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Scientific Article

Positive Association between Altitude and Suicide in 2584 U.S. Counties

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Abstract

Brenner, Barry, David Cheng, Sunday Clark, and Carlos A. Camargo, Jr. Positive association between altitude and suicide in 2584 U.S.counties. *High Alt. Med. Biol. 12,* 2011— Suicide is an important public health problem worldwide. Recent preliminary studies have reported a positive correlation between mean altitude and the suicide rate of the 48 contiguous U.S.states. Because intrastate altitude may have large variation, we examined all 2584 U.S. counties to evaluate whether an independent relationship between altitude and suicide exists. We hypothesized that counties at higher elevation would have higher suicide rates. This retrospective study examines 20 yr of county-specific mortality data from 1979 to 1998. County altitude was obtained from the U.S. Geologic Survey. Statistical analysis included Pearson correlation, t tests, and multivariable linear and logistic regression. Although there was a negative correlation between county altitude and all-cause mortality ($r = -0.31$, $p < 0.001$), there was a strong positive correlation between altitude and suicide rate ($r = 0.50$, $p < 0.001$). Mean altitude differed in the 50 counties, with the highest suicide rates compared to those with the lowest rates (4684 vs. 582 ft, $p < 0.001$). Controlling for percent of age >50 yr, percent male, percent white, median household income, and population density of each county, the higher-altitude counties had significantly higher suicide rates than the lower-altitude counties. Similar findings were observed for both firearm-related suicides (59% of suicides) and nonfirearm-related suicides. We conclude that altitude may be a novel risk factor for suicide in the contiguous United States.

Key Words: altitude; suicide; firearm; obesity; hypoxia

Introduction

In 2002 there were at least 1.5 million deaths worldwide from self-inflicted injuries, which made it the 14th most common cause of death (Mathers and Loncar, 2006). In the next 20 yr, suicide is expected to reach over 2 million deaths and will rank 12th in the world as a cause of mortality (Mathers and Loncar, 2006). Recognized risk factors for suicide include older ages, male sex, white race, low income, owning firearms, isolation, divorce, serotonin dysfunction, incarceration, substance abuse, and reduced levels of cholesterol (Stack, 2000; Ellison and Morrison, 2001; Goldsmith, 2001; Hemenway and Miller, 2002; Singh and Siahpush, 2002; Zill et al., 2004; Dumais et al., 2005; Daly et al., 2007). Psychiatric illness, mood disorders, and sociocultural issues are also important risk factors (Nock, 2010). Alcoholism has been associated with high suicide rates in Euopean countries, and impulsiveness and political violence are associated with suicide in southeast Asian countries (Maris, 2001). For unexplained reasons, suicide rates are higher in the western United States (CDC, 1997).

Increased altitude has recently been shown to have a protective association with certain medical illnesses, with apparent decreases in mortality among patients with end-stage renal disease receiving dialysis (Winkelmayer et al., 2009), coronary artery disease (Baibas et al., 2005; Faeh et al., 2009), and stroke (Faeh et al., 2009). By contrast, increased altitude may enhance psychiatric disorders, such as panic attacks (Roth et al., 2002). We (Cheng et al., 2005) have hypothesized a positive correlation between the mean altitude and suicide rate of the 48 contiguous United States. Because intrastate altitude may have wide variations, we have examined all 2584 contiguous U.S. counties to evaluate whether an independent relationship between altitude and suicide exists. We

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hypothesized that counties at high elevation would have higher suicide rates.

Methods

This retrospective study used mortality data assembled by the U.S. Centers for Disease Control and Prevention (CDC). The CDC mortality data are based on the underlying cause of death, which is defined by the World Health Organization as "the disease or injury which initiated the train of events leading directly to death, or the circumstances of the accident or violence which produced the fatal injury." (CDC Suicide Mortality, 2009). Suicide was selected by CDC staff from the conditions entered by the physician on the cause of death section of the original death certificate. When more than one cause or condition was entered by the physician, the underlying cause was determined by the sequence of conditions on the certificate, provisions of the International Classification of Diseases (ICD), and associated selection rules and modifications. For analysis of injury mortality data, the causes of death were classified by both intent and mechanism. The focus of the present study was death from self-inflicted injury, and the mechanism was either firearm-related or nonfirearm-related.

Accordingly, we used the Ninth International Classification of Disease (ICD9) codes to identify suicide deaths (ICD9 codes 950–959) and deaths from any cause (ICD9 codes 000–999.9). The suicide rates reported are age-adjusted deaths (>5 yr), with deaths per 100,000 at the county level for the contiguous 48 states during the 20-yr span of ICD 9 classification from1979 to 1998. Counties with unreliable suicide rates were defined by the CDC as having ≤20 cumulative deaths during this 20-year interval. All counties with unreliable data ($n = 484$ of 3068; 15.8%) were excluded from the primary analysis.

Covariates include percentage of people of age >50 yr, male, white, and median household income and population density, with all these variables obtained from the 1990 U.S. Census (U.S. Population Census, 2009). The 1990 Census was chosen, since this was midway in the 20-yr period that we used to extract mortality data from the CDC.

County elevation for all 2584 counties was obtained from the U.S. Geologic Survey (U.S. Geological County Survey, 2009). The latitude and longitude coordinates of the center of each U.S. county were joined to the National Elevation Database (NED) to determine and represent the elevation for each county. NED is a seamless database composed of the best raster elevation data only for the 48 contiguous U.S. states; NED's vertical accuracy is reported as 8 ft (root mean square error) (National Elevation Database, 2009).

Statistical analysis was performed using Stata 10.0 from StataCorp in College Station, Texas, USA. The specific tests were Pearson correlation, Student's t test, and multivariable linear and logistic regression. In addition to the primary analysis on altitude and suicide mortality, we examined altitude and all-cause mortality. We also performed a sensitivity analysis to examine if the altitude–suicide finding was modified by the firearm status (yes or no) of the suicide death. All p values are two-tailed, with $p < 0.01$ considered statistically significant.

Results

During the 1979–1998 span, there were 596,704 (1.4%) suicide deaths in the United States, among 42,868,100 total deaths. Overall, the median age-adjusted suicide rate per 100,000 in a U.S. county was 14 (interquartile range [IQR], 12–17). The median suicide rate across counties was higher among men (24, IQR 21–29) than women (6, IQR 5–7). When only the suicide rate by firearms was considered, the median rate was 10 per 100,000 (IQR, 8–12), while the nonfirearm median rate was 4 (IQR 3–5).

With regard to primary exposure, county elevation, the overall median value across counties was 892 ft (IQR 463–1594 ft). With regard to covariates, the median of the percentage of counties that was of age >50 yr was 27% (IQR 24–31%). The median value for other factors was male 49% (IQR 48–50%), white 94% (IQR 81–98%), median family income $22,662 (IQR $19,623–$26,802), and population density 38 (IQR 16–90) individuals per square mile.

Despite a negative correlation ($r = -0.31$, $p < 0.001$) between county altitude and the all-cause mortality rate, there was a strong positive correlation ($r = 0.50$, $p < 0.001$) between altitude and suicide rate at the county level (Fig. 1). Positive correlations were also observed for both firearm-related suicides ($r = 0.40$, $p < 0.001$) and nonfirearm-related suicides ($r = 0.31$, $p < 0.001$). Controlling for five potential confounders (percent of age >50 yr, percent male, percent white, median household income, median family income, and population density of each county), increasing altitude deciles were associated with significantly higher suicide rates (Table 1). The threshold value for increased suicide rates occurred in the range of 2000–2999 ft (Table 1). Similar findings were observed for firearm-related suicides, which comprise 59% (352,052 firearm suicides per 596,704 total suicides) of all suicides (Table 1).

We then compared the 50 counties with the highest suicide rates against the 50 counties with the lowest suicide rates in the United States. The ratio in average suicide rates between the 50 highest and lowest counties was 4.2 (30.5:7.2). Mean altitude greatly differed between the 50 counties with the highest suicide rates compared with those with the lowest rates (4684 vs. 582 ft, $p < 0.001$).

Because the Mountain Region (CDC region 8) is already known to have high suicide rates (CDC, 1997), we repeated this analysis, after removing the CDC Mountain Region, and then determined the 50 counties with the highest suicide rates and the 50 counties with the lowest suicide rates in the United States. The ratio between suicide rates remained high ($25.5:7.3 = 3.5$). Without the Mountain Region, mean altitude differed between the 50 counties with the highest suicide rates compared with those with the lowest rates, respectively (2075 vs. 497 ft, $p < 0.001$).

Because 59% of suicides involve firearms, we restricted the analysis to suicide by firearms only. We then compared the 50 counties with the highest firearm suicide rates with the 50 counties with the lowest firearm suicide rates. The ratio of the suicide rates in these two groups of counties also was elevated ($22.6:2.9 = 7.8$). The mean altitude again differed between the 50 counties with the highest firearm suicide rates compared with those with the lowest firearm suicide rates (4098 vs. 324 ft, $p < 0.001$).

It could be argued that altitude-related suicide may be owing to more firearm usage at higher altitude, and suicide per se may be unrelated to altitude. However, we also found a positive relationship between altitude and nonfirearm-related suicide. There was a 12.5-fold (10.0:0.8) difference in suicide rate between the counties with the 50 highest nonfirearm suicides versus those with the lowest nonfirearm suicides,

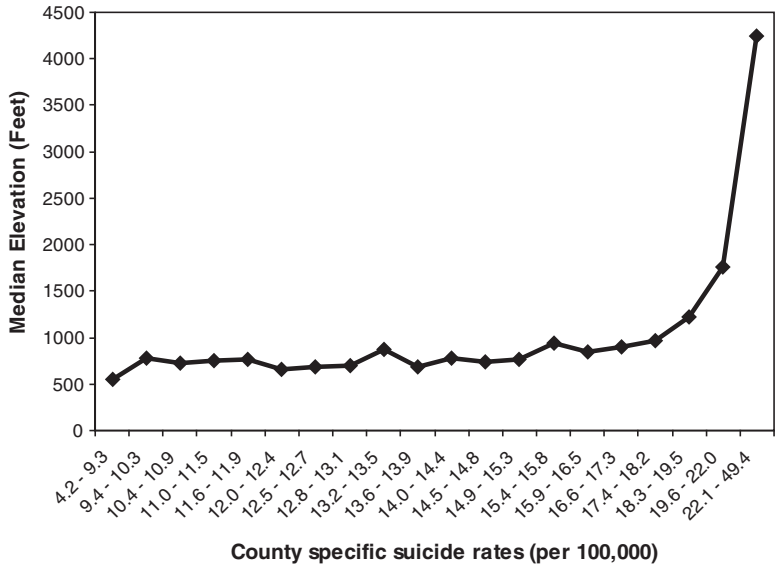

FIG. 1. Suicide rate by vingtiles of U.S. county altitude.

and the mean altitude in the 50 counties with the highest and lowest nonfirearm suicide rates was 3699 ft versus 954 ft ($p < 0.001$).

All the results in the previous analyses have been calculated using the reliable suicide data from 2584 counties. As noted under Methods, 484 counties did not have reliable data available owing to their having ≤20 suicide deaths in a 20-yr span; consequently, they were excluded from our analyses. Perchance, these missing data would affect the association between altitude and suicide. When these unreliable suicide rates were used, in lieu of removing them from the analysis, the positive correlation between county elevation and suicide rate persisted ($r = 0.45$, $p < 0.001$).

Discussion

Using U.S. national data from 1978 to 1998, we found that county altitude had a significant positive association with overall suicide rates, firearm-related suicide rates, and nonfirearm-related suicides. Altitude was associated with overall suicide rate even after controlling for five potential confounders. The correlation between altitude and suicide could be mitigated by a positive correlation between altitude and all-cause mortality over the same period. On the contrary, we found a significant negative correlation between altitude and all-cause mortality, a finding that highlights the novelty and strength of the observed relationship between altitude and suicide. Using a different methodology, a similar, strong positive correlation between altitude and suicide rates has recently been reported by Kim and colleagues, (2011) using all counties in the United States as well as all 233 counties in South Korea.

Our previous abstract work on altitude and suicide (Cheng et al., 2005) was done by comparing mean state altitude with suicide data for entire states and was repeated by others using peak altitude for each state and state capital city elevations (Haws et al., 2009). Although both studies reported strong correlations ($r = 0.75$ and 0.74, respectively), they were

Table 1. Adjusted Association between County Elevation and Suicide Rate (per 100,000) in 2584 United States Counties[a]

		Overall suicide rate		*Firearm suicide rate*		*Nonfirearm suicide rate*	
County elevation (ft)	n	*β*	*95% CI*	*β*	*95% CI*	*β*	*95% CI*
<1000	1743	Reference	—	Reference	—	Reference	—
1000–1999	722	0.17	−0.17, 0.50	−0.15	−0.47, 0.16	0.36	0.19, 0.53
2000–2999	230	3.25	2.64, 3.86	2.05	1.47, 2.62	1.01	0.69, 1.32
3000–3999	116	3.38	2.56, 4.20	2.42	1.67, 3.17	1.18	0.76, 1.59
4000–4999	98	6.23	5.45, 7.02	4.76	4.03, 5.49	1.94	1.53, 2.34
5000–5999	55	9.60	8.56, 10.63	6.26	5.30, 7.22	2.92	2.39, 3.45
6000–6999	41	7.95	6.77, 9.13	5.91	4.83, 7.00	1.85	1.26, 2.45
7000–7999	28	8.47	7.01, 9.91	6.11	4.79, 7.43	2.29	1.57, 3.01
8000–8999	16	7.40	5.40, 9.40	6.00	4.17, 7.80	0.60	−0.39, 1.60
≥9000	18	9.12	7.20, 11.050	6.69	4.78, 8.61	2.57	1.52, 3.62

CI, confidence interval.
[a]Controlling for percent of age >50 yr, percent male, percent white, median household income, median family income, and population density of each county.

inconclusive. In these studies the mean or highest state altitude (Cheng et al., 2005; Haws et al., 2009) or the elevation of the state capital city (Haws et al., 2009) was used to represent the altitude of the entire state. However, because U.S. states vary greatly in altitude and the foregoing methodology severely minimizes this variation, we considered these initial findings to be of a preliminary nature only. For example, New York varies from sea level to 5344 ft and California from −282 to 14,505 ft. With such heterogeneity in elevation on a state basis, it would be difficult to conclude that elevation might be related to suicide, despite the strong ecologic correlation. Counties vary much less in altitude than an entire state. For this reason, we thought that reexamining this association on a county level would address this limitation.

If there were no link between altitude and suicide, there is little reason why the 50 counties with the highest suicide rates should differ in elevation when compared to the counties with the 50 lowest suicide rates. We found, however, that there was an almost 8-fold difference in altitude in these two groups of counties. When suicides were divided by firearm status (yes or no), the difference in altitude between the 50 counties with the highest and lowest suicide rates was 4.3 and 3.8, respectively. Prior reports of increased suicides in the U.S. Mountain Region (e.g., Colorado) have prompted speculation that the excess is owing to greater access to firearms, increased isolation, or reduced income (CDC, 1997). Even after controlling for these variables in our analysis, the positive correlation between altitude and suicide still exists, which suggests that the increased suicide rate in the regions with greatest altitude, such as the Mountain Region, may be owing to, at least in part, its altitude per se.

Although a discussion of potential mechanisms is speculative at this juncture, we believe it appropriate to guide further investigation into this novel finding. For example, altitude is a well-known cause of hypoxia, and the greater the elevation, the greater the hypoxia. Chronic hypoxia also is thought to increase mood disturbances, especially in patients with emotional instability (Shukitt and Banderet, 1988; Nicholas et al., 2000; Nock et al., 2010). The relationship between mood and hypoxia is complex, because oxygen therapy, while beneficial to pulmonary function in hypoxic patients with sleep apnea, was found not to improve mood (Yu et al., 1999).

Humans have well-known physiologic responses to mild and moderate chronic hypoxia, such as increased 2,3-diphosphoglycerate and a shift to the right in the hemoglobin–oxygen dissociation curve (Winslow, 2007); but not all people respond equally to hypoxia or increased altitude owing to variations in hemoglobin affinity for oxygen and other mechanisms (Winslow, 2007). If the mechanism of the suicide–altitude relationship were hypoxia, we would anticipate that there may be increased mood disturbances at high altitude in those with sleep apnea (Peppard et al., 2009) or moderate or heavy smokers at high altitude.

Future studies may or may not confirm the altitude–suicide association in other parts of the world. Should the association not be present in some other locations with comparable variation in altitude, it is possible that our findings are owing to conditions that are more common in the United States. For example, although obesity rates are rising worldwide, they have been high in the United States for decades (Peppard et al., 2009). Obesity is known to cause increased hypoxia owing to sleep apnea and thereby may create a mood disturbance (Rigby et al., 2004); one might anticipate that the altitude–suicide finding might be heightened in obese individuals. Known periodic breathing at high altitude may further exacerbate the effects of sleep apnea and nocturnal hypoxia (West et al., 1986, Khoo et al., 1996; Bloch, 2010).

A potential limitation regarding the altitude–suicide finding is heterogeneity in altitude within counties. Although the problem is obviously worse when considering entire states (Cheng et al., 2005), it is a lesser concern even for large counties. However, the consistency of the association across different measures of altitude [i.e., when measured at both the state level (Cheng et al., 2005; Haws et al., 2009) and now the county level] suggests that the association is not spurious. We addressed other potential limitations in the analysis (e.g., contribution of Mountain states, exclusion of unreliable data), and the altitude–suicide finding was very robust.

Despite the strong association between suicide and altitude, other factors may be responsible for this association that are directly related to high altitude per se, for example, low barometric pressure (Shukitt et al., 1998). Many demographic, psychiatric, and sociocultural factors are associated with suicide, and association between high altitude and suicide is speculative. But when other risk factors were considered, the strong association between altitude and suicide was still present in suicides overall and in suicides both with and without firearms. This strong association ($r = 0.50$) is rendered even stronger by the overall negative association between all deaths and altitude ($r = -0.31$).

In summary, altitude is strongly associated with suicide rates in the United States. This novel finding is not explained by county differences in demographic factors, income, or geographic isolation. Future studies might focus on the individual differences between these high and low altitude areas, both at the biochemical level (e.g., glycolysis, serotonin metabolism, oxygen transport) and the level of the entire organism (e.g., differences in arterial oxygen compared with pulse oximetry, body mass index, sleep apnea, smoking, or behavioral distinctions). Ultimately, this mechanistic search might help clinicians to identify individuals at high altitude who may be amenable to relocation to lower altitude areas, oxygen therapy, or special monitoring and intervention (U.S. Department of Health and Human Services, 2009).

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Disclosures

The authors have no conflicts of interest or financial ties to disclose.

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