SPECIAL ARTICLE

Handgun Ownership and Suicide in California

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ABSTRACT

BACKGROUND

Research has consistently identified firearm availability as a risk factor for suicide. However, existing studies are relatively small in scale, estimates vary widely, and no study appears to have tracked risks from commencement of firearm ownership.

METHODS

We identified handgun acquisitions and deaths in a cohort of 26.3 million male and female residents of California, 21 years old or older, who had not previously acquired handguns. Cohort members were followed for up to 12 years 2 months (from October 18, 2004, to December 31, 2016). We used survival analysis to estimate the relationship between handgun ownership and both all-cause mortality and suicide (by firearm and by other methods) among men and women. The analysis allowed the baseline hazard to vary according to neighborhood and was adjusted for age, race and ethnic group, and ownership of long guns (i.e., rifles or shotguns).

RESULTS

A total of 676,425 cohort members acquired one or more handguns, and 1,457,981 died; 17,894 died by suicide, of which 6691 were suicides by firearm. Rates of suicide by any method were higher among handgun owners, with an adjusted hazard ratio of 3.34 for all male owners as compared with male nonowners (95% confidence interval [CI], 3.13 to 3.56) and 7.16 for female owners as compared with female nonowners (95% CI, 6.22 to 8.24). These rates were driven by much higher rates of suicide by firearm among both male and female handgun owners, with a hazard ratio of 7.82 for men (95% CI, 7.26 to 8.43) and 35.15 for women (95% CI, 29.56 to 41.79). Handgun owners did not have higher rates of suicide by other methods or higher all-cause mortality. The risk of suicide by firearm among handgun owners peaked immediately after the first acquisition, but 52% of all suicides by firearm among handgun owners occurred more than 1 year after acquisition.

CONCLUSIONS

Handgun ownership is associated with a greatly elevated and enduring risk of suicide by firearm. (Funded by the Fund for a Safer Future and others.)

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Suicide attempts are often impulsive acts, driven by transient life crises.[1,2] Most attempts are not fatal, and most people who attempt suicide do not go on to die in a future suicide.[3,4] Whether a suicide attempt is fatal depends heavily on the lethality of the method used,[5-8] and firearms are extremely lethal.[6-8]

These facts focus attention on firearm access as a risk factor for suicide, especially in the United States, which has a higher prevalence of civilian-owned firearms than any other country[9] and one of the highest rates of suicide by firearm.[10] In 2018, 24,432 suicides by firearm occurred in the United States.[11] Handguns are used in approximately three quarters of suicides by firearm.[12-14]

Ecologic[15-17] and case–control[18-25] studies have consistently shown a positive association between firearm availability and suicide. Collectively, the evidence indicates that the risk of suicide is three times as high when there is firearm access as when there is not — an excess risk attributable to higher rates of suicide by firearm, not of suicide by other methods.[17,26-29] However, the evidence base has gaps and limitations. For example, the case–control studies are relatively small in scale and prone to mismeasurement of firearm availability and, with one apparent exception,[25] rely on data from the 1980s and 1990s.

We tracked firearm ownership and mortality over 12.2 years in a cohort of 26.3 million adult residents of California. Nearly 700,000 cohort members acquired their first handgun during the study period (October 18, 2004, through December 31, 2016). Our goal was to estimate the effect of handgun ownership on their risk of suicide.

METHODS

STUDY OVERSIGHT AND REPORTING

Our study was approved by the institutional review board at Stanford University, and the results are reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[30] A checklist of the items recommended in the STROBE guidelines is provided in Table S21 in the Supplementary Appendix, available with the full text of this article at NEJM.org.

DATA

We formed the cohort by linking information on handgun transfers and all-cause mortality among adults in California to a series of historical extracts of the California Statewide Voter Registration Database (SVRD). The SVRD enumerates all registered voters in the state. The state must keep the SVRD up to date with new registrations and deregistrations (e.g., relocations and deaths). Thus, at the date of an extract, the SVRD consists of adults known to be alive and residing in California. We obtained 13 historical extracts of the SVRD spaced approximately 1 year apart and spanning our study period; the extracts included approximately 74% of residents of the state who were eligible to vote in California and 61% of all adult residents (Table S2).

Virtually all lawful transfers of firearms in California — including transfers between private parties, gifts, and loans — must be transacted through a licensed firearms dealer.[31] Dealers relay details of the transfers and transferees electronically to the California Department of Justice, where the information is archived in the Dealer Record of Sale (DROS) database. People who move to California with firearms are required to report or transfer their weapons within 60 days after arrival,[32] and these reports are also entered into the database. Although this regimen has governed handgun transfers for decades, transfers of long guns (rifles and shotguns) were not routinely archived until January 1, 2014.[33] We obtained records of the 9.1 million handgun and long-gun transfers archived in the DROS database over a 32-year period (from January 1, 1985, through December 31, 2016).

The California Death Statistical Master Files are the state's official mortality records. They contain detailed information on deaths of state residents, wherever the deaths occur. We obtained data on all deaths reported in the study period.

DATA CLEANING AND LINKAGE

Data-cleaning processes are described in Parts B and C in the Supplementary Appendix. We linked firearm acquisition and mortality records to the SVRD extracts at the individual level; the linkage methods are described elsewhere.[34]

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KEY MEASURES

Causes of death were coded according to the *International Classification of Diseases, 10th Revision*, in which suicides are specified according to method (Sections X60–X84), including suicide by firearm (Sections X72–X74). DROS data indicated which cohort members acquired handguns and the dates of acquisition. The age and sex of cohort members were derived from the SVRD. Race and ethnic group and missing values for sex were imputed with use of validated methods[35,36] (see Sections XIII and XIV in the Supplementary Appendix). We geocoded residential addresses and then assigned them to census tracts — geographically contiguous areas designed to approximate small neighborhoods.[37]

Using DROS data, we constructed three additional variables. First, to identify cohort members who already owned a handgun, we linked data on handgun transfers in the 19.8 years leading up to the study period. Second, we created a time-varying variable that indicated the cumulative number of handguns owned (based on acquisitions and deacquisitions) and used it to identify "divestments" — transfers of the last known handgun a cohort member owned. Finally, we flagged cohort members who had acquired long guns with an indicator variable that switched on at the date of their first-known long-gun acquisition. (For additional details on all study variables, see Part B in the Supplementary Appendix.)

DATA-SET STRUCTURE AND OBSERVATION AND EXPOSURE TIME

The final analytic data set was at the person–period level. It excluded cohort members who had acquired one or more handguns before coming under observation during the study period and cohort members with missing census tracts or birth dates (Fig. S1). We also excluded observation time from registrants younger than 21 years of age, the minimum age for lawful handgun acquisition in California.[38]

Cohort members entered the cohort on the date of the SVRD extract in which each first appeared as a registrant at the age of 21 years or older. Observation time ended on the day before the next extract in which they did not appear,[39] at the time of death, or at the end of the study period, whichever came first. We defined exposure as beginning on the date of first handgun acquisition, although acquirers were not eligible to take possession of the weapon until 10 days later, owing to California's mandatory waiting period.[40] Exposure time continued until observation time ended, except among divesters, for whom it ended on the date of divestment, at which time their nonexposure time recommenced.

STATISTICAL ANALYSIS

We used Cox proportional-hazards models to calculate hazard ratios estimating the relationship between handgun ownership and mortality (all-cause mortality, suicide, suicide by firearm, and suicide by other methods). The predictor of interest was a binary variable distinguishing exposed person-time (periods of handgun ownership) from unexposed person-time (periods of nonownership). The models allowed the baseline hazard to vary according to census tract and was adjusted for age at baseline, sex, race and ethnic group, and long-gun ownership. We plotted survival curves using the Kaplan–Meier method and estimated adjusted survival curves using inverse probability weighting.[41]

We tested for unmeasured confounding in two ways. First, we conducted negative control outcome analyses.[42] In these analyses, we used the same modeling approach and exposure time used in our main analyses, but the outcomes were three causes of death (lung cancer, endocarditis, and alcoholic liver disease) that are more common among people who smoke, inject drugs, or have alcohol-use disorder, respectively — established risk factors for suicide[43-47] that could not be measured directly in our data. Thus, a finding of no association between handgun ownership and these three causes of death would suggest minimal bias from confounding by these unmeasured behaviors in our main analyses. Second, we conducted bias analyses to calculate how strong the associations would need to be between an unmeasured confounder and our exposure and outcome variables, respectively, to explain our main results. In these analyses, we used the E-value calculator developed by VanderWeele and colleagues.[48,49]

In addition, we probed the effect of having anchored the cohort to registered voters in California. Handgun acquirers in the cohort were

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Table 1. Characteristics of the Study Sample According to Handgun-Ownership Status.*

Characteristic	Owners (N=676,425)	Nonowners (N=25,637,011)
Sex — no. (%)		
Male	528,111 (78.1)	11,324,350 (44.2)
Female	147,250 (21.8)	14,165,318 (55.3)
Missing	1,064 (0.2)	147,345 (0.6)
Age — yr†		
Mean (median)	41 (38)	43 (40)
Range	21–110	21–110
Race or ethnic group — no. (%)		
White	505,539 (74.7)	15,550,513 (60.7)
Hispanic	107,731 (15.9)	5,766,667 (22.5)
Asian	28,033 (4.1)	1,788,910 (7.0)
Black	30,490 (4.5)	2,239,863 (8.7)
Other	1,091 (0.2)	54,011 (0.2)
Missing	3,541 (0.5)	237,047 (0.9)
Residential location — no. (%)‡		
Urban	560,399 (82.8)	23,173,886 (90.4)
Suburban	78,285 (11.6)	1,716,930 (6.7)
Large rural town	21,727 (3.2)	443,986 (1.7)
Small rural town	16,012 (2.4)	302,048 (1.2)
Missing	2 (<0.01)	161 (<0.01)

* Handgun owners are defined as cohort members who acquired their first handgun on record (ever or since January 1, 1985) before coming under observation in the study period (October 18, 2004, through December 31, 2016). Nonowners are defined as cohort members for whom there was no recorded acquisition of a handgun between January 1, 1985, and the end of the study period. Percentages may not total 100 because of rounding.
† Values refer to cohort members' age on the first day they came under observation.
‡ Categories for residential locations are based on rural–urban commuting area (RUCA) codes (see Section III in the Supplementary Appendix). Values refer to cohort members' residential location on the day they entered the cohort. Missing values arise from census tracts that could not be mapped to RUCA codes from the 2010 Census.

weighted to represent all handgun acquirers in the state during the study period, not merely those who were registered voters, and nonacquirers were weighted to resemble all adult nonacquirers statewide. (For additional information about the generalizability and sensitivity analyses, see Sections VII and VIII in the Supplementary Appendix.)

Statistical analyses were performed with the use of R software, version 3.5.1 (R Foundation for Statistical Computing), and Stata software, version 14.1 (StataCorp). Confidence intervals for the hazard ratios were not adjusted for multiple comparisons. For additional details regarding the statistical analyses, see Section V in the Supplementary Appendix.

RESULTS

SAMPLE CHARACTERISTICS

The study sample comprised 26,313,436 people who were followed for an average of 6.9 years; 676,425 (2.6%) of them acquired one or more handguns during the study period. Handgun owners were younger than nonowners at baseline (mean age, 41 years vs. 43 years) and were more likely to be male (78.1% vs. 44.2%), white (74.7% vs. 60.7%), and residing outside an urban area (17.2% vs. 9.6%) (Table 1).

FREQUENCY AND RATE OF DEATH AND SUICIDE

A total of 1,457,981 cohort members died during the study period (Table 2); 17,894 died by suicide,

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Table 2. Counts, Crude Rates, and Adjusted Hazard Ratios for All-Cause Mortality and Suicide among Cohort Members, According to Handgun Ownership Status.

Cause of Death	Owners		Nonowners		Adjusted Hazard Ratio (95% CI)‡
	Deaths*	Crude Rate†	Deaths*	Crude Rate†	
All causes	10,863	382.94	1,447,118	820.91	0.80 (0.79–0.82)
Male	9,343	409.60	697,731	910.11	0.81 (0.79–0.83)
Female	1,500	271.78	739,924	747.99	0.72 (0.68–0.76)
Suicide	1,354	47.73	16,540	9.38	3.67 (3.46–3.89)
Male	1,132	49.63	11,376	14.84	3.34 (3.13–3.56)
Female	219	39.68	5,107	5.16	7.16 (6.22–8.24)
Suicide by firearm	1,200	42.30	5,491	3.11	9.08 (8.48–9.73)
Male	1,003	43.97	4,575	5.97	7.82 (7.26–8.43)
Female	194	35.15	900	0.91	35.15 (29.56–41.79)
Suicide by other methods	154	5.43	11,049	6.27	0.68 (0.58–0.80)
Male	129	5.66	6,801	8.87	0.64 (0.55–0.76)
Female	25	4.53	4,207	4.25	1.01 (0.68–1.50)

* Death counts for handgun owners refer to deaths among cohort members during a period in which they owned one or more handguns. Death counts for nonowners refer to deaths among cohort members during a period in which they did not own a handgun. Sex-specific totals for all-cause mortality, suicide, and firearm suicide do not sum to the overall total because the overall total includes cohort members with missing values for sex.

† Rate denominators for handgun owners consist of the exposure time they contributed while owners. Rate denominators for nonowners consist of the sum of nonexposure time contributed by handgun owners in their nonownership periods and the nonexposure time contributed by nonowners throughout their observation period.

‡ Adjusted hazard ratios were estimated with the use of Cox proportional-hazards models in which baseline hazards were stratified according to census tract. The models were controlled for age at cohort entry, sex (overall models only), race and ethnic group, and ownership of rifles or shotguns. Complete estimates from the 12 models are shown in Tables S16–S19.

of which 6691 were suicides by firearm. Men accounted for 70% of the suicides and 83% of the suicides by firearm. A firearm was used in 89% of the suicides among handgun owners and 33% of those among nonowners.

Handgun owners had lower rates of all-cause mortality than nonowners but substantially higher rates of suicide (Table 2). The rate of suicide by any method among male handgun owners was three times as high as that among male nonowners (hazard ratio, 3.34; 95% confidence interval [CI], 3.13 to 3.56), and the corresponding rate among female handgun owners was seven times as high as that among female nonowners (hazard ratio, 7.16; 95% CI, 6.22 to 8.24). These elevated suicide rates among handgun owners were attributable to much higher rates of suicide by firearm. Men who owned handguns had a rate of suicide by firearm that was nearly eight times as high as that among male nonowners (hazard ratio, 7.82; 95% CI, 7.26 to 8.43) and a lower rate of suicide by other methods (hazard ratio, 0.64; 95% CI, 0.55 to 0.76). The rate of suicide by firearm among female handgun owners was 35 times as high as the rate among women who did not own handguns (hazard ratio, 35.15; 95% CI, 29.56 to 41.79) and the rate of suicide by other methods was similar in the two groups of women (hazard ratio, 1.01; 95% CI, 0.68 to 1.50). (Complete estimates from these models are available in Tables S16 through S19.)

TEMPORALITY OF THE RISK OF SUICIDE BY FIREARM

Handgun owners had higher rates of suicide by firearm than nonowners throughout the study period, but the magnitude of this difference changed over time (Fig. 1 and Fig. S6). One suicide by firearm occurred among owners during the 10-day waiting period, followed by 9 on the day owners became eligible to take possession of their weapons and 102 in the first week thereafter. From the first day of eligibility through the 30th day after purchase, the rate of suicide by firearm among owners was 471 per 100,000

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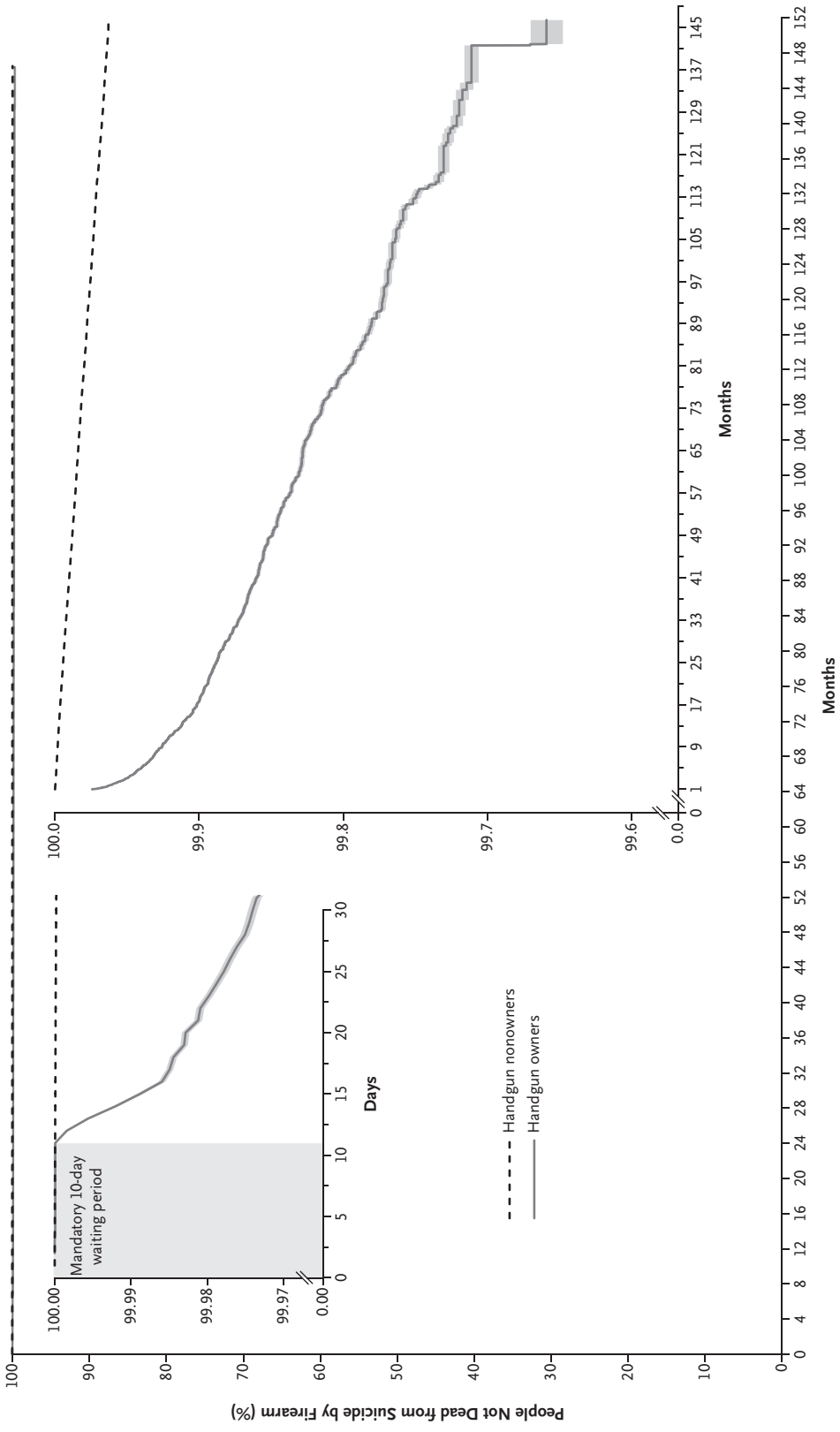

Figure 1. Adjusted Survival Curves for Suicide by Firearm among Handgun Owners and Nonowners.
The survival curves show the probability of not dying by suicide by firearm among handgun owners and nonowners over the 146-month study period and are adjusted for sex, age, and race and ethnic group. The shading around the curves indicates 95% confidence intervals, but these intervals are imperceptibly small for the curves for nonowners of handguns. Nonownership time is measured from the first day of observation, and ownership time is measured from the day of the first handgun acquisition. To address competing mortality risks, the survival curves do not censor cohort members who died of causes other than suicide by firearm (for details of this approach, see Section V in the Supplementary Appendix).

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Table 3. Counts, Crude Rates, and Adjusted Hazard Ratios for Suicide by Firearm among Handgun Owners, According to Time Period after First Handgun Acquisition.*

Suicides by Firearm	Period Since First Handgun Acquisition						
	1–10 Days	11–30 Days	31–90 Days	91–365 Days	366 Days–3 Yr	4–6 Yr	7–12.2 Yr
Suicides — no./total no. (%)	1/1200 (0.08)	172/1200 (14.33)	154/1200 (12.83)	251/1200 (20.92)	309/1200 (25.75)	194/1200 (16.17)	119/1200 (9.92)
Crude rate per 100,000 person-years	5.41	470.80	147.30	60.71	45.87	18.55	14.28
Adjusted hazard ratio (95% CI)	4.59 (0.82–25.52)	100.10 (55.75–179.90)	16.62 (12.98–21.29)	12.40 (10.48–14.67)	5.35 (4.64–6.17)	1.58 (1.34–1.86)	2.61 (2.14–3.19)

* "Acquisition" refers to the time of the application to purchase. California requires a 10-day (240-hour) waiting period from the date and time of the application to purchase to the time at which the purchaser is permitted to take possession of the firearm.

person-years (hazard ratio, 100.10; 95% CI, 55.75 to 179.90), and these suicides accounted for 14% of all suicides by firearm among owners during the study period (Table 3). The rate of suicide by firearm among owners declined in subsequent periods but remained elevated over the long term, with 52% of all suicides by firearm among owners occurring after the first year of ownership.

SENSITIVITY AND GENERALIZABILITY ANALYSES

Handgun owners did not have higher rates of death from alcoholic liver disease than nonowners (hazard ratio, 0.83; 95% CI, 0.72 to 0.95), and owners 50 years of age or older did not have higher rates of death from lung cancer (hazard ratio, 0.86; 95% CI, 0.79 to 0.93); mortality from endocarditis was higher among owners than among nonowners, but the confidence interval included 1 (hazard ratio, 1.60; 95% CI, 0.93 to 2.76) (Table S20). The bias analyses showed that a putative confounder would need to be very large to nullify the positive association detected between ownership and suicide; for example, it would need to both increase the risk of suicide by a factor of six and be six times more common among handgun owners than nonowners (E values: overall, 6.80; men, 6.14; women, 13.80) (Table S5). Analyses weighted to make the cohort more closely resemble the total adult population of California (i.e., with inclusion of people who were not registered to vote) produced estimates of the association between handgun ownership and suicide risk that were very similar to those in our main results (Table S6).

DISCUSSION

In this study of firearm ownership and mortality in a cohort of 26.3 million adult residents of California, we found an elevated risk of suicide among a large sample of first-time handgun owners. This risk was driven by a much higher rate of suicide by firearm — not by higher rates of suicide by other methods. Handgun owners' risk of suicide by firearm peaked in the period immediately after their first handgun acquisition but remained relatively high 12 years later, and the long-term risk accounted for a majority of the excess suicides by firearm among owners.

Nearly all previous studies of the relationship between firearm access and suicide have detected positive associations. These studies have limitations. In ecologic analyses, grouping people reduces information and may mask important individual-level differences between exposure and outcome.[50] Risk estimates from case–control studies range widely, in part because many have analyzed only a few hundred suicides.[18-20,22,25] Psychological autopsy, the standard method for determining gun access in case–control studies,[18,20-22,24] is vulnerable to recall bias, with proxies of recent victims of gunshot injuries plausibly more likely to report access than proxies of controls.[51] Some case–control studies have used dead controls[22,24] or drawn controls from a population other than that of the cases[21,22,24,25]; both approaches are potential sources of bias. Finally, case–control studies are ill-suited to measuring temporal changes in risk.

Cohort studies are well suited to measuring

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temporal changes, but the absence of centralized information on gun ownership has long impeded their conduct in the United States. In one previous cohort study involving recent purchases of handguns,[52] the rates of suicide by firearm among male and female handgun purchasers exceeded those in the general population, including gun owners (age-standardized mortality ratios of 3.23 and 15.50, respectively); the study did not adjust for other characteristics.

Our study is many times larger than previous ones and is unusual in estimating risks among first-time gun owners, accounting for divestment, and separately analyzing risks of suicide by firearm in both men and women. Our risk estimates are larger than those reported in some previous studies. However, direct comparisons are limited by the facts that case–control studies produce different measures of risk and that most define exposure as a gun in the home rather than personal ownership.

Although women accounted for only 16% of all suicides by firearm and had substantially lower suicide rates than men, the risk of suicide by firearm among female handgun owners (as compared with female nonowners) was substantially greater than that among male handgun owners (as compared with male nonowners). Women attempt suicide more frequently than men but have fewer completed suicides, largely because the means they tend to use (e.g., poisons) are less lethal than those men tend to use (e.g., guns or hanging).[5,7,8] Handgun ownership may impose a particularly high relative risk of suicide for women because of the pairing of their higher propensity to attempt with ready access to and familiarity with an extremely lethal method.

The lower risk of all-cause mortality detected among handgun owners should not be interpreted as a protective effect because it stems largely from owners' lower rates of death from common chronic diseases (e.g., cancer or heart disease) that do not have a clear relationship to handgun ownership. Two other explanations are more plausible. First, handgun acquisition involves participation in commerce. In California, this includes personal appearance at a dealer, which necessitates a degree of physical mobility and well-being. Second, handguns are expensive. People who can afford to buy them are wealthier,[53] and wealth is positively associated with health.

Unmeasured confounding is a threat to causal inference in observational studies.[54] Our bias analyses indicate that to substantially attenuate or erase the elevated rates of suicide by firearm we observed among handgun owners, any confounding difference between owners and nonowners would need to be as strong a predictor of suicide as well-established risk factors (e.g., major depressive disorders) and nearly an order of magnitude more common among handgun owners than nonowners, even after adjustment for the covariates accounted for in our analyses. What trait could reach that mark? One possibility is suicidal intent — owners who acquired handguns for the purpose of ending their life. Suicidal intent probably explains at least part of the spike in suicides by firearm soon after acquisition. However, intent is less plausible as an explanation for the elevated risk of suicide by firearm among owners over the longer term, when most occurred.

More generally, we were not able to adjust for mental illness; although it is a major risk factor for suicide, it is unlikely to be a strong confounder. Several national studies[55-57] have found that gun owners (or people with access to guns) and nonowners have similar rates of depression, suicidal ideation, and suicide attempts (for a review of these studies, see Section VI in the Supplementary Appendix). Moreover, our negative control outcome analyses did not detect consistent evidence of residual confounding from this source.

Our study has other limitations. First, we will have misclassified some handgun owners as unexposed because, for example, they acquired their handguns unlawfully or before our data on acquisition histories began. Such misclassification should bias toward the null any differences in the risk of death detected between owners and nonowners. Second, we only partially accounted for long-gun ownership, although the implications of this are mitigated by the fact that approximately three quarters of suicides by firearm involve handguns[12-14] and less than 20% of firearm owners in California own only long guns.[53] Finally, generalizability outside California is unknown. California has stricter gun laws than many other states, including universal background checks, a waiting period, and various prohibitions on firearm purchasing by people with severe mental illness.[58] Our results may underestimate the association between handgun

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ownership and suicide in states without such safeguards.

Fifty-nine people were killed in the mass shooting in Las Vegas in 2017, the deadliest in U.S. history. Approximately the same number die each day in the United States from suicide by firearm. Many of these deaths are preventable. Our study bolsters and extends the message from previous research: ready access to firearms, particularly handguns, is a major risk factor for suicide. Health care providers and policymakers should be aware of this risk. This information is also important for current and prospective firearm owners seeking to weigh the risks and perceived benefits of ownership.

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