Firearm injury research and epidemiology: A review of the data, their limitations, and how trauma centers can improve firearm injury research

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Trauma centers and surgeons manage the clinical care for injuries that are some of the leading causes of death in the United States including firearm injuries, which claimed the lives of 39,773 in 2017, more than falls and motor vehicle collisions.[1] Trauma centers treat approximately 70% of firearm injuries in the United States, but they comprise only 4.2% of injuries treated at trauma centers.[2,3] Unfortunately the in-hospital fatality rate is over three times higher than falls and motor vehicle collisions, and studies indicate that firearm case fatality rates have not significantly changed despite advances in trauma systems and care.[2–5] This is a problem unique to American society. Compared with other developed countries, the US firearm homicide and suicide rate is 25.2 and eight times higher, respectively, and there is a disproportionate burden of death on women, children and minorities.[6]

Despite this, research on firearm-related injuries and prevention efforts are limited. The American College of Surgeons Committee on Trauma (ACS-COT) has a clear position statement on firearm injuries, and advocates approaching firearm violence as a public health issue—joining other national organizations in the pursuit of decreasing firearm fatalities and injuries.[7–9] Trauma centers are at the epicenter of caring for victims of firearm injury and those with considerable risks for violence, and are uniquely situated to advance the research and prevention of firearm injuries. The purpose of this review is to provide an overview of what data and sources of information exist to inform our current understanding of firearm injury epidemiology, in addition to what limitations exist in the literature and how trauma centers can contribute to firearm injury research. This includes an extensive review of epidemiologic surveillance data, medical, and public health original research, and publically available data sets to answer questions regarding the incidence of firearm injuries, risk factors, outcomes and the mechanism itself.

FIREARM INJURY EPIDEMIOLOGY RESEARCH—A BRIEF HISTORY

Firearm injury research is shared by multiple disciplines since the complexity of firearm violence transcends many institutional silos, including those of medicine, public health, criminal justice, law, and the social sciences. The Centers for Disease Control (CDC) and National Institutes of Health, as well as many private organizations and individual researchers study the epidemiology and prevention of firearm injuries. However, injury prevention research is disproportionally underfunded compared to other leading causes of death.[10,11] Between 2004 and 2015, firearm violence received 1.6% of the funding and had 4.5% of the predicted volume of publications relative to the mortality rate.[11] Comparatively, annual firearm deaths are equivalent to deaths from sepsis but it is funded at a rate 0.7% of that of sepsis and has 4% of the publication volume.[11]

The disproportionate lack of firearm injury research is likely multi-factorial, but political opinion on this issue caused subsequent restrictions on CDC research and funding. In 1993, a CDC-funded, case-control study demonstrated that the presence of a firearm in the home increased the risk of firearm homicide, a finding some politicians viewed as promoting "gun control."[12,13] In response, the Dickey Amendment was passed, stating "no funds from the CDC and Prevention can be used to advocate for or promote gun control."[13] Subsequently, $2.6 million was removed from the National Center for Injury Prevention and Control budget—the exact amount appropriated the year prior for firearm injury research.[14] In 2011, the same language applied to the CDC was extended to all federal agencies including the National Institutes of Health.[15] Though the CDC has continued epidemiologic surveillance on firearm injury and death, the amendment significantly hampered the pursuit of federally funded firearm injury prevention research.[13]

An executive order by President Obama in 2013 directed the CDC to pursue research on firearm injury prevention.[16] Each year since the issuance of the executive order funding has been requested, but Congress has failed to appropriate funding. Despite limited federal funding, physicians and other researchers continue to study firearm violence and injury prevention. A variety of funding resources are available including the Department of Justice, nonprofit organizations and grants from local governments, but these funds remain limited leaving investigation of firearm injury significantly underfunded relative to the public health burden it conveys.

MAJOR SOURCES OF FIREARM INJURY DATA

Vital statistics are able to accurately measure firearm deaths. The CDC National Vital Statistics System (NVSS) provides surveillance of firearm mortality via the Web-based Injury Statistics Query and Reporting System (WISQARS) and the National Violent Death Reporting System (NVDRS), which has the most robust data on firearm fatalities.[17,18] It queries police reports, medical records, coroner reports, and other data to describe the circumstances surrounding firearm deaths such as preceding mental illness and life stressors in cases of suicide, and perpetrator relationships for homicides.[18] However, there is no dedicated firearm injury reporting system, and therefore no means to comprehensively collect or report nonfatal firearm injuries. The WISQARS includes data on nonfatal injuries deduced from probability estimates generated from approximately 100 hospitals.[17] The data for nonfatal firearm injuries is unreliable, with annual estimates between 2015 and 2016 dramatically increasing

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from 85,000 to 116,000.[1] This is not entirely understood, although the addition or removal of one or two high-volume trauma centers or small centers can dramatically change the estimates. Also, WISQARS does not capture firearm injuries that are cared for in all health care settings, nor does it include the same degree of descriptive data about risks and circumstances surrounding injuries that the NVDRS does. This information is vital when investigating means of injury prevention.

Data sets managed by the Agency for Healthcare Research and Quality that are part of the Healthcare Cost and Utilization Project (HCUP) utilize administrative coding data to report emergency department visits and hospitalizations for injuries including firearm injuries. They also utilize probability sampling, but the National Inpatient Sample (NIS) and Nationwide Emergency Department Sample (NEDS) include over 30 million hospital encounters, and are thus potentially better sources of injuries cared for in hospital settings.[19] Healthcare Cost and Utilization Project data are still subject to the flaws of using administrative coding, underrepresenting trauma centers to estimate injury incidence, and they do not capture detailed clinical data or circumstances surrounding injuries.

The National Trauma Data Bank (NTDB) is the most robust source of clinical information for firearm injuries.[20] Cases are queried by trained abstractors rather than relying on coding, and data suggest that HCUP data likely underreport the burden of injuries compared to estimates utilizing NTDB data.[21] However, the NTDB is limited by not including data from nontrauma centers, patients treated and discharged from the ED, and information regarding risks and circumstances preceding injuries.

The NTDB may play an important role in improving the quality of nonfatal firearm injury by addressing some of these limitations. Collecting information about the circumstances surrounding the injury and risk factors for injury, which is often performed in routine clinical care, can enhance our knowledge of nonfatal injuries and adjunct the strength of the NTDB to describe the clinical outcomes and resource utilization for such injuries. Despite this possibility, the expertise and time investment to collate these data sources has not been comprehensively undertaken.

These and other major epidemiologic, policy, and firearm data sources are described in Table 1. In addition to large surveillance data sets, retrospective and prospective data collected from medical records, patients, and high-risk communities through original research provide insight into the burden of disease, risk factors for experiencing injury from firearms, and how prevention and policy efforts impact firearm injury rates. Information collected from high-risk communities provides additional context to circumstances preceding firearm injuries as well as the social, health-related, economic, and behavioral impacts that occur from the injury. These data are crucial in identifying strategies to prevent firearm violence and are useful in assessing the outcomes of violence prevention and intervention programs.

An area of limited data related to firearm injury pertains to firearms themselves. Although federally licensed dealers are mandated to keep records of sales, there is no federal database accounting for firearm ownership in the United States. The National Instant Criminal Background Check System accounts for 60% to 80% of annual sales, but does not specify ownership.[25,31] Estimates of the number of civilian firearms in the United States come from sources, such as the Small Arms Survey and the National Firearms Survey, both of which likely significantly underestimate firearm ownership and are limited in accounting for illegal firearms.[26,32] The Bureau for Alcohol, Tobacco and Firearms (ATF) is responsible for oversight of firearm manufacturing and sales, in addition to preventing and investigating illegal firearm sales, use and trafficking.[25] The ATF data on firearms are often used for the prosecution of crimes and illegal gun sales. The public has limited access to such information, and the ATF is prohibited by Congress from maintaining an electronic record of firearm ownership in the United States, making query of the ATF data impossible for epidemiologic purposes.[25]

EPIDEMIOLOGY OF FIREARM ASSAULT AND HOMICIDE

Of the 39,773 firearm deaths in 2017, 14,542 (36.6%) were homicides, and 553 (1.4%) were legal interventions.[1] Due to limitations in nonfatal firearm injury surveillance, it is difficult to ascertain the annual incidence, which was approximately 75,000 to 80,000 in 2017 based on the HCUP data, but is likely higher due to undersampling from trauma centers and not accounting for injuries treated outside of hospitals.[19,21] Firearms overwhelmingly represent the most common mechanism for homicide, accounting for 74.5% of all homicides.[1] Most firearm homicides are isolated with single victims despite the attention paid to public "mass" shootings, which represent a small fraction of annual firearm homicides.[32] The majority of nonfatal firearm injuries are secondary to assault, representing 80% nonfatal firearm injuries in 2017.[1]

The firearm homicide rate peaked in 1992 at 6.8 per 100,000 individuals, then plateaued from 2010 to 2014 at 3.5[1] (Fig. 1). There has been an upward trend every year since, with an annual rate of 4.6 firearm homicides in 2017. It is important to note that the *nonfirearm* homicide rate has slowly *decreased* every year since 1999, making the impact of firearms on homicide greater in recent years.[1] Firearm homicides and assaults occur mostly among male youth and young adults, as 84% of firearm homicides are men, and the highest rates of death are between the ages of 15 to 34 years (Fig. 2). Blacks are disproportionately impacted by firearm assault, with 58% of all homicides being among blacks at rate of 17.7—over nine times higher than the white population. Although black females are more likely than other races to be killed with a firearm, young, black males face tremendous disparity. Between the ages of 20 years to 24 years, the firearm homicide rate among black men is 90, compared with 18.3 among Hispanics and 7.7 among whites (Fig. 2). It is hard to imagine a disease entity that has such glaring disparities.

The complexity of firearm violence and limited research make it difficult to determine what contributes to the fluctuations in firearm assault and homicide rates, although many theorize the burden of gang and drug-related violence in the 1990s fueled community and interpersonal violence in mainly urban areas that disproportionally impacted young, minority males. The decline of firearm assaults in the mid to late 1990s corresponded with increased policing and prosecution efforts in addition to stricter penalties for firearm-related crimes.[33] There is limited

TABLE 1. Major Sources of Firearm Injury and Epidemiology Data

Data Source	Agency	Access	Description of Data, Variables, Sources and Limitations
Vital Statistics and Surveillance Data			
NVDRS	CDC, NVSS	https://www.cdc.gov/violenceprevention/nvdrs/	NVDRS is a state-based surveillance reporting system that compiles data from multiple sources on all deaths from violence including homicides, suicides, legal interventions and acts of terrorism. It began in 2003 with just six states and has received funding to include all states. It compiles data from hospital records, death certificates, coroner, medical examiner and police reports. Over 100 variables are collected such as pre-existing mental health and substance abuse, prior suicide threats or major life stressors, the mechanism or weapon, and relationship of the perpetrator in cases of homicide. The CDC releases updated reports regularly from NVDRS data. It is robust but limited by a large number of missing variables, not all states are currently available, there is generally a 2-year delay in reports, and there is no clinical data for injuries preceding death.[18]
WISQARS	CDC, Injury Prevention and Control	https://www.cdc.gov/injury/wisqars/index.html	WISQARS is a national surveillance reporting system that compiles data on all fatal and nonfatal injuries and associated costs. The data are collated from other primary sources (NVDRS, NVSS, NEISS) with applied estimates of cost based on 2010 data. The system is an open, online platform that allows individuals to search and generate reports based on the type of injury (unintentional vs. intentional), mechanism, body region, and victim demographics. The CDC releases updated reports with comparative analysis and trends regularly based on the data. It does not include detailed data on circumstances surrounding firearm injuries, and likely significantly underestimates the number of annual firearm injuries as not all clinical encounters are captured nor are injuries that do not get medical attention.[17]
National Electronic Injury Surveillance System (NEISS)	US Consumer Product Safety Commission	https://www.cpsc.gov/Research–Statistics/NEISS-Injury-Data	NEISS is a national probability sample of U.S. hospital emergency room visits associated with an injury from a consumer product. It collects basic demographics, anatomic location of the sustained injury, injury characteristics and patient disposition from the hospital records. The NEISS does not collect data from every US hospital or acute visits occurring outside emergency departments; it uses probability sampling to estimate the prevalence and rates of injuries from only approximately 100 hospitals. It does not collect data from sources outside the medical record to report on circumstances preceding injury.[22]
NTDB	American College of Surgeons	https://www.facs.org/quality-programs/trauma/ntdb	The NTDB is a centralized database of traumatic injuries from participating trauma centers. It provides a robust source of data including demographics, mechanism of injury, characteristics of the injuries and associated medical problems, comorbid disease, interventions, payer sources, hospitalization characteristics, clinical outcomes and disposition data for patients admitted with injuries. It perhaps provides the most robust clinical information about firearm injuries themselves, but the data is limited to those who are evaluated at participating trauma centers and does not capture most patients treated and discharged from the ED. While the clinical information is detailed, there is little data collected on the circumstances surrounding firearm injuries.[20]
HCUP	Agency of Healthcare Research and Quality	https://www.hcup-us.ahrq.gov	HCUP consists of a number of databases including the NIS, the NEDS, and the Kid's Inpatient Database (KID). They collect data on hospitalizations and ED visits that include demographic data, detailed hospitalization characteristics and associated costs for major diagnosis and external cause of injury codes including firearm injuries. NEDS and the NIS include over 7 million annual ED visits and hospitalizations (30 million weighted) that are used to generate national estimates. They contain a number of valuable data elements including costs that have helped quantify the financial impact of firearm-related hospitalizations, but are limited in contextualizing the nature of firearm injuries, their surrounding circumstances and are limited by the accuracy of diagnostic codes and number of participating institutions.[19]

Continued next page

TABLE 1. *(Continued)*

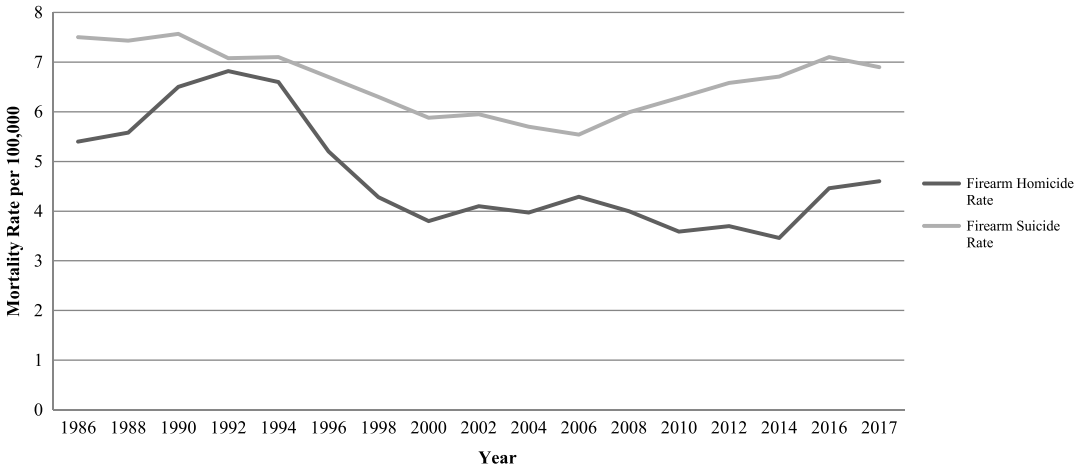
Data Source	Agency	Access	Description of Data, Variables, Sources and Limitations
Firearm-Related Crime, Sales, and Trafficking Data			
N/A	Federal Bureau of Investigation (FBI)	https://www.fbi.gov/file-repository/nics_firearm_checks_-_month_year.pdf/view	The FBI publishes annual data on firearm-related offenses including homicides, assaults and robberies in addition to mass shootings, and data from the National Instant Criminal Background Check System, which reports on the number of individuals that undergo and pass background checks. These data cannot be linked to specific cases of firearm deaths or injuries, but are helpful in assessing local trends in legal firearm purchases and firearm-related crimes.[23,24]
N/A	ATF	https://www.atf.gov/firearms	The ATF is a federal agency that oversees the inspection of federally approved firearm dealers, and is responsible for tracing firearms to help prosecute criminals and fight firearm trafficking. It reports data on firearm manufacturing and trade, and illegal firearm trafficking. Although ATF data could be very helpful in understanding where and how individuals acquire firearms used in assaults and suicides, and changes in illegal firearm sales after firearm legislation is implemented, most of the detailed information is not linked to specific cases of violence or made available for research purposes.[25]
N/A	Small Arms Survey	http://www.smallarmssurvey.org	The Small Arms Survey is an international agency that studies armed violence, firearm trafficking, firearm policy, and the economic and social impacts of firearm violence. It generates reports and analysis for multiple countries and regions, including the U.S. The data on firearm holdings in the US civilian population and firearm trades are limited by the inability to trace illegal firearm purchases and ownership.[25]
Nonprofit Firearm Research Agencies			
N/A	Everytown for Gun Safety	https://everytown.org	These nonprofit agencies assimilate data from original research and surveillance data to compile and disseminate reports on firearm injuries and deaths in addition to performing original research using surveillance data on subjects related to policy, mass shootings, and violence prevention programs. They all have up-to-date and thorough information on state-level firearm safety legislative efforts, and have scoring or ranking systems that determine the strength of states' firearm laws, which are frequently used in quasi-experimental studies. It is important to note that these agencies participate in many political advocacy efforts, but they do report firearm-related data useful for assessing epidemiologic trends associated with firearm legislation and public health efforts.[26–29]
N/A	Brady Campaign to Prevent Gun Violence	http://www.bradycampaign.org	
N/A	Giffords Law Center	http://lawcenter.giffords.org	
N/A	Gun Violence Archive	http://www.gunviolencearchive.org	The Gun Violence Archive is a unique source of up-to-date and real time firearm incidents collected through the media and police reports. It describes incidents (where the shootings occur, perpetrator, number of victims), aggregates them into regional areas and can be used to assess real-time trends. However, not all shootings are captured and incident data from both preliminary police reports and media sources may be subject to nonverified information. It also primarily includes assaults with limited information on cases of suicide.[30]

understanding about the recent increase in firearm homicides since 2014, although there appears to be an increasing rate of death among black males—32.6 in 2017 compared with 26 in 1999, while rates among white men have been relatively stable.[1] Some of the complex socioeconomic and community factors described below disproportionally impact young, black males but understanding what is influencing this recent upward trend will require further research.

Although mass shootings and active shooter incidents gain a great deal of media attention and have been increasing in recent years, they are not universally defined, and are not well studied or understood.[34,35] In addition, most are not random—the majority of mass shootings occur in the setting of family violence.[34] Using an inclusive definition of four or more individuals shot in any setting including gang and intimate partner violence (IPV), the Gun Violence Archive cites an increasing trend of mass shootings incidents with 346 in 2017 that resulted in 437 deaths and 1,803 nonfatal injuries.[29] The United States has the second highest rate of mass shootings in the world, and of 171 countries, the United States represents only 5% of the population but has 31% of the mass shootings.[36]

Risks Associated With Firearm Assault and Homicide Victimization

In addition to male sex, young age, and black race, there are many modifiable risks associated with firearm assaults (Table 2). Among teens and young adults, a previous assault-related injury increases the odds of experiencing a future firearm assault and death by homicide.[42–44] Witnessing or knowing a victim of a firearm assault, retaliatory views for violence, a history of



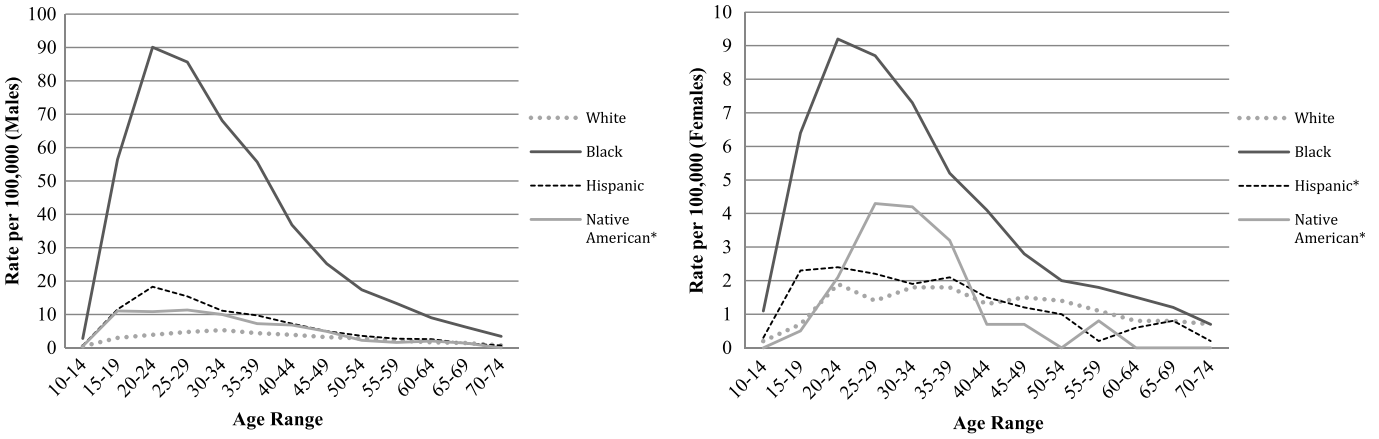
Source: Centers for Disease Control and Prevention, WISQARS Fatal Injury Reports, 1981-2017.

Figure 1. U.S. firearm homicide and suicide mortality rates, 1986–2017.

involvement in the juvenile criminal justice system, involvement in gangs, and illegal gun carrying all increase the risk of firearm injury.[37,40] Having personal contact within several degrees of separation of either a perpetrator or victim of firearm violence increases risk of becoming a victim, indicating that certain social networks impart increased risk.[37,40] Depression, post traumatic stress disorder (PTSD), and substance abuse disorders are associated with victimization.[37,42] Firearm access in the home independently increases the risk of firearm homicide in the home, with a meta-analysis finding that it increases the odds of homicide by 2.[41] While the causality of this has not been established, it is theorized that individuals are at higher risk of injury or death in the setting of interpersonal or family violence when there is a firearm in the home due to easy access of highly lethal means. Firearm ownership and carrying for defensive purposes can be secondary to experiencing and engaging in violence, increasing the risk of both perpetration and victimization.

In regard to community risk factors, urban areas have higher rates of firearm assault and typically have concentrated neighborhood "hot spots" of firearm violence.[38–40,51] Regardless of urbanization, higher rates of firearm assault and injury recidivism are associated with economic depression and inequality, high unemployment, higher proportions of minority residents, high rates of community firearm ownership, and single-parent households.[38,39,45,50,51] Economic and social policies that aim to reduce income inequality and improve employment, in addition to violence interruption and intervention programs may mitigate these modifiable risk factors; however, further study is needed to understand best practices for program implementation and policy outcomes.

While many of these factors impart a risk of community violence among male victims, IPV accounts for the majority of female firearm assaults.[46] Fifty percent to 60% of female homicides are committed by current or former intimate partners, and half are committed with firearms.[47] Women are 3.6 times more likely to be shot by an intimate partner compared with men, and the presence of a firearm in a home in the setting of abuse increases a woman's risk of death by 500%.[48,49] Firearm injuries are 10 times more lethal when committed by an intimate partner, and in the setting of nonfatal acts of IPV, perpetrator access to



Source: Centers for Disease Control and Prevention, WISQARS Fatal Injury Reports, 1981-2017.
*Low number of deaths in most age groups resulting in unreliable rates

Figure 2. Rate of firearm homicide for males and females by age and race, 2017.

TABLE 2. Major Contributors and Risk Factors for Firearm Homicide and Suicide

	Personal	Interpersonal	Community	Policy*
Assault and Homicide	• Male[1] • Black, Hispanic race/ethnicity[1,37–39] • Ages 15–34[1] • Involvement with juvenile criminal system[40] • Access to firearms[12,41] • Retaliation beliefs[37,42] • Illegal gun carrying[37] • PTSD[37,42] • Alcohol and illicit substance abuse[37,40,42]	• Previous assault (victim or perpetrator)[37,40,42–44] • Gang affiliations[40] • IPV[45–49] • Single parent households (adolescents)[39] • Knowing victims or perpetrators of firearm violence[40]	• High rates of concentrated community violent crime[38,39,50] • Urban areas[51] • Poverty[38,39] • High unemployment[39] • High firearm ownership in the community[45]	• Residing in states with *less* restrictive firearm laws such as[52–56]: • Universal background checks • Waiting periods • Permit-to-purchase • Strict penalties of firearm crimes • Restriction of firearms for IPV perpetration • Stand-your-ground laws[57]
Suicide	• Male[1] • White, Native American[1] • Access to firearms[41,58–60] • Storing firearms loaded, unlocked[61] • Depression, PTSD[18,62,63] • Veteran or active military[64,65] • Alcohol abuse[66]	• Loss of job, economic distress[63,67] • Interpersonal, relationship stressors[63,67]	• Rural areas[68] • High unemployment[68] • Publicized suicides in community (contagion effect)[69]	• Residing in states with *less* restrictive firearm laws such as[52,55,56,70]: • Universal background checks • Waiting periods • Permit-to-purchase • Child access laws

*Definitions of included policies: *Universal background checks* encompass background checks for *all* firearm sales or exchanges, not just sales from federally licensed dealers that are mandated to perform background checks under federal law. *Waiting periods* involve a mandatory period of time between applying to purchase a firearm and receiving the firearm. There is variability in the period from state to state, but most evidence favors a 30-day waiting period. *Permit-to-purchase* typically includes passing a mandatory background check for all firearm purchases, but states frequently have additional permit requirement such as mandatory firearm training, application and registration of the firerm with local authorities, and renewal of the permit after a specified period of time. *Strict penalties* of firearm crimes can encompass a number of prosecutorial efforts, but there is evidence that imposing mandatory minimum sentences for violent offenses involving firearms may reduce firearm assaults. *Restriction of firearms for IPV perpetration* includes not only prohibiting misdemeanor or felony offenders of IPV perpetration from purchasing firearms, but also taking currently owned firearms away from perpetrators who have domestic violence protective orders against them or are convicted of IPV-related offenses. *Stand-your-ground laws* allow for individual to use firearms to protect or defend themselves when under perceived and real threats, and data suggest are associated with increased firearm assaults and homicides. *Child access laws* vary by state, but impose criminal liability on adults for negligent storage of firearms in the event of a child gaining access to the firearm.

firearms is associated with increased severity of violence and threats with firearms.[48,49] Understanding how physicians can effectively screen for and mitigate the duplicative risks of IPV and firearms is poorly understood and represents an area of much-needed study.

IPV also increases the risk of firearm homicides in pediatric patients, notably in children younger than 12 years. Children ages 13 years to 17 years are more likely to be killed by an acquaintance or known perpetrator in the same age group, and these deaths are more likely to be associated with gangs, drug activity, and weapon carrying.[71] However, children younger than 12 years are more likely to be killed by an adult in the home compared with older children (85% vs. 39%)—most often in the setting of intimate partner and family violence incidents.[71] Children account for 45% of fatalities in domestic mass shootings but only 10% of public mass shootings.[34]

There are notable geographic and regional differences in firearm mortality rates, with significant variability between states. Firearm homicide rates are generally the highest in the Southeast; Louisiana has highest rate (11.7) followed by the District of Columbia (11.6), Alabama (10.9), Mississippi (10.4), and Missouri (9.7).[72] Certain risk factors, such as high rates of firearm ownership, density of gangs, economic, and employment disparities, may influence regional differences in incidence of firearm assaults and death. Data increasingly suggest that local firearm laws and legislation also influence the epidemiology of firearm deaths. Studies have shown that legislative efforts that aim to limit firearm access to high-risk individuals are associated with lower rates of firearm homicide. Universal background checks for all firearm purchases and restrictive licensing, mandatory waiting periods for purchases, stricter penalties for firearm-related crimes, and restriction or removal of firearms from offenders of IPV have resulted in lower firearm homicide rates.[52–56] In limited investigation, stand-your-ground laws have *increased* rates of firearm-related homicide, disproportionately impacting young and minority men.[57] Many of these studies that assess the impact of firearm legislation are quasi-experimental in nature and rely on nonvalidated ranking systems to determine the strength of state laws, but some effectively study individual legislative changes while controlling for confounders with similar findings.

Risks Associated With Firearm Assault Perpetration

Similar to risks associated with victimization, male sex, illegal firearm carrying, retaliatory attitudes, and perpetration of IPV are risk factors for committing firearm violence.[37,40,42–44] Alcohol abuse increases the risk of carrying firearms during interpersonal conflicts and increases the risk of perpetrating lethal violence.[73–75]

Mental illness is often cited in the press as a risk factor for committing firearm assault and homicide, but there is little data to suggest that mental illness alone increases the risk of perpetration. One study identified a 4% attributable risk of mental illness to violence perpetration, and the highest risk factors for violence were similar to the general population—young age, male sex, lower socioeconomic status, and alcohol or illicit substance abuse.[76] Those with serious mental illness who lack histories

of violence victimization, neighborhood violence exposure, or substance abuse have annual rates of violent behavior similar to the general population at 2%.[77] Contrary to what is often portrayed in the media, perpetration of firearm violence, especially against strangers, is exceedingly low among individuals with severe mental illness who were previously hospitalized.[78] Mental illness is often thought to be a risk factor in mass shooting perpetration, but there is little understood or studied about perpetrators of random mass shootings.[79]

FIREARM SUICIDE

Sixty percent of firearm deaths in 2017 were due to suicide (23,854), and firearms represent the most common mechanism for suicide (50.6%).[1] Firearm suicides have been increasing in recent years with a rate of 5.5 per 100,000 in 2006 compared with 6.9 in 2017.[1] Contrary to firearm homicides, non-Hispanic whites have the highest rate of firearm suicide at 9.1 per 100,000 and rates are highest in older age groups[1] (Fig. 3). Among women, white women have the highest rates of firearm suicide at all ages compared with other races and it peaks in the 50-year to 54-year age group.

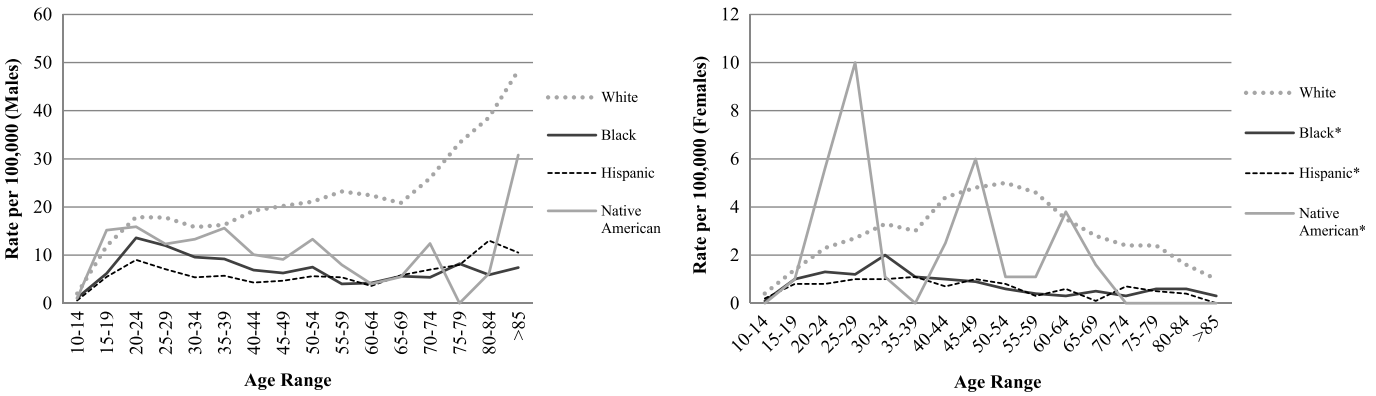
Risk Factors for Firearm Suicide

There are a number of potentially modifiable risk factors for firearm suicide, and other identifiable factors can help specify high-risk populations.[58–60,62,64–66,80–82] Nearly half of adults that commit suicide have a diagnosis of mental illness in the year preceding their suicide, and 30% are in active treatment at the time of their suicide.[18] Individuals with mental illness do not have a higher rate of firearm ownership compared to those without a mental illness, but access to a firearm in the setting of preexisting mental illness significantly increases the risk of suicide for both adults and adolescents.[58–60,62] However, recent NVDRS data revealed that 54% of those who committed suicide *did not* have a known mental illness, and these individuals were more likely to use a firearm compared with those with a known mental illness (55% vs. 41%).[63] Because the NVDRS captures some of the preceding circumstances to suicides, we know that relationship problems, a recent or upcoming personal "crisis" and employment or financial problems are common in such cases.[18,63] In addition, alcohol abuse and acute intoxication increase the risk of suicide, and a prior history of excessive consumption and alcohol-related hospitalization significantly increase the odds of suicide by firearm compared with other means.[18,66] Having access to a highly lethal means of suicide in the setting of acute life stressors and intoxication, even without prior suicidal ideation may explain the increased risk of impulsivity and suicide by firearm in such individuals.

In addition to those with mental illnesses, a high-risk population for suicide includes active and former military personnel.[18,64,65] Seventeen percent of suicide victims in 2014 were identified as veterans, and military members are more likely to commit suicide with a firearm compared with civilians.[17,64] There is an amplified risk among those with depression, PTSD, and those who used firearms as a part of their duty.[65] While firearm access may be higher among service members, the stress of deployment, return to civilian life, family separation, and increased rates of PTSD and alcohol abuse among military members are theorized to contribute to higher rates of firearm suicide.

Those who commit suicide with firearms are less likely to have a prior suicide attempt compared with those who die by other means (12% vs. 28.6%).[63] Most individuals who attempt but do not complete a suicide attempt will not go on to make another attempt.[67,83] This reflects the high lethality of firearms when used for suicide and debunks the common adage that individuals will "find another way." For suicide attempts, the mechanism certainly matters given 85% of adult and 74% of pediatric firearm suicide attempts result in death.[83] A meta-analysis demonstrated that a firearm in the home increased the odds of suicide by 3.24, although there is evidence that safe storage practices may reduce the risk for pediatric suicides and accidental shootings.[41,53]

Similar to firearm assault and homicide, higher suicide rates tend to be in areas with greater economic distress and unemployment, and suicides among teens and young adults may occur in social or geographic clusters as a "contagion effect."[68,69] Although much of the focus of firearm fatality occurs in the urban setting, rural areas have high firearm suicide rates, which contribute to higher overall firearm fatality rates. The Rocky Mountain states, including Montana, Wyoming, and Idaho, in addition to Alaska, have the highest firearm suicide rates in the United States.[72] State-level firearm legislation also influences firearm suicide rates: universal background checks with restrictive



Source: Centers for Disease Control and Prevention, WISQARS Fatal Injury Reports, 1981-2017.
*Low number of deaths in most age groups resulting in unreliable rates

Figure 3. Rate of firearm suicide for males and females by age and race, 2017.

licensing, mandatory waiting periods, and strong child access laws are associated with lower rates of firearm suicide.[52,55,56] Understanding these risk factors for firearm suicide is key to developing strategies to identify individuals at high-risk and to mitigate risks with mental health support, substance abuse treatment, safe firearm storage, and means reduction legislation.

IMPACT OF FIREARM INJURIES ON THE PATIENT, HEALTH CARE SYSTEM, AND SOCIETY

Multiple recent studies have attempted to estimate costs associated with firearm injuries. Variable findings illuminate the challenges and limitations in extrapolating costs from current data sources. Peek Asa et al.[84] estimated the annual cost of 30,617 annual firearm injury admissions to be US $622 million, and another study estimated the annual costs from both admissions and readmissions to be US $791 million.[84,86] The leading payers in both studies were Medicaid and Medicare (36–40%) followed by self-pay (25–27%), reflecting the disproportionate burden of firearm injury medical costs on tax payers and the uninsured. Given that many patients are treated in the emergency department and are not admitted, a recently published study might have a more accurate annual estimate: US $2.8 billion including costs from emergency department visits and hospitalizations.[85] None of these studies capture costs from urgent care facilities, long-term care facilities, physical therapy, outpatient visits and other forms of ongoing care. In an attempt to do this, Fowler et al.[83] estimated the annual total medical costs and productivity losses due to firearms at US $48 billion. Another study estimated the annual *societal* costs due to firearm injury and fatality to be US $174 billion based on 2010 data.[87] This includes cost estimates incurred from medical treatment, economic and employment losses, the criminal justice system, social and mental health services. The medical costs and resource utilization for firearm injuries are important areas for ongoing investigation because they have the potential to help convey the economic and social burden of this problem.

Perhaps one of the most poorly understood outcomes of firearm injuries is the long-term medical, social and financial impact on *victims*. Such outcomes likely widely vary depending on the nature and severity of the injury and disability. For instance, there is significantly reduced life expectancy, high morbidity, poor quality of life, and low return to meaningful education or work activities from firearm injuries that result in spinal cord paralysis.[88] Victims of firearm injuries are significantly more likely to suffer from PTSD and substance abuse and are more likely to suffer from further injury or death from assault.[42,89] There is little known about the long-term disabilities, medical problems, and emotional and financial impact on both victims and caregivers, and trauma providers are uniquely positioned to assess these outcomes.

FIREARM OWNERSHIP IN THE UNITED STATES

We cannot review the burden of firearm injury without specifically discussing the mechanism itself as data suggest that access to firearms increases the risk of injury. The United States has the highest rate of civilian firearm ownership in the world, estimated at 390 million firearms, or 120 firearms per 100 persons.[26] Household firearm ownership has decreased in recent years to 33%, but 65% of these households own more than one firearm.[32] Fourteen percent of all firearm owners own 50% of the civilian gunstock in the United States.[32] The most common types of owned firearms are handguns and pistols, followed by long guns such as rifles and shotguns.[32] Reasons for ownership vary, although the most common cited reason for ownership of handguns is self-defense. Handguns, being the most commonly owned firearm, are implicated in 80% of firearm-related offenses and over 70% of firearm injuries and deaths.[90] A significant amount of attention surrounds automatic and semiautomatic firearms with large ammunition capacities and firearms with military style features. They make up a smaller portion of the firearms owned by civilians but account for 7% of firearms used in crimes and cause higher rates of injury and death when used in active shooter incidents compared with other types of firearms.[91,92] Twenty percent to 30% of households with firearms keep them loaded and unlocked, and an estimated 7 million children live in such homes.[93,94] Safe storage practices can help mitigate risk of suicide and accidental shootings, and interventions that promote safe handling and storage warrant more investigation.[61,95]

An understanding of how and where at-risk individuals acquire firearms remains limited. The absence of a central database for firearm ownership, the 20% to 40% of firearms purchased without background checks, and the estimated 380,000 firearms stolen annually all create circumstances that challenge our ability to understand the acquisition of illegal firearms and high-risk ownership.[31,96,97] Other factors include the difficulty of tracing firearms linked to death and injury and the lack of investigation in the medical and public health literature on victims' acquisition and relationship with firearms. Investigation with patients and their families about firearm access and ownership, along with the linkage of law enforcement data to individual cases of firearm injury could help us understand how and why firearms are obtained, and storage practices for those at risk for violent perpetration, assault, suicide and accidental injury.

DISCUSSION

Although firearm research has been limited relative to its burden of disease, the data outlined here provide a foundation of understanding the extent of the problem and the questions that remain unanswered. The rates of firearm homicide and suicide are increasing, and while surveillance mechanisms are in place for firearm fatalities, there are major deficits in reliably understanding the incidence and context of nonfatal firearm injuries, their impact on patients, families, and the health care system. The trauma community must identify ways it can contribute understanding to the epidemiology of firearm injuries to better inform the design, implementation, and assessment of policies and intervention programs.

One of the ways to improve the understanding of firearm injury is to improve the quality of surveillance and data for nonfatal firearm injuries. The NTDB is a robust registry that could be used in combination with nontrauma center and ED data to better estimate the number of annual nonfatal firearm injuries. In addition, one of the major limitations of WISQARS is that it lacks risk and incident details preceding injuries that could better characterize nonfatal firearm injuries—a gap that the

TABLE 3. Potential Data Collection Elements to Improve Understanding of Firearm Injuries in Trauma Centers

	Circumstances	Risk Factors	Interventions Provided
Firearm assaults	Relationship to perpetrator Context of assault (argument, IPV, gang, bystander, etc.) Prior threats by perpetrator Physical setting of assault (home, public, work, etc.) Location of assault Type of firearm used	Prior violent injuries Past exposure to violence Prior incarceration Firearm access Gang involvement Substance Abuse Acute intoxication Mental illness Dementia	Safety assessment Ancillary support (psychology, psychiatry, social work, child protective services, etc.) Violence intervention specific services (hospital based violence intervention programs, high-risk adolescent support, gang intervention, IPV support referrals)
Suicide attempts	Contemplation vs. impulsive Prior threats of self-harm Precipitating events (declining mental illness, life stressor, major medical illness, etc.) Physical setting of attempt (home, public, work, etc.) Location of attempt Type of firearm used Who owned the firearm Family/friend/partner knowledge of suicidal ideation	Prior attempts Mental illness Dementia Substance abuse Acute intoxication Receipt of prior mental health services Firearm ownership and access Firearm storage	Safety assessment Firearm access reduction Safe storage counseling Ancillary support (psychology, psychiatry, social work, etc.)
Nonintentional injuries	Handler of firearm (self vs. another, and their relationship) Who owned firearm Context of injury (cleaning gun, hunting, playing with gun, etc.) Type of firearm Physical setting (home, public, work, etc.) Location of injury	Prior injuries Firearm ownership and access Firearm storage Substance abuse Acute intoxication Dementia	Safety assessment Safe handling and storage counseling Ancillary support (psychology, psychiatry, social work, etc.)

trauma community is in an opportune position to fill and report (Table 3). Studying risks and circumstances surrounding injury and what practices are used to mitigate them could significantly enhance the understanding and context of firearm injuries, especially among high-risk communities and populations including patients with mental illness, victims of IPV, veterans, and young minority males. Such data can be used at the local level to assess trends in firearm epidemiology and risk factors, and their association to community factors, such as unemployment, poverty, crime, firearm thefts, firearm legislation, firearm safety and education storage efforts, and both hospital-based and community violence intervention efforts. While it may not be feasible to expand data collection to all trauma centers, multicenter trials could be used to collect enhanced nonfatal firearm injury data for the purposes of better characterizing firearm injuries and determining the feasibility of expanding such efforts.

Another major gap in the literature is the long-term impact and cost of firearm injuries. We are in the position to prospectively assess long-term physical, mental, social, and economic impacts of firearm injuries among our patients and their caregivers. Firearm recidivism, justice system interaction, and changes in perceptions of firearms and firearm ownership after injury can also be examined. In addition, exploration into motivations, beliefs, acquisition, ownership, storage strategies, and other risk reduction methods for high-risk firearm access among our patients is also important, as these present major gaps in knowledge and present opportunities for intervention.

The ACS-COT and trauma community are in positions to enhance the body of knowledge regarding firearm injuries. This is not only necessary to understand the epidemiologic burden of injury and clinical outcomes, but to also inform the development, implementation and evaluation of firearm injury prevention strategies.

AUTHORSHIP

A.H. performed the literature review, interpretation of findings, and article preparation. S.B. and M.L. assisted with literature review, interpretation of findings and article editing. D.K., L.A., P.B., J.S., E.B., and R.S. assisted with interpretation of findings. All authors assisted with synthesis and critique of the review.

DISCLOSURE

On behalf of the American College of Surgeons Committee on Trauma, we have no conflicts of interest, disclosures, or sources of funding for the submitted work. It has not been presented at any conferences or meetings.

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