Alcohol, Boating Accidents, and the Interpretation of BAC

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Introduction and overview.

The problem of alcohol-impaired driving extends beyond highways to waterways. Epidemiologic data show that patterns of alcohol use in boating accidents resemble those of alcohol use in road accidents. However, interpretation of data on concentrations of alcohol (ethanol) in persons fatally injured in boating accidents is often less straightforward. Because some bodies are not recovered until many hours or even days later, one frequently encountered issue is whether concentrations of alcohol measured in bodily fluids are mostly due to consumption of alcoholic beverages before the accident or, alternatively, due to postmortem formation of alcohol by endogenous bacteria. Based on a review of the literature, we identify criteria to guide judgments concerning the likely origin of alcohol in the bodily fluids of persons fatally injured in boating accidents. These include detection of alcohol in blood or chest fluid but not in other fluids tested; other atypical distributions of alcohol; elevated concentrations of higher alcohols (e.g., isopropyl alcohol); and information on the consumption of beverage alcohol prior to the accident. A case study illustrates application of these criteria.

Alcohol, boating accidents, and drowning

The strong association between alcohol consumption and fatal traffic accidents extends, not surprisingly, to recreational boating and deaths due to drowning (e.g., Copeland 1986; Glover et al. 1995; Howland et al. 1990). Drowning is a leading cause of accidental death in the US, and as many as one in three victims (38%) may have consumed alcohol (Howland and Hingson 1988; Naranjo and Bremner 1993). About 90% of all deaths in boating accidents result from drowning with the remaining 10% caused by blunt trauma (Gomez et al. 1991).

Several studies have shown a strong association between elevated concentrations of alcohol and drowning, particularly among males. For example, Cairns et al. (1984) reported that over 50% of drowning victims had alcohol detected in their system, with 37% having a level greater than 0.10%; of 225 victims included in the study, 171 were male. Davis and Smith (1985) reported that 64% of drowning victims were under the influence of alcohol; of 346 victims, 286 were
male. In a study that illustrated the similarity between drowning victims and individuals fatally injured in highway accidents, Dietz and Baker (1974) state that 47% of drowning victims had alcohol in their system ranging from 0.03% to 0.26%. Plueckhahn (1984) found that of 135 accidental drownings, 122 were male. Finally, Wintemute et al. (1990) reported that 59% of male deaths due to drowning involved alcohol.

In the US, the reporting of boating accidents is required under the Federal Boat Safety Act (Title 46) and is the responsibility of the US Coast Guard in conjunction with local law enforcement agencies. The nationwide Boating Accident Report System (BARS) contains information on recreational boating accidents reported to the Coast Guard since 1969. The owner or operator of a vessel must report a boating accident when it involves (1) loss of life or disappearance from a vessel; (2) injury requiring treatment beyond first-aid, or (3) property damage exceeding $500 or complete loss of vessel. Reports by owners or operators may be supplemented by investigations of the Coast Guard or state authorities.

Early forms of the Boating Accident Report did not explicitly ask for data on alcohol or other drug use, although investigators could include such information in narratives. To improve reporting of alcohol and drug use in boating accidents, the US Coast Guard revised the Boating Accident Report form in 1987 and included an addendum. For the operator of the boat and passengers, the Addendum requests information on tests for alcohol (yes/no); the bodily fluid tested (blood, breath, urine, other); qualitative results of tests (+/-); and BAC (%). Note that alcohol testing is not mandatory in the investigation of boating accidents and requests for alcohol tests may only be made for those accidents where the investigator has reason to suspect, or has determined, that the operator was impaired or that alcohol was otherwise involved. Most usually, only qualitative information on alcohol use is found in BARS, even for operators of accident-involved boats in which at least one occupant died. Based on data from BARS, annual numbers of fatalities in recreational boating accidents gradually decreased in the US, from 1,063 in 1984 to 784 in 1994. For fatal boating accidents, patterns similar to those found for alcohol and fatal road accidents included highest percentages of "alcohol involvement" on weekend days, during nighttime hours, and in younger age groups.

Factors that can influence measured concentrations of alcohol.

Compared to most other chemicals, the pharmacokinetics of ethanol consumed as beverage alcohol — that is, the absorption, distribution, metabolism, and excretion of alcohol — is relatively simple and, thus, reasonably predictable. In fact, unusual distributions of alcohol among bodily fluids — for example, unexpectedly high or low ratios of concentrations between certain bodily fluids — can reflect abnormal conditions or processes. Of particular interest here is the postmortem formation of alcohol by bacteria, which can complicate or even confound the
meaning and interpretation of concentrations of alcohol.

From the moment of consumption through time of sampling, many factors can affect measured concentrations of alcohol in different bodily fluids and, thus, the ability to distinguish between antemortem consumption of beverage alcohol and postmortem production of ethanol. The most direct and informative data relate to ingestion itself, for example, the type and amount of beverage alcohol consumed over what period of time prior to accidental death. In cases of accidental death, however, this kind of information is often not available or not reliable. Other factors relate to analytical toxicology, for example, proper storage of specimens after sampling, including use of preservatives; methods of analysis; and procedures of quality assurance. Standard practices in most laboratories that participate in postmortem investigations should minimize the influence of such factors on results of chemical tests.

For the postmortem interpretation of concentrations of alcohol, other factors of concern include: the time elapsed between accident and recovery of the body; the conditions to which the body was exposed, especially ranges of temperature; the kind of bodily fluids available and obtained for chemical testing; and the degree of decomposition evidenced by specimens (e.g., Chikasue et al. 1988; Christopoulos et al. 1973; Collom 1974; Gilliland and Bost 1993, Nanikawa and Kotuko 1974; Plueckhahn 1967, 1972; Wintemute et al. 1990; Zumwalt et al. 1982). In general, the greater the time elapsed between accident and recovery of the body (for example, 24 hours or longer), and the more elevated the temperature of the body prior to recovery, the more likely postmortem formation of alcohol becomes.

**Antemortem consumption versus postmortem formation of alcohol.**

As chances for the postmortem formation of alcohol increase, so does the importance of considering the nature and number of different specimens needed for analysis. Elevated concentrations of alcohol (e.g., 0.15%) do not necessarily rule out endogenous production. At the same time, lower concentrations of alcohol (e.g., 0.03%) do not eliminate possible consumption of alcoholic beverages prior to death. Comparing concentrations of alcohol in different areas of the body to those expected given normal distribution of alcohol becomes a key step in distinguishing antemortem consumption from postmortem formation of alcohol. Thus, two or more different bodily fluids or specimens of tissue are usually required for reliable judgement.

Samples of bodily fluids or tissues should be taken from intact chambers and away from locations of trauma (Winek et al. 1995). For determining meaningful alcohol concentrations, several researchers have recommended bile as a good indicator of blood alcohol concentration (e.g., Backer 1980; Briglia et al. 1992; Budd 1982). Other bodily fluids and tissues
investigated include femoral blood (Plueckhahn 1967), synovial fluid (Winek et al. 1993), bone marrow (Winek et al. 1981), vitreous humor (Felby and Olsen 1969; Leahy et al. 1968; Pounder and Kuroda 1994; Zumwalt et al. 1982), liver (Jenkins et al. 1995), urine (Kuroda et al. 1995; Stevens et al. 1966), skeletal muscle (Nanikawa et al. 1982), and serum (Rainey 1993; Winek and Carfagna 1987). Advantages and disadvantages of different specimens are discussed in the cited literature.

Briglia et al. (1992) studied the distribution of ethanol in postmortem specimens in which alcohol was most likely not produced endogenously. They used the following criteria to select cases: presence of ethanol at a mean concentration of 0.05% or greater; absence of gross trauma to the body; absence of significant decomposition; and a complete autopsy. Of interest, Briglia et al. found no statistical differences between concentrations of alcohol in blood, brain, vitreous humor, cerebrospinal fluid, and pericardial fluid. They did report, however, wide variability in concentrations of alcohol in various blood samples from some of the same cadavers examined. Gilliland and Bost (1993) also investigated the postmortem synthesis and distribution of alcohol. They specified criteria to identify cases in which endogenous production of alcohol was likely: presence of alcohol in only one of more than one fluid or tissue specimen; atypical distributions of alcohol among different specimens; concentrations of “higher alcohols” (e.g., 2-propanol) in specimens; and reliable information that alcohol was not consumed prior to death.

In 1989, during a gunnery exercise aboard the USS Iowa, an explosion occurred in one of the turrets, killing 47 people. Autopsies were done to determine causes of death, and toxicologic analyses were performed to measure concentrations of carbon monoxide, cyanid (CN), volatiles (including ethanol), and a comprehensive array of psychoactive drugs. Mayes et al. (1992) reported findings of the toxicologic investigation. Because of flooding of the turret, many of the bodies were significantly decomposed, which increased the likelihood of postmortem formation of alcohol due to microorganisms and, thus, increased the need for careful interpretation of findings related to alcohol.

According to Mayes et al. (1992), there was no evidence suggesting any of the victims had consumed alcoholic beverages prior to the explosion. Nonetheless, alcohol was detected in 23 of the 47 victims in concentrations ranging from 0.01 to 0.19 g/dL. Mayes et al. (1992) considered that 13 of the cases with alcohol concentrations 0.03 g/dL or less could “rather easily be attributed to postmortem ethanol formation” (p.1356). In other cases with higher concentrations of alcohol in blood, analyses of specimens other than blood showed much lower concentrations of alcohol than would otherwise be expected, thus making postmortem formation the most likely explanation for elevated BACs observed in some victims.
In summary, a review of the literature suggests a general approach to the interpretation of alcohol concentrations in postmortem specimens, especially for victims of boating accidents whose bodies are recovered many hours afterwards. The obvious point of departure is whether or not alcohol is detected in any specimen taken from the victim. If only one viable specimen with minimal signs of putrefaction is obtained for determining alcohol concentration, then elevated concentrations above 0.06% coupled with reliable information on consumption of beverage alcohol prior to the accident will provide solid grounds for the opinion of antemortem consumption. Comparable or even higher alcohol concentrations in single putrefied specimens, with no information about drinking prior to the accident, simply represent equivocal evidence.

If two or more specimens are obtained for analysis, then one must first consider the quality of the specimens and then judge whether the concentrations of alcohol are consistent with, or divergent from, known patterns of distribution of alcohol in bodily fluids and tissues. Concentrations of alcohol that differ significantly from ranges of ratios reported in toxicologic studies, coupled with longer times of submersion at moderate temperatures strongly indicate endogenous production of alcohol. If concentrations of alcohol in various specimens are both consistent with observed ratios and higher than 0.06%, then antemortem consumption of beverage alcohol is most likely. Lower concentrations of alcohol in specimens consistent with usual patterns of alcohol distribution leave open the question of antemortem consumption versus postmortem formation of alcohol: Either or both sources of alcohol detected in specimens may have contributed. In such cases, pre-accident activity and drinking behaviors as well as strong circumstantial evidence (e.g., time of day and day of week of the accident, age and sex of victim, empty containers of beverage alcohol at the scene, etc.) may support expert judgement.

Case Study.

A representative case involved a young male, 22 years of age, who invited three acquaintances for a late-night cruise in a boat borrowed for that purpose without permission from the owner. At 2:30 A.M. on a weekend night during the summer, about 90 minutes after the party of four was last seen leaving a bar, the boat operated by the 22 year-old collided at high speed with a partially submerged dredging pipe being pulled across a portion of a channel they were travelling. Three of the young people were killed, including the operator. The operator's body was recovered about 56 hours after the accident, and an autopsy took place about 78 hours after the accident. Specimens of chest fluid and bile, neither of which evidenced "toxicologically significant degrees of decomposition", were obtained for analysis of alcohol. The handling and storage of specimens, as well as the analytical procedures in the laboratory, met standards of forensic toxicology. The concentration of alcohol in both specimens was 0.22%, much higher
than might be expected given that no one observed or remembered the operator drinking "excessively" prior to the crash. Nonetheless, the presence of alcohol in both chest fluid and bile in similar concentrations well above those most probable with endogenous production strongly indicated antemortem consumption of alcohol. This evidence was also consistent with the time and circumstances of the accident, which epidemiologic data show have a positive association with alcohol-related boating accidents. Moreover, the operator of the boat had a documented history of problems with alcohol, including prior arrests for driving while intoxicated. Thus, findings of toxicologic analysis; information about the pre-crash activity and drinking behavior of the operator; and other, more circumstantial evidence led to firm conclusions (1) that the operator was indeed impaired by alcohol at the time of the boating accident and (2) that the highly elevated concentrations of alcohol found in chest fluid and bile were due primarily to antemortem consumption, not endogenous production of alcohol postmortem.

REFERENCES

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