Death Resulting from Motor Vehicle Immersions: The Nature of the Injuries, Personal and Environmental Contributing Factors, and Potential Interventions

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Abstract: We present an epidemiologic characterization of deaths from motor vehicle immersions, based on 77 deaths in 63 motor vehicle immersions in Sacramento County, CA, during 1974–85. All persons were autopsied; all but one of the deaths were due to drowning. Average annual mortality rates per million person years were 12 for males, four for females, 30 for Hispanics, six for White non-Hispanics, Blacks and Asians. Seventy-one percent of drivers and 60 percent of passengers had a blood alcohol concentration ≥22 mmol/L.

Most cases (57 percent) had an Injury Severity Score of 1 (minor injury) or 0 (no injury). Alcohol use was associated with higher Injury Severity Scores. Road curvature of 20° or greater was far more common at crash sites than at matched control sites one mile away(OR = 6.57, 95% CI = 2.93, 14.71). Guard rail placement along highly curved sections of roadway may be an effective preventive measure. (*Am J Public Health* 1990; 80:1068–1070.)

Introduction

Each year there are approximately 350 deaths in the United States resulting from motor vehicle immersions (unpublished data, Fatal Accident Reporting System, 1988). High motor vehicle-related drowning rates have been noted previously in places with many inland waterways such as Florida and Louisiana.[1] In Sacramento County, California, site of a large river delta and the location of this study, autopsy-confirmed drownings from motor vehicle immersions are more common than drownings from boating incidents (unpublished data, The Sacramento Drowning Study, 1987). To our knowledge, the nature and epidemiology of these deaths have not been described.

This study therefore sought answers to the following questions. Are deaths due to motor vehicle immersion actually drownings, or are they due to biomechanical trauma resulting from the crash event itself? By convention all such deaths have been classified as motor vehicle deaths, rather than drownings, since the adoption of the fifth revision of the International List of Causes of Death in 1939. What are the personal and environmental contributing factors for these deaths? What countermeasures are available and likely to be effective?

Sacramento County had 783,381 residents in 1980. The southwestern portion of the county is a river delta. Roads in this area are generally built on levees, some 30 feet above river level. These roads are two lanes wide, with lane widths of 10–12 feet, and have narrow shoulders. The roads are level except for the short distances needed to mount a levee; curves are generally not banked. We observed that speeds of travel commonly exceed 55 mph on major levee roads. In other rural portions of the county, roads may be built next to irrigation canals or other waterways.

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Methods

The study period was 1974–85. Cases were identified through a register maintained by the coroner's office, which lists both the anatomical and external causes of death. Cases were defined as persons, regardless of their cause of death at autopsy, who were motor vehicle occupants and who entered the water by means of a motor vehicle immersion. We reviewed coroner's and police reports and interviewed investigative personnel. We also reviewed coroner's records for all motor vehicle deaths occurring in the county for 1980–85, but found no additional cases.

All cases were autopsied. Causes of death were abstracted directly from the autopsy report. Analyses pertaining to blood alcohol concentration (BAC) were restricted to cases in which death occurred within six hours of immersion, and blood sampling occurred within 24 hours of death. These criteria avoid spuriously low values resulting from post mortem sampling after prolonged survival, and spuriously high values resulting from putrefaction.[2]

Traumatic injuries were scored for severity using the Abbreviated Injury Scale (AIS), which assigns to individual injuries a numerical score between 1 (mild) and 6 (unsurvivable).[3] Injury Severity Scores (ISS) were computed.[4] As used in this article, the term "head injury" includes injury to the external soft tissues of the head and face, such as lacerations and abrasions. In calculating Injury Severity Scores, however, these superficial head injuries were coded as "External" injuries as required by standard scoring procedures.

Following the case-control method developed by Wright and Robertson,[5] each crash site (defined as the point at which the vehicle left the roadway) was compared with a point one mile distant, on the same road except as noted below, in the direction from which the vehicle had come. When the path of travel could not be reconstructed with certainty because of an intersection within one mile of the crash site, preference was given first to arterial rather than tributary roads; when the choice involved two roads of the same type, preference was given to the road adjacent to the water. Eleven of 63 immersion events were excluded from this analysis (path of travel uncertain, three cases; vehicle traveled less than one mile prior to immersion, three cases; crash occurred on private or restricted roadway and the investigators could not gain access, two cases; other, three cases). We limited the crash site—control site comparison to road curvature, determined by the middle ordinate method.[5] Curvature was measured at 100 foot intervals for 500 feet in either direction from the point at which the vehicle left the roadway. Gradient and banking, evaluated in Wright and Robertson's earlier work, were each present in only two of the sites we studied.

Using our case identification methods as a "gold standard" procedure for crash site identification, we calculated the sensitivity and specificity of various minimum-curvature criteria as screening tests for identifying known crash sites. Sensitivity was defined as the number of known crash sites identified divided by the total number of known crash sites. Specificity was derived in an analogous manner.

We also inventoried risk-reduction features at crash sites, such as warning signs and guard rails, to learn whether post-crash modifications had been made. We used each crash site as its own historical control, comparing the detailed written and pictorial description in the earlier police reports with our observations in 1987–88. This analysis was limited to the 34 cases for which detailed police reports were available.

Average annual mortality rates were calculated based on place of occurrence, using Sacramento County data from the 1980 US Census to approximate a mid-interval population. All denominators are age-, race-, and gender-specific as appropriate. Rates are rounded.

Confidence intervals were calculated by the exact binomial method using Confidence Interval Analysis software.[7] Other analyses were performed with PC-SAS.

Results

There were 78 deaths identified, but one was excluded as the coroner's record could not be located. The 77 remaining deaths resulted from 63 motor vehicle immersions, all single vehicle events, of which seven led to multiple fatalities. Twenty-five immersions also involved a total of 37 vehicle occupants who survived. (Further information on survivors was not available.)

A car was involved in 65 deaths, a truck in 11, and a motorcycle in one. Fifty persons were drivers, and 27 were passengers. Three deaths were specified as job-related. Seventy-five deaths were classified by the coroner as unintentional, one as suicidal, and one as of undetermined intent.

In all but one fatality, drowning was reported as the sole cause of death, or drowning and one or more traumatic injuries were listed as multiple causes of death. The cause of death for the remaining case was "craniocerebral trauma with possible drowning."

The average mortality rate was eight per million person years. Cases ranged in age from seven months to 73 years; 38 were age 15–34; 57 cases were male. Mortality rates were 12 for males and four for females, per million person years.

The mortality rate for Hispanics was five times those for White non-Hispanics, Blacks, and Asians (30 for Hispanics, six for the other groups, per million person years). Hispanics accounted for 36 percent of these deaths, but made up only 9 percent of the county's population in 1980. This difference was not due to a disproportionate number of nonresidents among Hispanic cases. Sixty-three percent of Hispanic cases, and of all cases, lived in the county. While immersions involving any Hispanic deaths were more likely than others to result in multiple fatalities (OR = 7.5, 95% CI = 1.6, 35.3), this difference did not fully explain the high Hispanic mortality rate. The fatal immersion event rate was also higher for Hispanics than for non-Hispanics (20 and six per million person years, respectively).

Forty deaths occurred on Saturday or Sunday, twice the number predicted by the hypothesis of equal occurrence throughout the week ($\chi^2 = 17.19$, df = 6, $p < .01$). There were no significant differences in incidence by time of day.

A blood alcohol concentration (BAC) was determined in 75 cases; the specified eligibility criteria were met in 56. Five cases were children under age 15, none of whom had a positive BAC. Among older persons, 74 percent of drivers and 73 percent of passengers had a positive blood alcohol concentration; 71 percent of drivers and 60 percent of passengers had a BAC ≥ 22 mmol/L.

Serious biomechanical trauma was unusual (Table 1). Most persons had an Injury Severity Score of 1 (minor injury) or 0 (no injury). Fifty-one cases sustained a head injury, but 26 of these were AIS 1 injuries. Alcohol use was associated with higher Injury Severity Scores. Among cases meeting the alcohol sampling criteria, 15 of 18 cases with a score ≥ 10 had a BAC ≥ 11 mmol/L, as opposed to 23 of 36 cases with an ISS of 0 or 1 (OR = 2.83, 95% CI 2.05, 3.89).

Post-event interventions were uncommon. Only four cases involved immersion times of 30 minutes or less. Three of these four people, and 11 of all 77 cases, were given emergency care after retrieval from the water. One person survived long enough to be admitted to a hospital.

There were large differences in road curvature between crash and control sites. Crash sites had a median curvature of 19° over 1000 feet; the median curvature for control sites was 8° (difference = 11°, approx 95% CI = 2°, 18°). The differences in mean curvature were greatest over the 500 feet approaching the point where the vehicle left the roadway (Figure 1). Crash sites were far more likely than control sites to involve a curvature of 20° or greater (OR = 6.57; 95% CI = 2.93, 14.71). Conversely, crash sites were less likely than control sites to have curvatures of less than 5° (OR = .42; 95% CI = .24, .73).

The sensitivity and specificity of several minimum curvature criteria for identifying crash sites varied inversely (Table 2). None of the criteria evaluated was highly sensitive, but it was possible to identify approximately 50 percent of crash sites with a specificity of 75 percent or greater.

There were four multiple-crash sites, each of which had two fatal motor vehicle immersions during the study period. Three of these sites had curvatures of greater than 30° (34°, 66°, 84°) over 1000 feet. The fourth had a curvature of 4° (less than its control) and no other explanatory features.

At two of 34 crash sites for which complete police reports were available, guard rails existed between the road and water at the time the crash occurred. Guard rails had been added to

TABLE 1—Incidence and Severity of Head and Other Injuries in 77 Motor Vehicle Immersion Deaths, Sacramento County, California 1974–85

Overall Injury Severity		Head Injury Severity	
Injury Severity Score	N (%) of Cases	Head Injury AIS*	N (%) of Cases
0	16 (21)	0	26 (34)
1	28 (36)	1	26 (34)
2–9	4 (5)	2	9 (12)
10–19	19 (25)	3	9 (12)
20+	10 (13)	4	7 (9)
Total	77	Total	77

*Includes external injuries to the head and face.

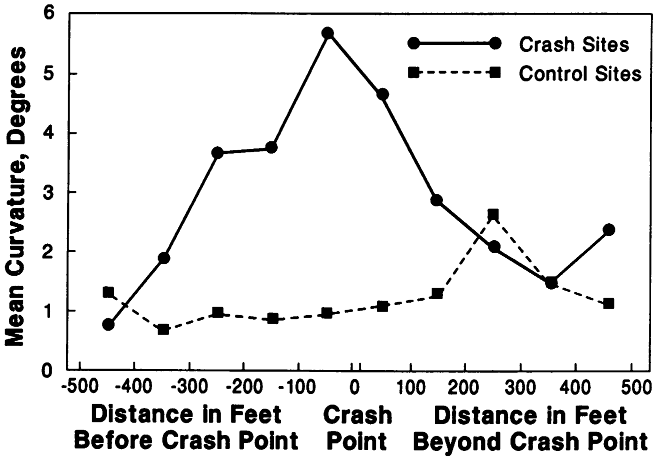

FIGURE 1—Mean Road Curvature over 1,000 Feet at 52 Fatal Motor Vehicle Immersion Sites and Matched Controls, Sacramento County, California 1974–85

five other sites, and extended at one of the first two locations, by the time our field investigation was conducted.

Discussion

These deaths represent an unusual subset of motor vehicle-related deaths, in that traumatic injury was generally minor if present at all. Death, generally by drowning, appeared to result more directly from the hostile environment in which the crash occurred. This may be particularly true for those cases involving minor head injury; transient disorientation or loss of consciousness may well result in death given that immersion has occurred. From the pathophysiologic viewpoint, these deaths are more properly considered drownings. From the prevention standpoint, their current classification as motor vehicle deaths seems appropriate.

The mortality rate for Hispanics was approximately five times that for other groups. These rates were calculated based on place of occurrence, but the observed difference did not result from a high proportion of out-of-county residents among Hispanic fatalities. A number of other factors may be involved. First, fatal immersions involving Hispanic vehicle occupants were more likely than others to result in multiple deaths. Second, the high risk roadways are in agricultural areas of the county. Since Hispanics in the Sacramento area are heavily involved in agriculture, their higher fatal immersion rate may result from a higher exposure to these roadways than that of other groups. Differences in alcohol use and driving experience may also play a role. A controlled study will be necessary to evaluate these possibilities.

TABLE 2—Sensitivity and Specificity of Various Minimum Curvature Criteria for Identifying Sites of 52 Fatal Motor Vehicle Immersions Occurring in Sacramento County, California 1974–85

Minimum Curvature over 1,000 feet (degrees)	Sensitivity (95% CI)	Specificity (95% CI)
10	.58 (.43, .71)	.58 (.43, .71)
15	.50 (.36, .64)	.75 (.61, .86)
20	.46 (.32, .61)	.88 (.76, .96)
30	.37 (.24, .51)	.94 (.84, .99)

Alcohol was a major contributing factor. Seventy-four percent of drivers meeting our sampling criteria had a positive BAC, as did 69 percent of drivers killed in single vehicle crashes nationwide in 1985.[8] Alcohol use was associated with increased injury severity. It is likely that alcohol use contributes to these deaths in two ways: by increasing the likelihood that an immersion event will occur, and by impairing the ability to escape a sinking vehicle.

Finally, we have demonstrated that roadway curvature is an important environmental contributing factor for fatal motor vehicle immersions. Similar results have previously been described for fatal crashes involving roadside fixed objects[5] and single vehicle fatal rollover crashes.[9,10] Sites at high risk for future crash involvement can therefore be identified for environmental modification.

Placing guard rails along waterside roadways would substantially decrease the incidence of immersions. The guardrail now in use in the study area is a w-beam, blocked-out design. Field studies have demonstrated that this design is highly efficient at redirecting impacting vehicles, with a penetration rate of less than 15 percent.[11] The cost of installing this guard rail averaged $14.50 per linear foot in 1988,* or $76,560 to protect one side of a mile of roadway.

It is probably not cost-effective to install guard rails throughout an entire system of waterside roadways. Using a curvature criterion would permit resources to be focused on the most hazardous locations. Nearly half of high-risk locations would be protected by installing guard rails along sections of roadway with curves of 20° or greater over 1000 feet, while minimizing installation in low-risk areas.

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