine of the 10 counties in the bottom oral health class—51%–65%—are located in the Appalachian region. The cartogram in Figure 2b, as transformed by county population, depicts counties with the largest populations as also having the largest areas, and typically better oral health per the oral health outcome. The cartogram in Figure 2c, as transformed by dentists per 10,000 population, shows a similar trend as Figure 2b in that counties with the largest areas—i.e., higher ratios of dentists per 10,000 population—also had the lowest percentage of adults with six or more teeth removed. Counties with lower ratios of dentists per 10,000 population tend to be Appalachian and have worse oral health as measured by our oral health outcome. Thus, Figure 2 illustrates three spatial disparities: an oral health disparity between Appalachian and non-Appalachian Kentucky, between higher and lower population counties, and between counties with higher and lower numbers of dentists per 10,000 population.

The Table shows that the mean population and mean number of dentists per 10,000 population in

Figure 2. Percentage of adults 18 years of age or older with six or more permanent teeth removed because of tooth decay or gum disease in Kentucky shown in (a) an untransformed choropleth map, (b) a 2006 county population cartogram, and (c) a 2007 dental workforce cartogram[a]
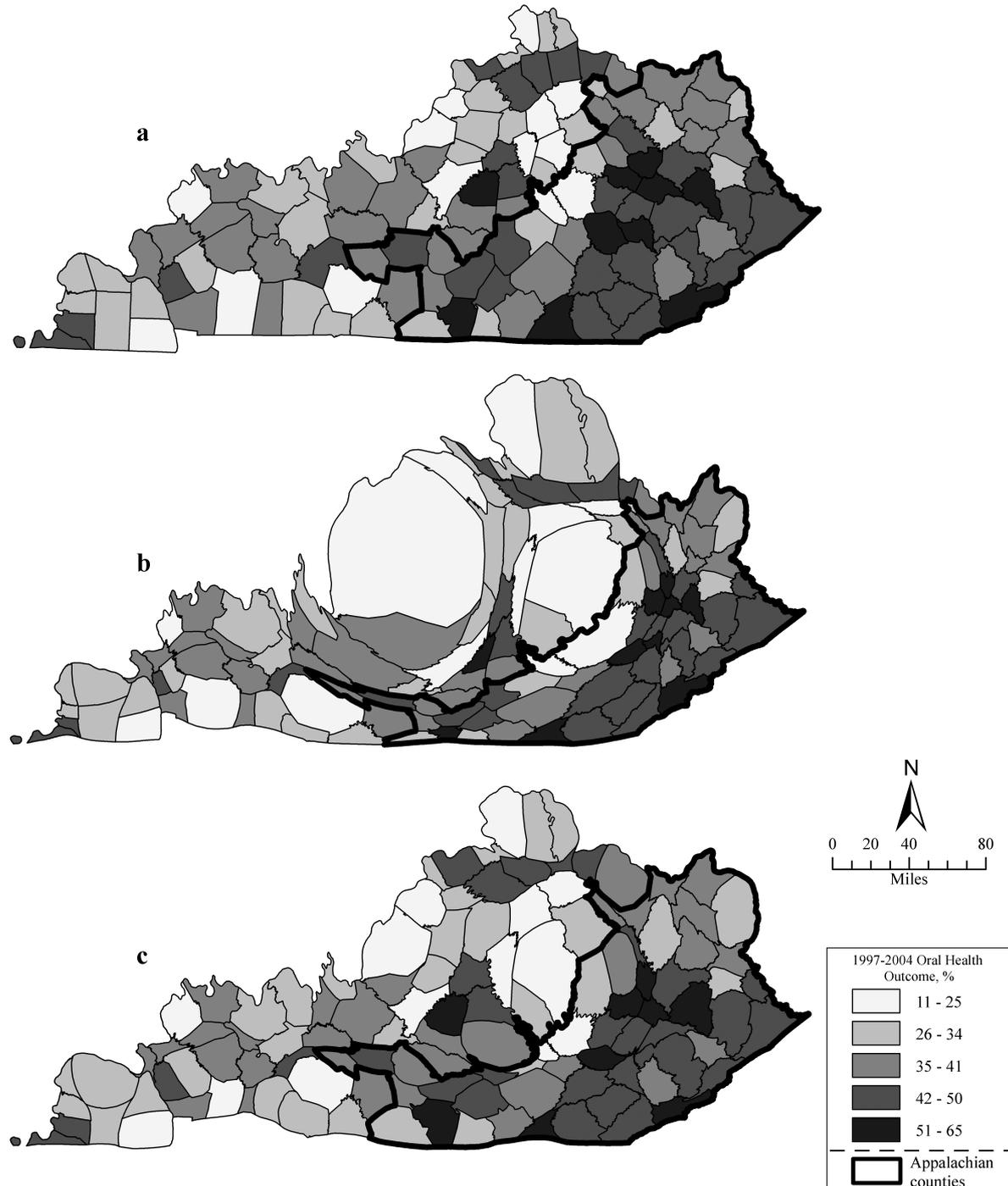
[a]Kentucky counties transformed proportional to county populations for 2006 (b) and proportional to the ratio of dentists per 10,000 population within each county (c). Two Appalachian counties (Robertson and Owsley) have zero dentists and are distorted enough not to be visible (c).

Appalachia were lower than in non-Appalachian Kentucky and Kentucky, and the mean percentage of adults with six or more teeth removed was higher in Appalachia than in non-Appalachia and Kentucky. We found no significant differences between Appalachia and non-Appalachia for the number of dentists per 10,000 population, but we did find significant differences between the two regions for the oral health outcome ($p<0.0001$) and population variables ($p<0.05$).

Figure 1 shows that counties with a higher percentage of adults with six or more teeth removed because of tooth decay or gum disease (darker counties: >1.96 SD) were statistically significantly clustered (i.e., nonrandomly distributed) in the Appalachian region, thus confirming the results of an oral health spatial-based disparity between Appalachian and non-Appalachian Kentucky. The map also shows that counties with a lower percentage of adults with six or more teeth removed because of tooth decay or gum disease (lighter counties: <1.96 SD) were statistically significantly clustered in the non-Appalachian region. We repeated this analysis for the ratio of dentists per 10,000 population variable with some similar results: high clusters (>1.96 SD ratios of dentists per 10,000 population) were found in five non-Appalachian counties, and one Appalachian county was a statistically significant low cluster (<1.96 SD) (data not shown).

DISCUSSION

The depictions of a distorted, or rescaled, Kentucky via cartograms in addition to the hot-spot analysis provide policy makers with evidence of spatially and statistically based oral health disparities between Appalachian and non-Appalachian Kentucky and some evidence of a dental workforce misdistribution. These two geographic analytical techniques were useful in conjunction because, while the results in Figure 2 show the effect that dentist and population density have on the oral health outcome (i.e., generally worse oral health in counties with lower dentist and population densities), Figure 1 pinpoints specific clusters of counties with significantly high rates of the percentage of adults with six or more teeth removed because of tooth decay or gum disease. Both figures offer policy makers a clear guide to county-level funding allocation for the improvement of oral health. Together, these geographic techniques present an informative visualization of the state by oral health and a thorough and accurate depiction of the spatial component of oral health disparities with respect to our outcome. This study also brought light to the importance of accounting for place of residence

in dental public health research through the use of spatial statistical techniques and GIS.

The public health significance of these findings is broad. The implications of these results can drive policy-making and funding allocation, and provide a basis for further investigation into the causes of these patterns. Specifically, this study provides policy makers with a visualization of the oral health burden faced in Appalachian Kentucky to direct efforts in that region and improve overall oral health. Also, the use of cartograms coupled with a hot-spot analysis offers a unique way of visualizing health-related disparities to policy makers, the lay public, and researchers.

In addition, these findings are important to the field of public health because oral health is often an overlooked component of general health and well-being. In 2000, the Surgeon General called oral disease a "silent epidemic" because of its ubiquitous nature and disproportionate effect on ". . . our most vulnerable citizens—poor children, the elderly, and many members of racial and ethnic minority groups."[34] Moreover, poor oral health has been associated with an elevated risk of heart disease.[35,36] Among adults, poor oral health has also been associated with absences from work[34] and low self-esteem.[37,38]

The hot-spot analysis showed counties with a higher percentage of adults with six or more teeth removed because of tooth decay or gum disease clustered in the Appalachian region—a region characterized by low population densities, low dentist densities, and high poverty rates. These variables inextricably define much of Appalachian Kentucky[39,40] and may explain why an oral health disparity exists. Future studies should seek to perform regression analyses to try to more thoroughly explain why much of Appalachian Kentucky is experiencing poorer oral health relative to non-Appalachian Kentucky. Moreover, although not every county with a high percentage (51%–65%) of the oral health outcome is shown as being part of a significantly high cluster, policy makers should not neglect those counties simply because they are not part of a high cluster. Counties that were not high clusters but had a high percentage of adults with six or more teeth removed because of tooth decay or gum disease still represent areas in which funding should be focused.

Limitations
This study had several limitations. One limitation was the artificially abrupt change in the oral health outcome that occurred from county boundary to county boundary and the use of county-level choropleth

thematic mapping that depicted a synthetic uniformity (ecological fallacy) of the oral health outcome across counties. In addition, the oral health outcome used in this study was limited to adults aged 18 years and older with six or more permanent teeth removed because of tooth decay or gum disease. While it was necessary to be specific for the sake of this research, this outcome does not sufficiently provide an exhaustive understanding of oral health in Kentucky. Future studies should seek to offer a more rounded assessment of oral health by examining more oral health outcomes and indicators using geospatially based methods. In addition, although cartograms represent an important visual tool in oral health epidemiology and health geography, they may at first seem difficult to interpret. It has been shown, however, that providing a basic briefing on cartograms allows for a better understanding of the maps.[41]

CONCLUSIONS

Cartograms and hot-spot analysis, though only two elements in the spectrum of geography and spatial statistics, provide a more novel representation of spatial disparities than classic tabular presentations, minimize limitations associated with choropleth maps, add a dimension of data (i.e., spatial weighting) beyond the typical map, and identify nonrandom clusters of health events. These two tools can be used by policy makers to determine where oral health disparities exist and pinpoint specific areas of need when allocating funds for and improving oral health across entire populations. Finally, this study highlights certain areas in a predominantly rural state that are experiencing oral health-related disparities and demonstrates the need to account for place of residence when performing public health research.

Daniel Saman is a Doctor of Public Health Student at the University of Kentucky College of Public Health (UK CPH) Department of Epidemiology in Lexington, Kentucky. Andrew Johnson is an Assistant Professor at the UK CPH Department of Health Services Management in Lexington. Oscar Arevalo is a Resident in Pediatric Dentistry at the University of Puerto Rico School of Dental Medicine, Department of Pediatric Dentistry in San Juan, Puerto Rico. Agricola Odoi is an Assistant Professor at the University of Tennessee Department of Comparative Medicine in Knoxville, Tennessee.

Address correspondence to: Daniel M. Saman, MPH, University of Kentucky College of Public Health, Department of Epidemiology, 121 Washington Ave., Lexington, KY 40536; tel. 859-218-2227; fax 859-257-8811; e-mail <dmsama2@uky.edu>.

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