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Firearm-Related Traumatic Brain Injury Homicides in the United States, 2000-2019

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Abstract

BACKGROUND: Traumatic brain injury (TBI) is a leading cause of homicide-related death in the United States. Penetrating TBI associated with firearms is a unique injury with an exceptionally high mortality rate that requires specialized neurocritical trauma care.

OBJECTIVE: To report incidence patterns of firearm-related and nonfirearm-related TBI homicides in the United States between 2000 and 2019 by demographic characteristics to provide foundational data for prevention and treatment strategies.

METHODS: Data were obtained from multiple cause of death records from the National Vital Statistics System using Centers for Disease Control and Prevention's Wide-Ranging Online Data for Epidemiologic Research database for the years 2000 to 2019. Number, age-adjusted rates, and percent of firearm and nonfirearm-related TBI homicides by demographic characteristics were calculated. Temporal trends were also evaluated.

RESULTS: During the study period, there were 77 602 firearm-related TBI homicides. Firearms were involved in the majority (68%) of all TBI homicides. Overall, men, people living in metro areas, and non-Hispanic Black persons had higher rates of firearm-related TBI homicides. The rate of nonfirearm-related TBI homicides declined by 40%, whereas the rate of firearm-related TBI homicides only declined by 3% during the study period. There was a notable increase in the rate of firearm-related TBI homicides from 2012/2013 through 2019 for women (20%) and nonmetro residents (39%).

CONCLUSION: Firearm-related violence is an important public health problem and is associated with the majority of TBI homicide deaths in the United States. The findings from this study may be used to inform prevention and guide further research to improve treatment strategies directed at reducing TBI homicides involving firearms.

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Keywords

Homicide; Firearms; Traumatic brain injury; Penetrating TBI

Head injury is common after intentional violence[1-3] and may result in blunt or penetrating traumatic brain injury (TBI) including subsequent morbidity and mortality. Approximately 1 million deaths in the United States were attributed to TBI over the past 2 decades,[4] and brain injury is repeatedly reported as the most common cause of trauma-related deaths.[4-6] Although most TBIs are caused by blunt mechanisms, penetrating TBI (pTBI) is associated with a 60% to 90% mortality rate and accounts for approximately 20 000 civilian deaths per year in the United States.[7-9] This exceptionally high lethality rate resulting from pTBI may be further associated with intentional violence and firearm use.[10]

Almost half of all TBI-related deaths (44.4%) in the United States from 2016 to 2018 were attributable to intentional causes including suicide and homicide.[11] Nearly all TBI-related deaths from suicide involve firearm-related mechanisms of injury in the United States.[4] However, little is known regarding the epidemiology of TBI-related homicide due to firearms. Specifically, pTBI secondary to firearms presents a complex and often catastrophic wounding mechanism that is associated with a higher mortality rate than a firearm injury to other regions of the body.[12] This is due to the highly destructive nature of a firearm-related primary and secondary injury to brain tissue and the potential for associated pathophysiology involved in this type of trauma (e.g., cardiac arrest).[13-15] Firearm-related TBIs commonly lead to hemorrhage, further cerebrovascular injury, cerebrospinal fluid leak, and introduction of foreign material into brain, all of which contribute to a higher risk of morbidity and mortality as compared with those with non-pTBI or blunt TBI mechanisms.[16,17]

Advances in medical and prehospital care have improved mortality rates and facilitated the development of clinical guidelines for treating patients after a firearm-related TBI.[13,18,19] More recent strategies to care for these patients include multi-disciplinary neurotrauma teams proactively seeking and addressing factors related to secondary brain injury, earlier cranial decompression, and prevention of cerebrospinal fluid leak.[10] Still, recent estimates indicate that 45% to 55% of individuals initially alive at the scene and triaged to a level I or II trauma center (the highest levels of trauma care) die after firearm-related pTBI secondary to interpersonal violence (homicide).[8,20]

Currently, there are very limited large-scale, national published studies on firearm-related TBIs and even fewer on firearm-related TBI homicides.[21] When available, recently published studies on firearm-related TBIs generally focus on firearm-related suicide, suicidality, and self-harm[22-26]; contain small sample sizes or present clinical case studies[7,27-31]; and/or examine a specific population (eg, patients seen in trauma centers).[8,20] Given the unique characteristics of firearm-related TBI homicides, greater understanding of the burden of this injury is warranted. Moreover, additional attention on these potentially preventable violent deaths may also prompt further public health response and expansion of research and effective medical interventions.[32] Thus, using a large, national data set, the aim of this study was to conduct an epidemiologic study to explore comparative incidence patterns of firearm-related TBI homicides in the United States between 2000 and 2019 by demographic characteristics (sex, age, race/ethnicity, and nonmetro/metro residence status) and examine temporal trends for sex and metro/nonmetro residence status.

METHODS

Comprehensive mortality data from 2000 to 2019 were obtained from the National Vital Statistics System using multiple cause of death records from Centers for Disease Control and Prevention's Wide-Ranging Online Data for Epidemiologic Research (WONDER) database[33] and were analyzed in 2021. National Vital Statistics System collects data for all deaths among US residents using a detailed methodology (https://www.cdc.gov/nchs/nvss/index.htm). This study was exempt from institutional review board review because of secondary data use.

Statistical Analysis

Number, age-adjusted rates per 100 000 population (calculated using the direct method adjusted to the 2000 US standard population), and percent (increases or decreases in percentage might vary because of rounding) of reported TBI homicides, defined as death secondary to interpersonal violence/assault, were calculated, stratified by firearm and nonfirearm. Firearm-related and nonfirearm-related TBI homicides were classified using codes from the *International Classification of Diseases, 10th revision* (ICD-10) using an established surveillance definition.[34-36] Homicides were identified with the following ICD-10 codes: X85-Y09, Y87.1, and U01-U02. To identify TBI-related deaths the following ICD-10 codes were used: S01.0–S01.9, S02.0, S02.1, S02.3, S02.7–S02.9, S04.0, S06.0–S06.9, S07.0, S07.1, S07.8, S07.9, S09.7–S09.9, T90.1, T90.2, T90.4, T90.5, T90.8, and T90.9. TBI homicides that did not involve firearms included those caused by a cut/pierce; drowning; fall; fire/flame; hot object/substance; other land transport; other transport; poisoning; struck by or against; suffocation; other specified classifiable injury; other specified, not elsewhere classified injury; and unspecified injury. Homicides were categorized as TBI-related if any of the multiple codes for causes of deaths recorded in the death record specified a TBI-related diagnosis, and the single underlying cause of death was recorded as an injury. Nonmetro was defined as micropolitan (nonmetro) and noncore (nonmetro). Metro was defined as large central metro, large fringe metro, medium metro, and small metro. The 2013 National Center for Health Statistics urban-rural 6 classification scheme for counties was collapsed from 6 to 2 categories to provide meaningful analysis. Racial/ethnic groups were classified as non-Hispanic White, non-Hispanic Black, non-Hispanic American Indian or Alaska Native, non-Hispanic Asian or Pacific Islander, and Hispanic. The results were stratified by year, sex, age group, race/ethnicity, and nonmetro/metro status. Numbers, rates, and 95% CIs were produced using Centers for Disease Control and Prevention Wide-Ranging Online Data for Epidemiologic Research. Differences in rates were considered statistically significant when confidence intervals were not overlapping. Temporal trends were evaluated by applying the Joinpoint regression program (version 4.7.0.0; National Cancer Institute) to the annual rates. Annual percent change estimates were calculated for each trend segment and were considered significantly different from 0 for P-values <.05. Changes (increase or decrease) in percentage are also reported and might vary because of rounding; these percentages were calculated using rates with 4 significant figures, whereas the data presented in this study are rounded to 1 significant figure.

RESULTS

During the study period (2000-2019), there were 355 297 homicides from all causes, and notably, 245 261 (69%) from firearm-related homicides involving injury to any body part (data not shown). Thirty-two percent of all homicides (113 656) during the study period were TBI-related. Of those, 68% (77 602) were specifically firearm-related TBI homicides. Men had higher age-adjusted rates of firearm-related and non-firearm–related TBI homicides (1.9 and 0.8, respectively) compared with women (0.7 and 0.4, respectively); 70% of men had a firearm-related TBI homicide compared with 63% of women (Table). Between 2000 and 2019, the highest percentages of firearm-related TBI homicides were among individuals aged 10 to 54 years (10-17: 88%; 18-34: 85%, 35-54: 63%). The rate of firearm-related TBI homicides among all racial/ethnic groups was greater than non–firearm-related TBI homicides with the exception of non-Hispanic American Indian or Alaska Natives. The highest percentage of firearm-related TBI homicides was among non-Hispanic Black persons (79%). Metro residents had a higher rate of firearm-related TBI homicides (1.3) compared with nonmetro residents (1.1). Conversely, the rate of nonfirearm-related TBI homicides was higher among nonmetro residents (0.7) compared with metro residents (0.6).

The rate of firearm-related TBI homicides per 100 000 population declined 3% from 2000 (1.4) to 2019 (1.3) while the rate of nonfirearm-related TBI homicides declined 40% (0.7-0.4). Between 2000 (0.7) and 2013 (0.6), there was a significant 19% decrease in the rate of firearm-related TBI homicides for women, followed by a significant 20% increase in the rate between 2013 and 2019 (0.7) (Figure 1). Among men, the rate of firearm-related TBI homicides decreased significantly by 21% from 2006 (2.1) to 2013 (1.7) and remained stable thereafter. For nonfirearm-related TBI homicides, the rate for men and women declined significantly 39% and 33% from 2000 (1.0 and 0.4, respectively) to 2019 (0.6 and 0.3, respectively). A similar pattern of firearm-related and nonfirearm-related TBI homicides was observed among nonmetro and metro residents (Figure 2). From 2000 to 2012, the rate of firearm-related TBI homicides among nonmetro residents decreased significantly by 21% (1.2-1.0) and then increased significantly by 39% between 2012 and 2019 (1.4). Among metro residents, there was a 22% significant decrease in the rate from 1.4 in 2006 to 1.1 in 2013 and then remained stable thereafter. Over the duration of the study period, the rates of nonfirearm-related TBI homicides significantly decreased 18% (0.7-0.6) for nonmetro residents and 41% (0.7-0.4) for metro residents.

DISCUSSION

This is the first study to provide national incidence estimates of firearm-related TBI homicides to our knowledge. The findings demonstrate that one-third of all homicides are associated with a TBI-relevant diagnosis. Of these, firearms were associated with the majority (68%) of TBI homicides in the United States over the past 2 decades underscoring the lethality of this mechanism of injury. Specifically, pTBI secondary to firearms has a higher mortality rate than a firearm injury to other regions of the body.[12] In addition, there is also a higher mortality rate when compared with other deadly weapons (eg, knives or bats).[37] This is due to the mid-to-high velocity of firearms, which when penetrating the skull, commonly leads to hemorrhage, further cerebrovascular injury, cerebrospinal fluid leak, and introduction of foreign material into brain, all of which contribute to a higher risk of morbidity and mortality as compared with those with non-pTBI or blunt TBI mechanisms.[16,17]

These epidemiologic data spanning 20 years in the United States demonstrated that men, young adults (aged 18-34 years), and non-Hispanic Black individuals had the highest rates of firearm-related TBI homicides. These findings are consistent with previous smaller reports.[4,38,39] Structural factors, such as where one lives, opportunities for employment, experience of poverty, and exposure to racism, likely contribute to these inequities that warrant further research.[40,41] Preventive strategies to reduce violence, including firearm homicides, include strengthening economic supports, promoting family environments that support healthy development, providing quality education early in life, strengthening young people's skills, connecting youth to caring adults, and creating protective environments.[42] In addition, when developing interventions, care should be taken to ensure efforts include a health equity framework.

Approximately 40% of all TBI deaths occur within the first 24 hours of injury,[43,44] and those secondary to firearm-related pTBI likely makeup a significant proportion of immediate deaths.[9] However, advances in the science directing treatment approaches to victims of pTBI, including those sustained by firearms, offer opportunity for improved outcome. Areas of current research include biomarker use in prognostication,[45-48] pathophysiologic processes associated with injury,[49,50] exploration of regenerative models and materials pertinent to pTBI,[51,52] and other strategies to prioritize injury and treatment including new guideline development.[10,29]

As many patients with firearm-related pTBI likely die on scene, multipronged prevention efforts may be most beneficial in affecting morbidity and mortality.[53-55] The results of this work may direct future research informing civilian-relevant prevention strategies based on trends of firearm and nonfirearm-related TBI homicides over time by sex and metro/nonmetro residence. For example, the overall rate of firearm-related TBI homicides among men was higher than women. However, there was a 21% decrease among this population between 2006 and 2013. This is consistent with the overall temporal pattern of male firearm homicides, which demonstrated a 16% reduction in the rate of male firearm homicides during this same period.[56] We also found that rates of firearm-related TBI homicides among women decreased between 2000 and 2013 and then increased between 2013 and 2019. Those decreases and increases could be the result of natural variation. However, the decrease seen between 2000 and 2013 may be due in part to a decrease in rates of intimate partner violence (IPV) perpetrated against women in the 1990s and 2000s.[57,58] Rates of IPV and rates of TBI homicide in women are likely closely tied. Among 40 states in the United States in 2018, more than one-third (34.9%) of homicides among women were IPV-related, and approximately two-thirds (63.7%) of IPV homicides among women were committed with firearms.[58] To our knowledge, there are no available estimates of the percentage of

TBI homicides among women that are IPV-related. However, because of the likelihood that female homicide victims are killed by their intimate partners, it is probable that many of the women in our study also had a history of IPV and potentially had previously sustained TBIs due to IPV. A previous study found that 75% of battered women sustained at least 1 IPV-related TBI, and 50% experienced multiple IPV-related TBIs.[59] Prevention strategies such as strengthening economic supports for families, creating protective environments, and supporting survivors to increase safety and lessen harms have been shown to prevent IPV or key risk factors for IPV.[60]

Although the overall rate of nonmetro firearm-related TBI homicides is lower than metro residents, this study also found that rates of firearm-related TBI homicides among nonmetro residents increased between 2012 and 2019. Public opinion research has demonstrated that rural residents are much more likely to report owning a firearm compared with both those who live in suburbs and in urban areas.[61] Previous research has found that rates of suicide and unintentional injury due to firearms is also higher in rural than urban areas.[62-64] However, more research is needed to determine why rates of firearm-related TBI homicides increased among individuals living in nonmetro areas during the study period.

It is unclear why these shifts in TBI homicides occurred for women and nonmetro residents, but they follow the same pattern as overall firearm-related homicides.[65] The rate of non–firearm-related TBI homicides declined by one-third over the past 2 decades. There was only a 3% decline in firearm-related TBI homicides during the same period, suggesting that greater efforts may be needed to stem firearm-related homicides, including those that are TBI-related.

Limitations

There were several limitations to our study. First, misclassification of race and ethnicity is a common problem on death certificates (eg, American Indian/Alaska Native, Asian/Pacific Islander, and Hispanic populations being misclassified as White non-Hispanic). Therefore, mortality estimates for specific groups may be underestimated or overestimated to a degree. Second, incomplete reporting or misclassification of cause of death on death certificates (eg, TBI was not explicitly documented) might underestimate firearm-related TBI deaths. For example, not all firearm-related homicides specify information about the site of injury; the death certificate might specify “GSW” or “multiple injuries due to gunshot wound” rather than “gunshot wound to the head,” which could lead to missed cases. Third, although this study was not able to examine structural factors that may predict firearm-related TBI deaths, it provides an epidemiologic foundation for a future study. Fourth, the homicide codes do not determine criminality, and a proportion of firearm homicides may be the result of self-defense not described in this data set.

CONCLUSION

This is the first study to provide national incidence estimates of firearm-related TBI homicides and demonstrated that firearms were associated with most TBI homicides (68%) during the study period. The findings may be used to inform future research surrounding treatment strategies as well as reducing firearm-related TBIs, especially among groups most affected (men, people living in metro areas, and non-Hispanic Black individuals) and groups with recent increasing rates over time (women and nonmetro residents). Furthermore, broader implementation of existing interventions that have been shown to be effective in reducing risk for firearm-related and nonfirearm-related violence may be beneficial.

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ABBREVIATIONS:

ICD-10	International Classification of Diseases, 10th revision
IPV	intimate partner violence
pTBI	penetrating TBI
TBI	traumatic brain injury

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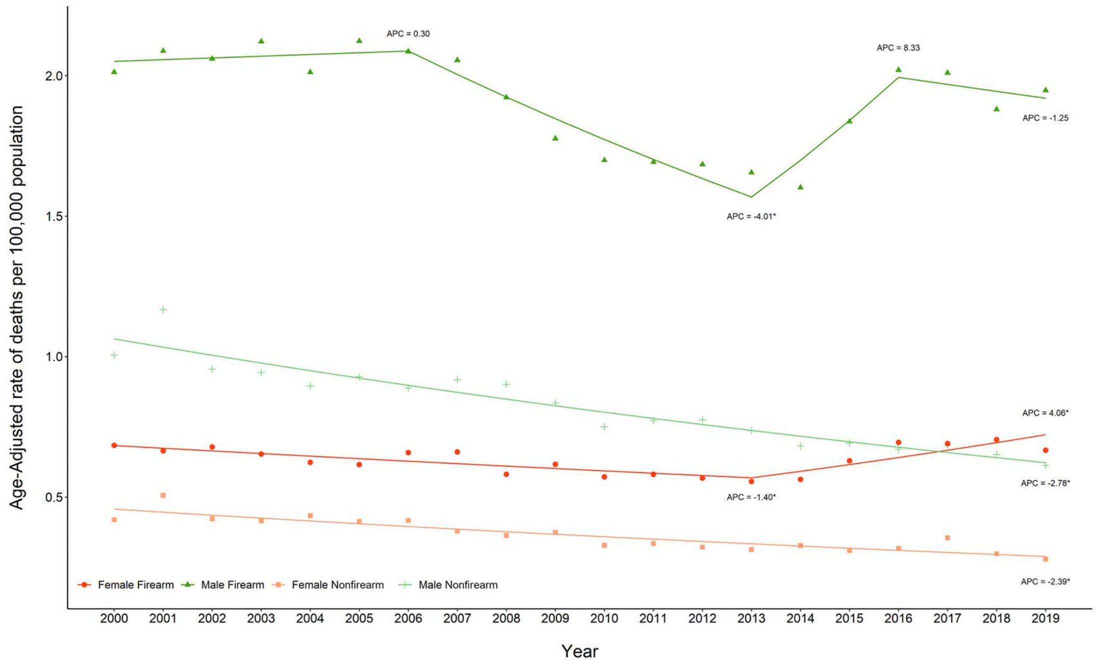

FIGURE 1. Traumatic brain injury related homicides, by year, sex, and firearm involvement—the United States, 2000 to 2019.

*Denotes a significant joinpoint, $p < 0.05$. APC = Annual percent change

NOTE: data source is CDC WONDER

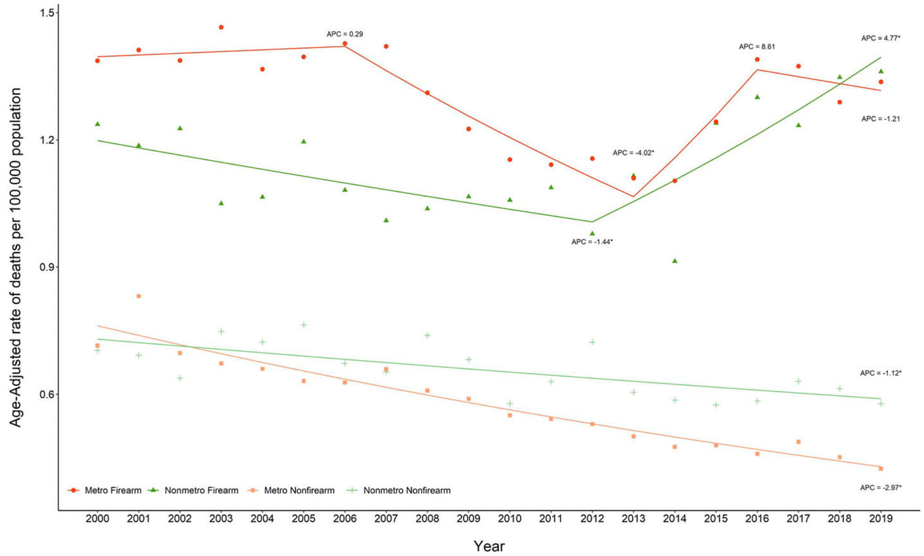

FIGURE 2. Traumatic brain injury related homicides, by year, metro/nonmetro residence, and firearm involvement—the United States, 2000 to 2019.

*Denotes a significant joinpoint, $p < 0.05$. APC = Annual percent change

NOTE: data source is CDC WONDER

TABLE.

Number[a], Age-Adjusted Rates[b], and Percent of Firearm-Related and Nonfirearm-Related TBI[c] homicides[d] by Demographic Characteristics—The United States, 2000 to 2019

	Firearm-related TBI homicides			Nonfirearm-related TBI homicides[e]			Percent of TBI homicides that are firearm-related
Variable	No.	Rate	95% CI	No.	Rate	95% CI	Percent, %
Sex							
Male	58 224	1.91	1.89-1.92	24 848	0.84	0.83-0.86	70.09
Female	19 378	0.66	0.65-0.67	11 206	0.36	0.35-0.36	63.36
Age group (y)[f]							
0-17	6790	0.46	0.45-0.47	7584	0.52	0.50–0.53	47.24
0-9	1430	0.18	0.17-0.19	6828	0.85	0.83-0.87	17.32
10-17	5360	0.8	0.78-0.82	756	0.11	0.10-0.12	87.64
18-34	42 712	2.98	2.95-3.01	7604	0.53	0.52-0.54	84.89
35-54	20 481	1.21	1.19-1.23	12 125	0.72	0.70-0.73	62.81
55-74	6103	0.53	0.51-0.54	6594	0.57	0.55-0.58	48.07
75+	1467	0.39	0.37-0.41	2090	0.55	0.53-0.58	41.24
Race/ethnicity							
Non-Hispanic White	24 741	0.63	0.62-0.64	18 006	0.46	0.46-0.47	57.88
Non-Hispanic Black	37 150	4.48	4.44-4.53	9843	1.28	1.25-1.30	79.05
Non-Hispanic American Indian or Alaska Native	787	1.50	1.39-1.61	985	1.93	1.81-2.06	44.41
Non-Hispanic Asian or Pacific Islander	1552	0.45	0.43-0.47	1007	0.33	0.31-0.35	60.64
Hispanic	13 034	1.21	1.19-1.23	5921	0.63	0.61-0.64	68.76
Nonmetro or metro residence[g]							
Nonmetro	9883	1.11	1.09-1.14	5845	0.67	0.65-0.69	62.84
Metro	67 719	1.30	1.29-1.31	30 209	0.58	0.57-0.58	69.15
Total	77 602	1.26	1.25-1.27	36 054	0.59	0.59-0.60	68.28

TBI, traumatic brain injury.

Centers for Disease Control and Prevention Wide-Ranging Online Data for Epidemiologic Research Multiple Cause of Death database.

[a] Records with missing age were excluded where appropriate (N = 42 for firearm-related TBI and N = 57 for nonfirearm-related TBI). Records with missing ethnicity were excluded where appropriate (N = 338 for firearm-related TBI and N = 292 for nonfirearm-related TBI). Numbers subject to rounding error.

[b] Age-adjusted rates per 100 000 population were calculated using the direct method and the 2000 US standard population.

[c] To identify TBI-related deaths, the following ICD-10 codes were used: S01.0–S01.9, S02.0, S02.1, S02.3, S02.7–S02.9, S04.0, S06.0–S06.9, S07.0, S07.1, S07.8, S07.9, S09.7–S09.9, T90.1, T90.2, T90.4, T90.5, T90.8, and T90.9.

[d] Homicides were identified with the following ICD-10 codes: X85-Y09, Y87.1, U01- U02.

[e] Includes cut/pierce, drowning, fall, fire/flame, hot object/substance, other land transport, other transport, poisoning, struck by or against, suffocation, other specified, classifiable injury, other specified, not elsewhere classified injury, and unspecified injury.

[f] Crude rate.

[g] Each death is associated with a category based on the county of the person’s legal residence. Nonmetro was defined as micropolitan (nonmetro) and noncore (nonmetro); where micropolitan (nonmetro) is part of a micropolitan statistical area (has an urban cluster of ≥10 000 but <50 000 population) and noncore (nonmetro) is not part of a metropolitan or micropolitan statistical area. Metro was defined as large central metro, large fringe metro, medium metro, and small metro, where large central metro is part of a metropolitan statistical area with ≥1 million population and includes a principal city; large fringe metro is part of a metro statistical area with ≥1 million population but does not include a principal city; medium metro is part of a metro statistical area with ≥250 000 but <1 million population; and small metro is part of a metro statistical area with <250 000 population.