Z-Score Burden Metric: A Method for Assessing Burden of Injury and Disease

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Introduction: Traditional methods of summarizing burden of disease have limitations in terms of identifying communities within a population that are in need of prevention and intervention resources. This paper proposes a new method of burden assessment for use in guiding these decisions.

Methods: This new method for assessing burden utilizes the sum of population-weighted age-specific *z*-scores. This new *Z*-Score Burden Metric was applied to firearm-related deaths in North Carolina counties using 2010–2017 North Carolina Violent Death Reporting System data. The *Z*-Score Burden Metric consists of 4 measures describing various aspects of burden. The *Z*-Score Burden Metric Overall Burden Measure was compared with 2 traditional measures (unadjusted and age-adjusted death rates) for each county to assess similarities and differences in the relative burden of firearm-related death.

Results: Of all 100 North Carolina counties, 73 met inclusion criteria (≥5 actual and expected deaths during the study period in each age strata). Ranking by the Overall Burden Measure produced an ordering of counties different from that of ranking by traditional measures. A total of 8 counties (11.0%) differed in burden rank by at least 10% when comparing the Overall Burden Measure with age-adjusted and unadjusted rates. All the counties with large differences between the measures were substantially burdened by firearm-related death.

Conclusions: The use of the *Z*-Score Burden Metric provides an alternative way of measuring realized community burden of injury while still facilitating comparisons between communities with different age distributions. This method can be used for any injury or disease outcome and may help to prioritize the allocation of resources to communities suffering high burdens of injury and disease.

INTRODUCTION

A common situation in epidemiology is the need to compare the incidence of an outcome between communities to identify groups in greatest need of prevention resources. Although a range of epidemiologic measures exist (e.g., standardized mortality ratio, years of potential life lost) for quantifying burden in communities, some of the most popular measures used to make comparisons include counts, unadjusted rates, and standardized rates. This paper reviews these methods, discusses their strengths and limitations, and introduces a new measure for comparing populations that is closer to the true realized community burden of injury.

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Standardization

Standardization is a fundamental epidemiologic tool to compare outcomes in 2 or more populations.[1] Standardization elucidates the disease or injury incidence that would have been observed had the underlying population characteristics (e.g., age distribution) of different populations been the same. The choice of whether to standardize and which standardization method to use must be aligned with the goals of the analysis, especially when used to allocate prevention resources by identifying areas that are experiencing the greatest burden of a given illness or injury.[2] Deciding which standardized measure to use to quantify burden is complicated because existing unadjusted and standardized measures have limitations.[2] For example, using count data (i.e., without accounting for population size) may prioritize urban counties over rural counties. Estimates of burden that account for population size, such as unadjusted incidence rates, can be misleading if there are heterogeneous patterns of disease incidence and age distribution between the places being compared.[2] Failing to account for these differences can produce biased conclusions, such as an incidence rate suggesting that a county is doing worse than its neighbors, even if the rates within each age group in that county are lower than corresponding rates among neighboring counties.

One solution is to conduct standardization by applying age-group–specific rates to a reference population. These *directly standardized rates*, sometimes referred to as age-adjusted rates, allow for comparisons between places that have different population age distributions, but as summary measures, they can still obscure age-specific subgroup trends.[2] Furthermore, many potential reference populations could provide weights for standardization, and there often is no obvious clinical, scientific, or policy justification for selecting a specific set of weights. Many epidemiologists use certain sets of weights, such as the overall state, nation, or world, as defaults without full consideration of the implications.

Finally, it is important to realize that age-adjusted rates are counterfactual[1] and do not reflect the true burden experienced in a county. They reflect the burden that would have been experienced in the county had the underlying population had the same distribution as the (arbitrary) reference population. Resources devoted to counties on the basis of this metric are therefore being allocated on the basis of a counterfactual rather than the actual burden experienced by the county. More sophisticated standardization techniques have been developed, such as the small area burden estimates used by the Global Burden of Disease Collaborative Network,[3–8] but these require statistical skills beyond those available to many local and regional public health agencies.

Z-Score Burden Metric: an Alternative to Standardization

The optimal metric for the purpose of prioritizing areas for intervention and response resources would address both the issue of population distribution to facilitate direct comparisons of relative burden across populations with disparate age structures and also reflect the realized burden in the community (rather than a reference population). Unadjusted incidence rates focus on the latter but do not address the former. Direct standardization is successful in the former but does not satisfy the latter. It would also be helpful if such a metric could be easily calculated in under-resourced situations.

This paper introduces a novel burden metric adapted from the use of *z*-score prioritization assessments in other injury work; population-weighted *z*-scores have also been used in meta-analyses and widely in nutrition and obesity research.[9–13] This *Z*-Score Burden Metric (ZSBM) consists of 4 unique measures designed to meet the needs of state and local public health officials making decisions about how to use limited resources. Firearm-related injury data were used to show this metric. Firearm-related injury has well-documented heterogeneous incidence by age. This paper shows that the ZSBM retains the advantages and addresses some of the shortcomings of unadjusted and age-adjusted rates. Specifically, it allows for comparisons between communities while better reflecting the true burden experienced in each community.

METHODS: CALCULATION OF MEASURES

Unadjusted Rates

Unadjusted rates are calculated by taking the sum of events in a location of interest and dividing by the total time the population in that location was at risk of injury (denominator unit = person−years).[2] Firearm-related injury deaths were used as the events, counties were used as the locations of interest, and annual population was used to estimate person-years.

Age-Adjusted Rates

Rates of events per person-year are calculated separately for each age group, then weighted to the relative size of that age group in the reference population,[2] and then summed to produce the final age-adjusted (direct standardized) rate (Appendix Figure 1, available online).

Z-Score Burden Metric

To show the ZSBM, county-level rates for 3 age groups were calculated: 0–29 years, 30–59 years, and ≥60 years. These age groups represent different injury patterns among young adults, middle-aged adults, and older adults while addressing the issue of small numbers because of multiple categories. Within each age group, the state rate was subtracted from the county's rate and then

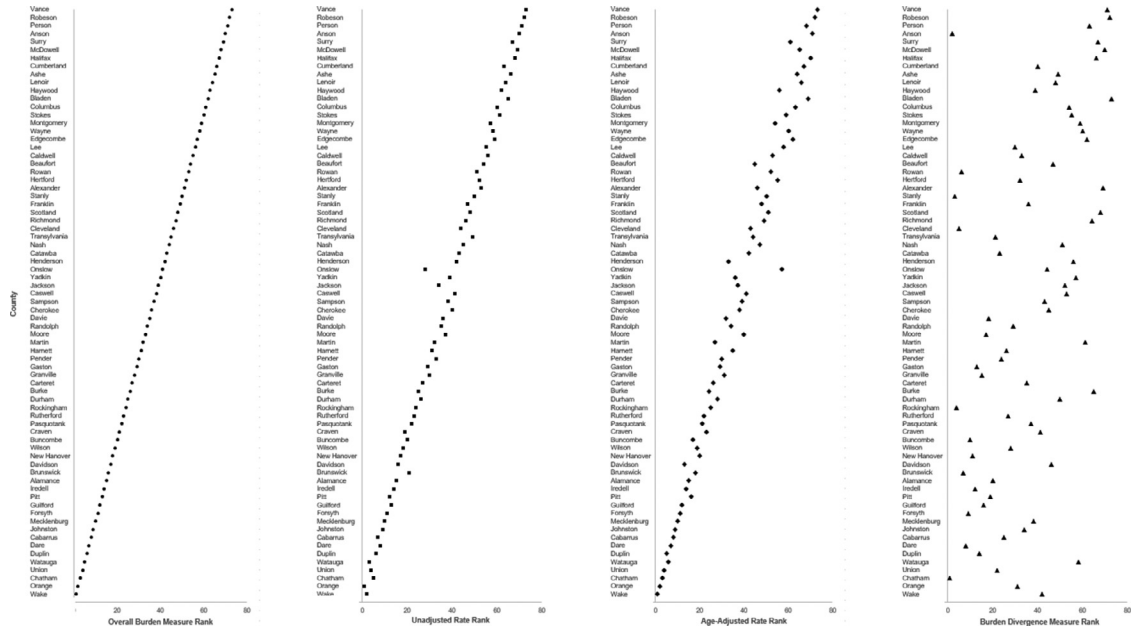

Figure 1. Relative rank by Overall Burden Measure, unadjusted rate, age-adjusted rate, and Burden Divergence Measure.

divided by the standard deviation (SD) of all counties to produce a *z*-score. The age group–specific *z*-score was multiplied by the proportion of the population in the county within that age group, and all weighted rates were summed (Appendix Figure 1, available online). The ZSBM compares age-specific rates with those of the state as a whole and then collapses them to depict the burden imposed on a county on the basis of its own age distribution rather than that of the reference population as in age-adjusted rates.

The ZSBM approach can be used to generate 4 complementary measures describing various components of overall burden (Appendix Figure 1, available online). The Overall Burden Measure (OBM) can be used as an alternative to unadjusted and age-adjusted rates to compare counties and assess which, overall, are suffering the highest burdens. The remaining 3 measures provide more details about burden within the county's age subgroups. The Above-Average Burden Measure (AABM) and Below-Average Burden Measure (BABM) allow for identifying counties where specific age subgroups may have increased risk or protective factors, respectively, compared with the state mean; separately adding positive and negative *z*-scores ensures that those trends are not obscured by heterogeneous patterns between age groups in a county. However, the presence of heterogeneous trends can itself be instructive in identifying counties where certain age groups are suffering disproportionately and may be priorities for intervention. This heterogeneity is captured by the Burden Divergence Measure (BDM) (Appendix, available online).

The ZSBM measures have an interpretation as an SD-scaled indicator of how each county compares with the state as a whole. At a basic level, a county with an OBM of 0 would match the state mean. Counties with an OBM above 0 are doing worse than the state, and counties with an OBM below 0 are doing better than the state. An OBM of 1 would indicate that age group–specific outcomes within a county (weighted by their population proportion) were 1 SD above the state mean, whereas a score of −1 would indicate that a county was 1 SD below the state mean. It is important to note that this calculation is valid only for strata with at least 5 expected events, so the binomial approximation of normality for rates is in effect,[14] and as with rate calculations, the larger the size of the sample, the more stable the estimates. Future work will focus on deriving valid variance estimators for ZSBM measures.

EXAMPLE: RATES OF FIREARM-RELATED DEATH

This section shows the ZSBM and compares it with age-adjusted and unadjusted rates using the outcome of firearm-related deaths in North Carolina (N.C.). Data from the 2010–2017 North Carolina Violent Death Reporting System (NC-VDRS) was used to assess the burden of fatal firearm-related injuries across the state using ZSBM measures.

The NC-VDRS is a surveillance system designed to collect robust data on homicide, suicide, and unintentional violent deaths and has been managed since 2004 by the N.C. Division of Public Health's Injury and Violence Prevention branch and funded by the National Center for Injury Prevention and Control at the Centers for Disease Control and Prevention. Data are abstracted from death certificates, medical-examiner findings, and law enforcement reports. Previous validations of the NC-VDRS have found that all cases meeting the definition for inclusion were identified using existing procedures, making the NC-VDRS a complete census of all

violent deaths in the state.[15] For this analysis, firearm-related deaths were determined on the basis of manner of death and weapon/means used to cause death. All homicide, suicide, unintentional, and undetermined intent firearm-related deaths were included. Population data for this analysis were taken from the National Center for Health Statistics National Vital Statistics System Bridged-Race Postcensal Population Estimates,[16] allowing for user-specified age and race categorizations at the county-year level.[17] Analyses were conducted in 2021 using Stata SE, version 15.1 (StataCorp), and Microsoft Excel 365. No patients were involved in the design of this study. This project was exempted by the University of North Carolina IRB.

RESULTS

Overall: Firearm-Related Death

From 2010 to 2017, there were 9,969 firearm deaths in N.C. After removing deaths in non-N.C. residents (n=298), those with an unknown residence county (n=1), and those missing age (n=1), there were 9,669 firearm deaths. The mean number of firearm deaths during the study period per N.C. county was 97, with a range of 1–801. Of the 100 N.C. counties, 73 met the criteria for inclusion on the basis of having ≥5 actual or expected deaths in each age group (0–29 years, 30–59 years, and 60+ years). Those 73 counties had a total of 9,064 deaths (range = 26–801 deaths) and an overall incidence of 12.1 deaths per 100,000 person-years.

The ZSBM OBM by county is shown in Appendix Figure 2 (available online). The use of the z-score indicates where each county falls compared with the state mean, including below average (blue) and above average (orange). White counties were excluded from the analysis because of their small numbers.

Comparison of Measures

Comparing unadjusted rates, age-adjusted rates, and the OBM revealed differences in relative burden assessment when counties were ranked from low (1) to high (73) for each measure (Figure 1). The OBM and unadjusted rate showed a similar overall trend along the full spectrum of low to high burden counties, with small changes in some cases because of the use of z-scores. Age-adjusted rates changed rankings more, especially at the high burden end of the spectrum, suggesting that for many counties, the population structure between the N.C. reference population and the actual county was quite different. A total of 8 counties (11.0%) differed by at least 10.0% between their OBM, unadjusted rate, and age-adjusted rate rank (Tables 1 and 2). All of these 8 counties placed in the top 50% of counties for relative burden by at least 1 measure and only 2 of their combined 24 age groups (3 age groups for each of the 8 counties) had fewer than 10 deaths, indicating that the measure heterogeneity was not owing to instability from small numbers. Comparison with the BDM revealed that even within counties with a low overall burden by the other measures, some populations are disproportionately affected by firearm-related injury and may justify prioritization of intervention and response resources.

ZSBM Preserves Burden Experienced by County Subgroups

An examination of select counties shows varying trends depending on the measure used and the utility of the ZSBM in describing county burden (Table 1). For example, Henderson and Moore Counties seem similar; Henderson is slightly larger with slightly more deaths in the study period. The unadjusted rate for each county is similar (14.86 vs 14.34). However, age adjustment flips this relationship and increases the difference between the 2 counties from 0.52 to 0.87 deaths/100,000. The OBM switches back, showing Moore with a slightly lower burden than Henderson. The ZSBM also shows that Henderson has at least 1 population-weighted age group that is much higher than the state mean compared with Moore age groups (AABM) as well as at least 1 age group that is much lower than the state mean (BABM) compared with Moore age groups. The difference between the 2 most extreme age-groups (BDM) in Henderson is 0.73 compared with 0.30 in Moore.

Examining age subgroups in Henderson and Moore counties explains these findings (Table 2). The age distributions in Henderson and Moore counties differ from those of N.C. and the U.S.; the counties have high older adult population proportions, with small youth populations and slightly smaller middle-age populations than the state mean. Compared with N.C., Henderson has a very low unadjusted rate for youth and very high rates for middle-aged and older adults. Moore has a high rate for youth, a slightly high rate for middle-aged adults, and a slightly low rate for older adults. Henderson's low youth rate, when applied to the much larger N.C. reference population, overshadows its much higher middle-aged and older adult rates (the latter of which is substantially down weighted when applied to the smaller older adult N.C. population). For 2 of the 3 age groups, Henderson has a much higher rate than Moore and N.C. overall, and yet it is ascribed a lower rate than Moore when standardized to the N.C. population. However, the ZSBM measures show that Henderson has both a higher burden than Moore and more heterogeneity between age groups, meaning that resources may be targeted to

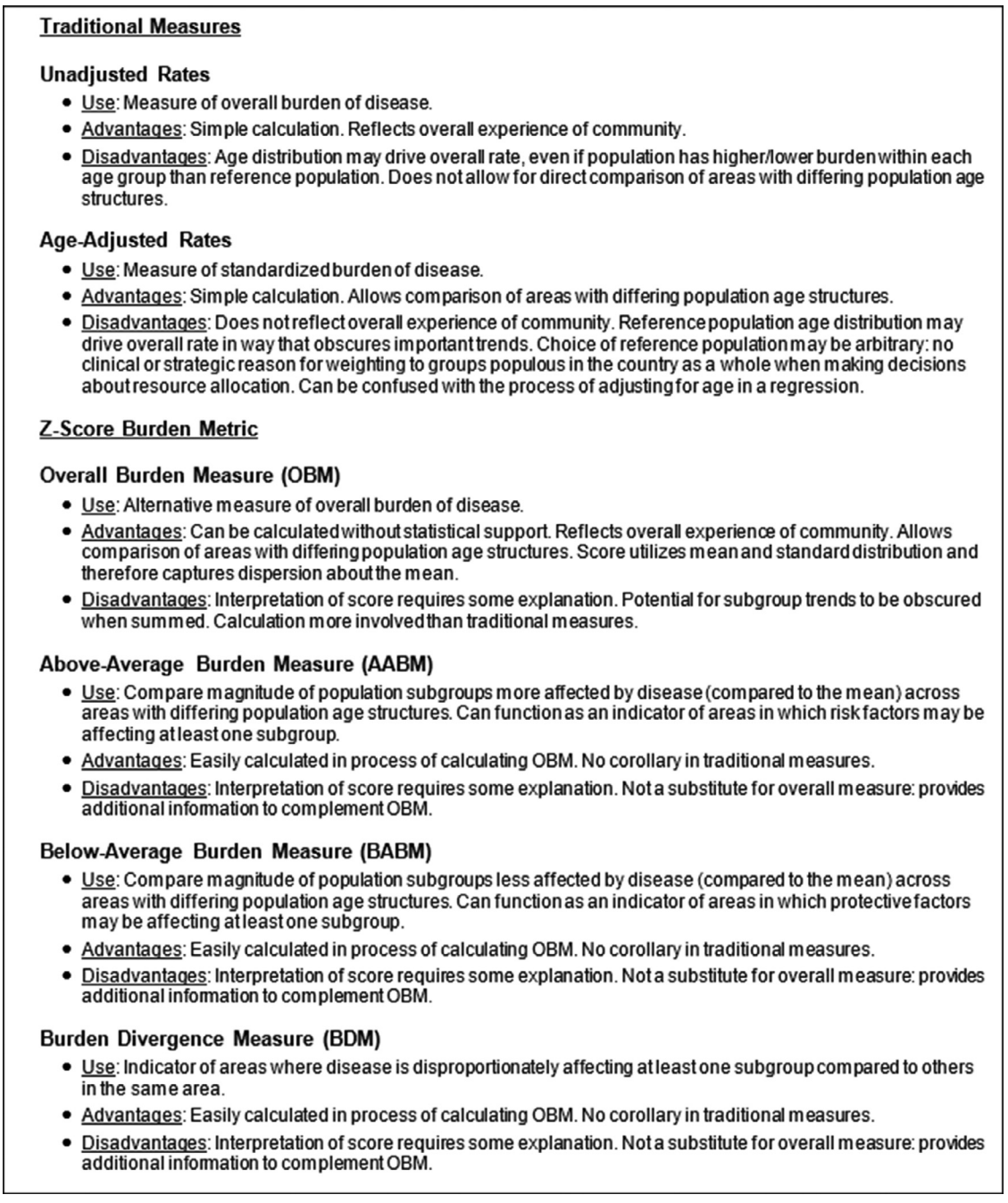

Figure 2. Summary of strengths and weaknesses of measures.
AABM, Above-Average Burden Measure; BABM, Below-Average Burden Measure; BDM, Burden Divergence Measure; OBM, Overall Burden Measure.

specific groups in the population that are suffering disproportionately.

ZSBM Is Sensitive to Disproportionate Subgroup Burden

The ZSBM also showed utility in comparing counties even when all the 3 measures showed the same general trend. For example, Haywood and Surry counties have similarly high overall unadjusted rates (Table 1). Age adjustment lowers each rate slightly but preserves the difference between the 2 counties (0.84 unadjusted rate difference, 0.85 age-adjusted rate difference). However, the OBM for Surry county is much larger than that of Haywood, and the AABM and BDM show that at least 1 age group in Surry county is experiencing a very high burden of firearm death, even compared with other age

Table 1. North Carolina Firearm-Related Injury Deaths in 2010–2017: Comparison of Burden Measures in Select Counties

					Z-score burden metric			
Residence county	**Deaths (N)**	**Person-years**	**Unadjusted rate**	**Age-adjusted rate**	**OBM**	**AABM**	**BABM**	**BDM**
Alexander	47	296,416	15.86	15.25	0.71	0.93	−0.22	1.08
Beaufort	61	379,440	16.08	15.22	0.80	0.83	−0.03	0.51
Bladen	48	275,011	17.45	18.06	0.95	1.37	−0.42	1.35
Haywood	81	475,448	17.04	16.01	0.97	0.97	0.00	0.47
Henderson	131	881,812	14.86	13.59	0.53	0.82	−0.29	0.73
Moore	106	739,015	14.34	14.46	0.36	0.43	−0.07	0.30
Onslow	205	1,527,233	13.42	16.01	0.48	0.61	−0.13	0.49
Surry	104	581,809	17.88	16.86	1.23	1.46	−0.23	1.02
North Carolina	9,064	74,631,229	12.15	12.14	–	–	–	–

AABM, above-average burden measure; BABM, below-average burden measure; BDM, burden divergence measure; OBM, Overall Burden Measure.

groups within the county. Similar to Henderson and Moore, both Haywood and Surry have older populations than N.C. and the U.S. as a whole (Table 2). Both counties have higher unadjusted rates for middle-aged and older adults, but Surry's rates are much higher than Haywood's. In both unadjusted and age-adjusted rates, Surry's low youth rates tempered the extremely high rates in older groups (especially when weighted to the younger N.C. population). The OBM identified that compared with the state mean, Surry was experiencing a higher burden than Haywood, and the heterogeneity in the remaining ZSBM measures suggested that certain age groups in the county might be experiencing very high rates and be a priority for intervention.

DISCUSSION

For the purpose of directing resources to localities suffering a high burden of disease, the ZSBM provides some advantages relative to traditional measures (Figure 2). It allows comparisons between counties with different age distributions but better reflects the burden experienced by the county because subgroup scores are weighted to the population in the county rather than an arbitrary reference population. Although the ZSBM may initially require some explanation, *z*-score–based measures have an intuitive appeal because they are computed from each county's age-specific incidence scaled relative to the mean and SD of the state, and *z*-score measures have been widely used in other areas of research.[9–13] Computations can be performed using spreadsheets and do not require regression. Finally, 3 ancillary submeasures (the AABM, BABM, and BDM) provide more information about intracounty subgroup trends. These measures lack any corollary in traditional age-adjusted rates.

A limitation of all the measures discussed in this paper is that their focus on incidence misses the dimensions of burden captured by other measures, such as severity of illness, cost of illness, and years of potential life lost. Assessments of burden should be tailored to the particular issue at hand; the ZSBM methodology could be applied to additional dimensions of burden or combined with other measures to form a composite metric as a more comprehensive way to describe burden.[9] A further limitation of both the ZSBM and traditional measures described in this paper is that a focus on

Table 2. Firearm-Related Injury Death Rate and Population Proportion by Age in Select North Carolina Counties, 2010–2017

Residence county	**Ages 0–29 years unadjusted rate (per 100K PY)**	**Ages 0–29 years population proportion (%)**	**Ages 30–59 years unadjusted rate (per 100K PY)**	**Ages 30–59 years population proportion (%)**	**Ages ≥60 years unadjusted rate (per 100K PY)**	**Ages ≥60 years population proportion, n (%)**
Henderson	4.4	31.2	20.0	37.4	19.1	31.4
Moore	12.7	33.0	16.9	36.8	13.0	30.3
Haywood	10.2	30.9	19.1	38.5	21.3	30.6
Surry	5.8	35.3	22.6	39.6	27.4	25.1
North Carolina	9.2	39.9	14.2	40.1	13.9	20.0
U.S.	–	40.0	–	39.9	–	20.1

K, thousand; PY, person-year.

comparing communities with each other and with state means can distract from the public health goal of lowering incidence to zero. Although the overall goal is to reduce incidence to zero, a reasonable and equitable place to start is by reducing incidence for all disproportionately affected groups in a given community to match those who are faring the best overall. The ZSBM BDM partially addresses this issue because it focuses solely on the heterogeneity within a county.

The example presented in this paper also has limitations. Small numbers in some N.C. counties precluded conducting calculations for all the 100 counties. It would be ideal to conduct this analysis with more precise age groups and with other demographic breakdowns such as sex and race. Although counties were used as the geographic unit in this analysis, future analyses could use regional data combining neighboring counties to allow for more precise demographic breakdowns.

CONCLUSIONS

Policy decisions require tools designed to facilitate equitable resource allocation. The ZSBM may improve on traditional measures to better address this need. Similar to age-adjusted rates, the OBM is intended to facilitate comparisons of injury and disease burden between locations while accounting for potential confounding because of differences in age distribution between populations. The ZSBM uses weights derived from the locality itself rather than an external reference and thus is a place-based measure of burden. In addition, *z*-scores provide an intuitive means of relating rates in small geographic areas to the mean and SD of the larger population and can be readily computed using ubiquitous tools such as Excel spreadsheets.

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CREDIT AUTHOR STATEMENT

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SUPPLEMENTAL MATERIAL

Supplemental materials associated with this article can be found in the online version at https://doi.org/10.1016/j.amepre.2022.03.029.

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