

SHORT REPORT

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Epidemiology of alcohol-related unintentional drowning: is post-mortem ethanol production a real challenge?

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Abstract

Background: Post-mortem (PM) ethanol production may hamper the interpretation of blood alcohol concentration (BAC) in victims of drowning. Different exclusion criteria (e.g. cases with low BAC or with protracted interval between death and toxicological analysis) have been proposed with no factual figures to reduce the potential bias due to PM ethanol production when examining the prevalence rates for alcohol-related drowning. The aim of this study is to verify the extent to which PM alcohol production may affect the accuracy of studies on drowning and alcohol.

Findings: Unintentional fatal drowning cases ($n = 967$) for which a full medico-legal autopsy and toxicological analysis was performed, in Finland, from 2000 to 2013, and relevant variables (demographic data of the victims, month of incident, PM submersion time, blood alcohol concentration, urine alcohol concentration (UAC), vitreous humour alcohol concentration (VAC) were available. Overall, out of 967 unintentional drownings, 623 (64.4%) were positive for alcohol (BAC > 0 mg/dL), 595 (61.5%) had a BAC \geq 50 mg/dL, and 567 (58.6%) a BAC \geq 100 mg/dL. Simultaneous measurements, in each victim, of BAC, UAC, and VAC revealed PM ethanol production in only 4 victims (BAC: 25 mg/dL – 48 mg/dL). These false positive cases represented 0.4% of drownings with BAC > 0 mg/dL and 14.3% of drownings with BAC > 0 mg/dL and < 50 mg/dL.

Conclusions: The present study suggests that PM ethanol production has a limited impact on research addressing the prevalence rate for alcohol-related drowning and that the use of too rigorous exclusion criteria, such as those previously recommended, may lead to a significant underestimation of actual alcohol-positive drowning cases.

Keywords: Unintentional drowning, Alcohol, Post-mortem ethanol production, Epidemiology

Background

Post-mortem (PM) endogenous alcohol production may hamper accurate assessment of blood alcohol concentration (BAC) in victims of fatal injuries (Kugelberg and Jones 2007; Appenzeller et al. 2008). A range of micro-organisms can produce ethanol via the process of fermentation, mainly by using glucose as a substrate (Corry 1978). PM ethanol production, if it occurs, usually remains below 70 mg/dL (Gilliland and Bost 1993), although PM production has been reported at even higher than 150 mg/dL (Corry 1978).

PM alcohol production is recurrently mentioned in studies on drowning and alcohol (Lunetta et al. 2004; Ahlm et al. 2013; Pajunen et al. 2017). Accurate blood alcohol assessment is crucial as ethanol has been identified as a major risk factor for drowning especially in adults. Cut-off times for toxicological sampling (Schuman et al. 1978; Hoxie et al. 1988; Wintemute et al. 1990) or exclusion of cases with low BAC (Ahlm et al. 2013; Peden et al. 2017) have been proposed to minimize false-positive alcohol-related cases. However, most studies focus on BAC alone and overlook the potential of concurrent urine and vitreous humour analysis to discriminate ante-mortem (AM) alcohol ingestion from any PM artefact.

The aim of this study was to estimate to what extent PM alcohol production may hamper epidemiological

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studies on drowning and alcohol by reducing their accuracy.

Materials and methods

Design and setting

This retrospective study focuses on drownings that underwent a medico-legal autopsy and toxicological analysis in Finland from 2000 to 2013. Of 2563 fatal drownings, 2015 were identified as unintentional using ICD-10 external cause codes for drowning (V90, V92, W65-W74). Among these, the following cases were excluded: a) date of death not certain or date of body retrieval unspecified ($n = 736$), b) blood samples or both urine- and vitreous-humour samples missing or not analysed for alcohol ($n = 262$) c) deaths at hospital or in an ambulance ($n = 86$). After these exclusions, the study included 967 unintentional drownings for which BAC was available, and urine or vitreous humour or both were also tested for alcohol.

The main assumption was that cases with PM endogenous alcohol production disclose ethanol in blood samples but not in the urine or vitreous humour or in both, as such substrates are less susceptible than blood to PM ethanol production (Kugelberg and Jones 2007).

Data collection and analysis

The data were collected from two sources (Pajunen et al. 2017). The free-text of the death certificates issued by a medical examiner and supplied by Statistics Finland (permission TK53-277-15) were manually screened for information as to date of death and of body retrieval, site of death (bath, lake, river, pond, sea, well, canal, rapids, ditch, pool, other), and pre-drowning activities (boating, bathing, wading, swimming, land traffic, falling, swimming, diving, other) by a member of our research group. BAC, urine alcohol concentration (UAC), and vitreous humour alcohol concentration (VAC) were extracted from the database of the Laboratory of Forensic Toxicology, Department of Forensic Medicine, University of Helsinki. The relevant data were linked by individual autopsy-case codes.

The same laboratory (Testing Laboratory No. T115) performed PM toxicological analysis for all medico-legal autopsies performed in Finland during the study period.

Its analytical methods have been accredited since 1997 by the Centre for Metrology and Accreditation according to SFS-EN 45001 ISO/IEC Guide 25. The blood and urine samples were usually collected at the beginning of the internal examination directly from the femoral vein and urinary bladder; the vitreous humour samples by penetrating the organs with a sterile needle and syringe. The samples were preserved in tubes containing sodium fluoride. BAC, UAC, and VAC were measured by a dual-column head-space gas-chromatography. Four independent measurements are required for the final mean concentration value.

Findings

Overall, among the 967 unintentional drowning victims, 595 (61.5%) had a BAC ≥ 50 mg/dL and 28 (2.9%) a BAC > 0 and < 50 mg/dL (Table 1). In 220 (22.8%) cases, both UAC and VAC were available; in 943 (97.5%), UAC but not VAC; and in 24 (2.5%), VAC but not UAC was available.

The monthly distribution of overall unintentional drownings showed a peak during the summer months. Most victims were recovered from water ≤ 1 day PM. A statistically significant difference appeared in distribution of death months between groups with BAC 0 mg/dL and BAC ≥ 50 mg/dL ($p < 0.05$, χ^2 -test; JMP Pro 13.2.1). No statistically significant difference, however, emerged in death months between groups with BAC 0 mg/dL and BAC > 0 and < 50 mg/dL. In addition, a significant difference emerged in distribution of submersion times between groups with BAC 0 mg/dL and BAC > 0 and < 50 mg/dL, and between groups with BAC 0 mg/dL and BAC ≥ 50 mg/dL ($p < 0.05$, χ^2 -test; JMP Pro 13.2.1) (Tables 1 and 2).

In comparison of BAC, VAC, and UAC, no cases that were both BAC-positive and VAC-negative appeared. Only four victims (0.4% of unintentional drownings) were BAC-positive and urine-negative. Such cases, all with BAC < 50 mg/dL (Table 3), raise the suspicion of PM alcohol production. These drownings occurred in March, April, June, and August¹ (see Additional file 1) and the victims' PM time of submersion ranged from less than 1 day to 50 days. Worth mentioning is that among cases with PM

Table 1 Unintentional drownings, 2000–2013, by PM submersion time and BAC

PM submersion time	No of cases	BAC 0 mg/dL (%)	0 < BAC < 50 mg/dL (%)	BAC ≥ 50 mg/dL (%)
< 1 day	776	296 (38.1)	15 (2.0)	465 (59.9)
1 day	70	26 (37.1)	0 (0)	44 (62.9)
2 to 6 days	69	11 (16.0)	5 (7.2)	53 (76.8)
≥ 7 days	52	11 (21.1)	8 (15.4)	33 (63.5)
Total	967	344 (35.6)	28 (2.9)	595 (61.5)

BAC blood alcohol concentration, PM post-mortem

Table 2 Unintentional drownings, 2000–2013, by months and BAC

Months of death	No of cases	BAC 0 mg/dL (%)	0 < BAC < 50 mg/dL (%)	BAC ≥ 50 mg/dL (%)
January–April	99	56 (56.6)	4 (4.0)	39 (39.4)
May–August	687	207 (30.1)	20 (2.9)	460 (67.0)
September–December	181	81 (44.8)	4 (2.2)	96 (53.0)
Total	967	344 (35.6)	28 (2.9)	595 (61.5)

BAC blood alcohol concentration

submersion time ≥ 7 days, of which more than half occurred during the warm season, of 52 cases, 50 showed no evidence of PM ethanol production.

Other 619 (99.4%) cases that were BAC-positive, alcohol was detectable also in urine or vitreous humour or in both, suggesting AM ingestion.

Discussion

Alcohol is the most important single contributing factor in adult drowning (Driscoll et al. 2004; Lunetta et al. 2004; Peden et al. 2016; Pajunen et al. 2017). The present survey shows that 61.5% of the victims in Finland had BAC ≥ 50 mg/dL, a percentage consistent with findings of earlier studies performed in Finland (Lunetta et al. 2004; Pajunen et al. 2017).

PM endogenous alcohol production can, in principle, lead to overestimation of both the number of alcohol-positive drownings in large series and the actual BAC at time of death in particular cases. Some authors have suggested the use of cut-off times between death and sampling for alcohol analysis (ranging from 6 h to 72 h), in order to exclude cases with potential PM alcohol production (Schuman et al. 1978; Hoxie et al. 1988; Wintemute et al. 1990). Such cut-off times can, however, considerably reduce the percentage of actual drownings considered alcohol-positive. In the present study, use of a 24-h cut-off would exclude at least 20.5% of alcohol-positive drownings, a 48-h cut-off 12.4%, and a 72-h cut-off 11%.

Other drowning studies exclude low BAC values (< 50 mg/dL) to avoid any bias related to PM alcohol production (Ahlm et al. 2013; Peden et al. 2017). In Finland in 2000–2009, approximately 60% of alcohol-positive unintentional drowning victims had BAC ≥ 200 mg/dL (Pajunen et al. 2017), and in this survey, only 28 (2.9%) had BAC > 0 and < 50 mg/dL. Exclusion of cases with BAC < 50 mg/dL would therefore in Finland have had a less striking effect

than had we used cut-off times. In countries reporting drowning to occur at lower BAC (Warner et al. 2000; Browne et al. 2003; Peden et al. 2017), exclusion of cases with low BAC may, however, have more tangible effects on the percentage of alcohol-positive drowning. Moreover, this approach would hamper studies on the effects on drowning of low BAC, with low BAC also being a potential risk factor for unintentional injuries (Ling et al. 2010; Amlung et al. 2014).

In the present survey, the higher percentage of drowning with BAC < 50 mg/dL during the summer months and in bodies with protracted PM submersion time may suggest a relationship between temperature- and time-dependent putrefaction and PM alcohol production. This hypothesis, nevertheless, was not demonstrated in our series. Indeed, several factors, including pre-drowning activities, exposure to water, patterns of alcohol consumption in aquatic settings, and circumstances of drowning (Lunetta et al. 2004; Bessereau et al. 2015), may well explain BAC differences across the seasons.

No studies have thus far addressed PM alcohol production in large series of drownings by comparing BAC, UAC, and VAC (Hadley and Smith 2003). PM ethanol production is usually presumed when BAC is positive and UAC and VAC are negative (Levine et al. 1993). Indeed, urine and vitreous humour are less prone to PM ethanol production than is blood, because these substrates do not contain—in a healthy individual—a significant amount of glucose, and the risk for micro-organism contamination is lower than in blood (FINE 1965; Kugelberg and Jones 2007; Belsey and Flanagan 2016).

Interestingly, the current study disclosed only four cases with potential PM ethanol production. These drownings represented 0.4% of overall unintentional drownings but surprisingly as much as 14.3% of drownings with BAC < 50 mg/dL, higher than the corresponding percentage (8%) in a US study including

Table 3 Unintentional drowning, 2000–2013: potential cases with PM ethanol production

Age (yrs), all male	BAC (mg/dL)	UAC (mg/dL)	VAC (mg/dL)	Month of death	Submersion time (days)	Activity, site	Witnesses
54	46	0	NA	April	0	falling, sea	NA
56	36	0	NA	June	3	falling, pond	no
48	25	0	NA	August	24	boating, lake	no
2	48	0	NA	March	50	falling, river	yes

BAC blood alcohol concentration, UAC urine alcohol concentration, VAC vitreous humour concentration, NA not available

381 forensic autopsies with BAC < 50 mg/dL (Levine et al. 1993).

Some caution is essential regarding the interpretation of these results. First, victims who were BAC-positive and UAC-negative may have ingested alcohol shortly before drowning (Jones 2006). The lack of measured VAC concentrations among these cases hampers verification of this hypothesis. Alcohol ingestion shortly before death may have occurred, for instance, in one unwitnessed cold-water drowning with PM submersion time < 24 h, in which the victim's BAC was 46 mg/dL and he was UAC-negative. In vitro experiments show that PM endogenous ethanol production does not generally occur in temperatures < 4–5 °C, although it is still possible (Vuori et al. 1983) and takes place at the earliest after 24 h (Boumba et al. 2012; Boumba et al. 2013). Since vitreous humour was unavailable, the interpretation of this case remains a matter for speculation, however. Therefore, vitreous humour, when ever possible, should always be sampled at autopsy and tested for alcohol.

Second, we did not consider UAC/BAC ratios. UAC/BAC ratios < 1 may suggest drowning during the ethanol-absorptive phase (Jones 1992) or, alternatively, suggest PM ethanol production in urine or passive diffusion of ethanol from the gut to the urinary bladder (Kugelberg and Jones 2007). UAC/BAC ratios in drowning victims will be addressed in an ongoing study by our research group. Third, the presence of alcohol in urine and vitreous humour do not always indicate AM ingestion, because PM ethanol production may occur in these substrates, for instance in those victims with diabetes or in bodies with extensive injuries (Kugelberg and Jones 2007). As a further limitation, the present study allowed identification of drowning cases in which alcohol in victims' blood may have been produced entirely PM; such data were of no value in evaluating overestimation of BAC, because of PM ethanol production in cases who had indulged in actual AM consumption.

In medico-legal cases involving potential criminal or civil litigation, a detailed case-by-case assessment of PM ethanol production remains crucial. It should include evaluation of the victim's medical history and the circumstances leading to drowning, and also comparison of BAC, UAC, VAC, and analysis of putrefactive alcoholic indicators (e.g. n-propanol) and of ethanol metabolites (e.g. glucuronide), as well as including bacterial culture, molecular analysis, and fermentation test to identify micro-organism capable of producing PM ethanol (Vuori et al. 1983; Moriya and Hashimoto 2004; Ziavrou et al. 2005).

The present survey, however, suggests that, at least in Finland, PM endogenous alcohol production has a limited impact on epidemiological research on drowning and alcohol. Using too rigorous cut-off criteria, such as those previously recommended, may lead to significant

underestimation of actual alcohol-positive drowning cases. This assumption should be verified by means of combined blood, urine and vitreous humour testing in other countries and settings, where higher ambient temperature and protracted PM submersion times may boost the putrefaction process and enhance PM alcohol production.

Endnotes

¹The surface temperatures of inland waters are measured during the open water season by Finnish Environment Institute. In Finland the inland waters typically freeze in November–December and the ice break-up in April–May. The peak temperatures are reached in July and August. The lowest mean, mean and highest mean temperatures (°C) of inland water in years 2000, 2006 and 2013 are presented in Additional file 1.

Additional file

Additional file 1: Inland waters mean temperatures in Celsius degrees during years 2000, 2006 and 2013. (DOCX 15 kb)

Abbreviations

AM: Ante-mortem; BAC: Blood alcohol concentration; PM: Post-mortem; UAC: Urine alcohol concentration; VAC: Vitreous humour alcohol concentration

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Availability of data and materials

The data that support the findings of this study are stored at the Department of Biomedicine, Pathology and Forensic Medicine, University of Turku but restrictions apply to their public availability. Restrictions apply also to the data provided by Statistics Finland, which were used under license (permission TK53-277-15) for the current study, and so are not publicly available.

Authors' contributions

PL and TP were responsible for the planning of the study and contributed to the analysis and interpretation of the data, drafting and revising the manuscript. EV contributed to the interpretation of the data and revised the manuscript. The final manuscript version was approved by all authors.

Ethics approval and consent to participate

This study was conducted retrospectively as a register study and no ethical approval was required.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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