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ORIGINAL ARTICLE

Practical use of ethyl glucuronide and ethyl sulfate in postmortem cases as markers of antemortem alcohol ingestion

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Abstract In postmortem toxicology, it could be difficult to determine whether a positive blood ethanol concentration reflects antemortem ingestion or postmortem synthesis of alcohol. Measurement of the nonoxidative ethanol metabolite ethyl glucuronide (EtG) has been suggested as a marker of antemortem ingestion of alcohol, but EtG might degrade postmortem which could make interpretation difficult. So far, the published articles concern EtG only. Another nonoxidative metabolite, ethyl sulfate (EtS), which is more stable, has therefore been included in this study. We present a material of 36 deaths where postmortem formation of ethanol was suspected and where both EtG and EtS were measured in blood and urine to assist the interpretation. In 19 cases, EtG and EtS were positive in the body fluids analyzed. The median concentration of EtG and EtS in blood was 0.4 (range 0.1–23.2) and 0.9 mg/L (range 0.04–7.9), respectively. The median concentration of EtG and EtS in urine was 35.9 (range 1.0–182) and 8.5 mg/L (range 0.3–99), respectively. In another 16 cases, there was no trace of EtG or EtS in the specimens analyzed. In one case, there was inconsistency between the results of EtG and EtS; they were both positive in urine, while only EtS was positive in blood. This study showed that, out of 36 cases, antemortem ingestion of alcohol was very likely in 19 and unlikely in 16, according to EtG and EtS results. In the last case, the interpretation was more difficult. One possible explanation would be postmortem degradation of EtG in blood.

Keywords Ethanol · Postmortem · EtG · EtS

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Introduction

Postmortem formation of ethanol is a significant problem in forensic toxicology [1–4]. Although this is prevented by routines applied in sampling, storage, and analysis in most laboratories, as addition of preservatives and storage at 4ºC [5, 6], it still occurs in a number of cases. It was previously suggested that 50% of ethanol findings at the level of 0.1 g/L could be explained by postmortem formation [7], but the frequency will decrease at higher ethanol levels. The findings are often irrelevant as the cause of death, as the concentrations are usually too low, but they could anyway be relevant and of major importance in for instance drivers or pilots in air plane accidents. Also, numerous cases with postmortem formation of blood alcohol concentrations above 1.5 g/L are reported in the literature [1, 8, 9].

Different criteria, like case history, distribution of ethanol between different body fluids, degree of putrefaction of the corpse, and detection of other putrefactive products like *n*-propanol, are traditionally used to determine the origin of a postmortem ethanol finding [9, 10]. However, a significant number of cases could not be classified with great certainty. The nonoxidative ethanol metabolites ethyl glucuronide (EtG) and ethyl sulfate (EtS) have previously been investigated as markers of antemortem formation of alcohol [11–13]. Stability has been studied quite thoroughly in vitro, indicating that EtG could be very unstable and totally disappear, at least from blood, if the corpse was subject to putrefaction before sample collection [14–16]. This instability demands presence of bacteria as well as high temperature. After adding of preservatives and refrigerating, EtG was stable [14, 17]. Also, some researchers have found formation of EtG in the presence of bacteria [18]. On the other hand, EtS has been shown not to degrade or being formed under different conditions postmortem [14, 15, 18], although a very

recent publication, under extreme conditions, found some instability also of EtS [19]. Both false negative and false positive results could therefore occur for EtG, while such errors appear to be less probable for EtS. Considering the available research, a positive result for both EtG and EtS would therefore be a very strong indication for alcohol ingestion.

In vivo studies have shown that EtG and EtS measured in blood would indicate alcohol ingestion during the latest 24 h, while positive results in urine could arise from ingestions a couple of days earlier [20]. In that way, blood would be the most useful medium. On the other hand, stability problems for EtG could be less pronounced in urine, mainly caused by higher concentrations initially [16]. The strongest evidence would therefore be obtained if interpreting results from blood and urine together.

Reports on the practical use of EtG and EtS in postmortem cases are missing in the literature, but a small number of case reports have been published the latest years [21–23], in addition to our previous publications of larger materials [11, 16]. With the exception of the case report from Politi et al. [23], all these articles concern only EtG. This is a weakness considering the assumed difference in stability between them. We therefore present a material of 36 postmortem cases where postmortem formation of ethanol was considered as a possibility and where both EtG and EtS were used to verify or disprove this suspicion. The EtG and EtS results are compared to the traditional criteria (case history, distribution of ethanol between different body fluids, degree of putrefaction of the corpse, and detection of other putrefactive products) for evaluating postmortem alcohol formation.

Materials and methods

This study presents cases which were handled according to standard routines at the Norwegian Institute of Public Health and studied retrospectively. Approximately 1,700 forensic autopsy cases are received for toxicological analyses each year, constituting 90% of the total amount in Norway. Samples of blood (preferably from the femoral vein), urine, and possibly other matrices are collected by the forensic pathologist and submitted for analysis together with a laboratory form which includes the case history (especially information about drug use), postmortem interval, and information about putrefaction of the corpse, among others.

During the period June 2007–December 2008, cases where postmortem formation of alcohol was suspected were routinely analyzed for EtG and EtS. These are presented in this article. The main criterion for such suspicion was alcohol concentration in blood or other media below 0.5 g/L, but the following additional criteria were also assessed: no alcohol use before death according to the case history (both chronic alcoholism and acute intake before death were recorded), unusual distribution between different body fluids, reported putrefaction of the corpse, and *n*-propanol detected. The determination whether to suspect postmortem alcohol formation was made after an overall assessment of all these criteria, but there was no definite rule how many had to be present. If for instance there was a substantial difference between blood and urine ethanol concentrations, additional criteria were not required. Postmortem ethanol formation was also suspected in cases where the ethanol level was higher than 0.5 g/L, if there were other important reasons (extreme putrefaction, the deceased being a teetotaller or large difference between ethanol in different body fluids).

Sterilin tubes (Bibby Sterilin, UK) containing 1% *w/v* potassium fluoride were used for the collection of both blood and urine. Samples were stored at 4ºC in the laboratory until analysis. Analysis of ethanol and detection of *n*-propanol was performed in blood and urine by headspace gas chromatography equipped with a flame ionization detector [24].

EtG and EtS were analyzed in blood using a previously published liquid chromatography–mass spectrometry (LC–MS) method [11, 25]. All methodological details for EtG and EtS in blood are given in these references. EtG and EtS were analyzed in urine using also a previously published LC–MS method [11], which contains methodological details for EtG. EtS in urine was analyzed as follows: EtS was supplied by TCI (Tokyo Chemical Industry, Tokyo, Japan) and EtS-d_5 (internal standard) by Lipomed (Cambridge, MA). The MS instrument, a Waters ZQ 2000 single-hexapole MS with an electrospray ionization (ESI) interface was operated in negative mode for detection of EtS and EtS-d_5 at the following mass-to-charge ratios: *m/z* 125.1 for EtS and *m/z* 130.1 for EtS-d_5. EtS was identified by comparing the retention times and ions with corresponding compounds in reference standard and control samples. Limit of detection and limit of quantification for EtS in urine were 0.05 and 0.1 mg/L, respectively. Day-to-day variation at concentration level 0.1 mg/L was 12% and 14% at concentration level 7.6 mg/L ($n=10$). Intraday variations at the same concentration levels were 5.1% and 3.1%, respectively ($n=10$). The EtS calibration curve was linear up to 25 mg/L.

An administrative cutoff in blood was set at 0.09 mg/L for EtG and 0.03 mg/L for EtS. In urine, this administrative cutoff level was 0.2 mg/L for EtG and 0.1 mg/L for EtS. Only results above these values were reported as positive, and results below are reported as not detected (n.d).

Determination of EtG and EtS were performed after the results of ethanol analysis were available, most often a very few days after arrival. Preferably, both blood and urine were analyzed for EtG and EtS, but in some cases with

restricted amount of material available, only one material was used. Two parallels were analyzed in each medium. For positive results, the presence of EtG and EtS in both blood and urine was considered forensically accepted proof.

If two media were not available or if the results differed between blood and urine, another verification method using an ultra performance liquid chromatography–tandem mass spectrometry (UPLC–MS/MS) technique was performed: The samples were analyzed using modifications of the above-mentioned methods. LC was performed using an integrated system from Waters (Waters Corp., Milford, MA, USA) with an Acquity™ Ultra Performance LC. Chromatographic separation was performed at 65°C on an Acquity UPLC® HSS T3 column (2.1×100 mm, 1.8 µm particle size, Waters, Wexford, Ireland) using gradient elution with a mobile phase consisting of 25 mM formic acid (A) and methanol (B). The flow rate was 0.4 mL/min. A gradient was carried out starting from 1% B, increased to 20% over the next 2 min and then stepped to 90% within 0.01 min and maintained for 2.99 min, before returning to its initial conditions within 0.5 min. Total run time was 3.5 min. Injection volume was 2.5–3 µL. MS detection was performed on a Quattro Premier XE triple quadrupole mass spectrometer. Ionization was achieved using electrospray in the negative mode (ESI−) and multiple reaction monitoring (MRM). Data acquisition, peak integration, and calculation were interfaced to a computer workstation running MassLynx 4.1 SCN627 software. The following MRMs were used for detection: EtG 221.0>84.7, EtS 124.7>96.7, EtG-d_5 226.0>85.0, and EtS-d_5 129.7>97.7. An additional transition was used for blood analysis for both compounds. The retentions times for EtG and EtG-d_5 were 1.8 min and for EtS and EtS-d_5 1.1 min. This latter method was only used qualitatively, and the quantitative values from the first analysis (LC–MS method) are reported.

In addition, according to standard routines, blood samples were analyzed for illegal drugs and a selection of 64 medicinal drugs with toxic potential, according to standard routines. Urine samples were also analyzed for illegal drugs [26]. These results are not reported.

Statistics were calculated using SPSS for Windows, version 14.0. All concentrations are reported as median (range).

Results

During the 18-month study period, 2,585 postmortem cases were received for toxicological analyses at the Norwegian Institute of Public Health. Eight hundred forty-eight of these contained alcohol, 236 in low levels (<0.5 g/L in the media available for ethanol analysis). After an overall assessment of all the given criteria, postmortem formation of ethanol was suspected in 36 cases, and these were analyzed for EtG and EtS. In 19 cases, both EtG and EtS were positive. In another 16, both EtG and EtS were negative, while in one case, there were inconsistency between the results of EtG and EtS.

In the 19 cases where both EtG and EtS were positive, the median concentration of ethanol was 0.1 g/L (range n.d–0.7) in blood and 0.2 g/L (range n.d–2.3) in urine (Table 1). Individual details of each case are shown in Table 2. Fourteen cases were analyzed for EtG and EtS in blood and urine, two only in urine and three only in blood. The median concentration of EtG and EtS in blood was 0.4 (range 0.1–23.2) and 0.9 mg/L (range 0.04–7.9), respectively. The median concentration of EtG and EtS in urine was 35.9 (range 1.0–182) and 8.5 mg/L (range 0.3–99), respectively (Table 1). The median ratio between EtG and EtS in blood was 0.7 (range 0.1–4.2). This ratio in urine was median 2.2 (range 0.03–7.8).

In the 16 cases where both EtG and EtS were negative, the median concentration of ethanol was 0.2 g/L (range n.d–1.0) in blood and 0.2 g/L (range n.d–0.8) in urine (Table 1). Individual details of each case are shown in Table 3. In the cases where the case history included information about alcohol use, this was report of chronic alcoholism in four cases, while there was a suspicion of acute alcohol intake prior to death in one case. Nine cases were analyzed for EtG and ES in blood and urine, four only in urine and three only in blood. In all these cases, there was no EtG and EtS detected in blood or urine (Table 1).

In one case, the results differed between EtG and EtS. In this case, ethanol was detected in concentrations of 0.3 g/L in blood and 0.4 g/L in urine. EtG and EtS were positive in urine (12.1 and 3.2 mg/L, respectively). EtS was detected just above the cutoff level in blood, while EtG was not detected. In this case, *n*-propanol was detected, and putrefaction of the corpse was reported; and there was also report of alcohol ingestion in the case history.

Discussion

This work retrospectively studied the usefulness of EtG and EtS in routine forensic autopsies where postmortem ethanol formation was suspected. According to the available previous research, EtG and EtS together could be a reliable criterion for postmortem alcohol formation [11, 13, 15, 16, 23, 27, 28]. Therefore, in somewhat more than half of the cases studied in the present work, postmortem alcohol formation could be excluded with great certainty, as both EtG and EtS were detected in the media available for analysis. In the remaining somewhat less than half of the cases, postmortem alcohol formation could be concluded with great certainty, as there were no trace of EtG and EtS

Table 1 Levels of ethanol, EtG, and EtS in blood and urine in 19 cases where EtG and EtS were positive as well as 16 cases where EtG and EtS were negative

Group according to EtG and EtS results	Ethanol blood	Ethanol urine	EtG blood	EtS blood	EtG urine	EtS urine	Case history without alcohol *n* (%)	Unusual distribution *n* (%)	Putrefaction reported *n* (%)	*n*-propanol detected *n* (%)
EtG and EtS positive (*n*=19)	0.1 (n.d–0.7)	0.2[a] (n.d–2.3)	0.4 (0.1–23.2)	0.9 (0.04–7.9)	35.9 (1.0–182)	8.5 (0.3–99)	9 (47)	5 (26)	5 (26)	3 (16)
EtG and EtS negative (*n*=16)	0.2 (n.d–1.0)	0.2 (n.d–0.8)	n.d	n.d	n.d	n.d	11 (69)	3 (19)	5 (31)	6 (38)

This also presents the frequency of fulfillment of traditional criteria for postmortem alcohol formation (ethanol in gram per liter; EtG and EtS in milligrams per liter). Median and range values are given

n.d not detected

[a] In one case, vitreous humor was analyzed for ethanol instead of urine

in the media available for analysis. According to fulfillment of one or more of the traditional criteria for postmortem alcohol formation (low level of ethanol, no alcohol ingestion according to case history, unusual distribution of ethanol between different body fluids, reported putrefaction of the corpse, and detection of *n*-propanol), postmortem alcohol formation was initially suspected in all cases in both these groups. There was no major difference in the fulfillment of the traditional criteria between the two groups, but there were somewhat more frequent detection of *n*-propanol in the EtG and EtS negative group and also somewhat more frequent information about alcohol use in the EtG and EtS positive group (Table 1). If considering EtG and EtS together as reliable markers of antemortem alcohol ingestion, our overall assessment of the traditional criteria would have a low specificity.

One case in the present study showed different results for EtG and EtS. They were both positive in urine, while only EtS was positive in blood. The most possible explanation is degradation of EtG in blood, which originally had been present in a low concentration, according to the EtS result. Therefore, the detected ethanol was most probably ingested

Table 2 Levels of ethanol, EtG, and EtS in blood and urine as well as presence of putrefaction and *n*-propanol in 19 cases where EtG and EtS were positive

Ethanol blood (g/L)	Ethanol urine (g/L)	EtG blood (mg/L)	EtS blood (mg/L)	EtG urine (mg/L)	EtS urine (mg/L)	Putrefaction of the corpse?	*n*-propanol detected?
0.1	0.5	4.7	2.1	109.1	n.a	Y	N
n.d	1.4	4.2	2.2	53.6	21.6	N	N
0.1	0.2	2.5	1.3	181.8	7.0	Y	N
0.7	0.8	1.8	1.4	127.1	10.0	Y	Y
n.d	0.7	1.6	0.7	n.a	n.a	N	N
0.7	n.d	1.1	0.6	3.0	0.3	N	N
0.4	n.a	0.3	0.04	n.a	n.a	Y	Y
0.1	0.2	0.3	0.2	n.a	n.a	N	N
0.3	0.2	n.a	n.a	1.0	0.4	Y	N
n.d	0.2	0.2	0.1	38.2	2.8	N	N
n.d	0.1	0.08	0.9	15.9	23.2	N	N
n.d	0.1	0.1	0.1	33.5	7.1	N	N
0.1	0.2	0.7	1.6	1.5	27.0	N	N
n.d	0.1	0.3	0.5	143	24.2	N	N
n.d	2.3	23.2	7.9	167	44.0	N	N
n.d	0.1	n.a	n.a	9.1	1.1	N	Y
0.2	0.3	0.4	0.5	5.1	2.4	N	N
0.1	n.d	0.3	0.9	19.2	9.0	N	N
n.d	0.6	0.3	0.9	164	99.5	N	N

n.d not detected, *n.a* not available, *Y* yes, *N* no

Table 3 Levels of ethanol, EtG, and EtS in blood and urine as well as presence of putrefaction and *n*-propanol in 16 cases where EtG and EtS were negative

Ethanol blood (g/L)	Ethanol urine (g/L)	EtG blood (mg/L)	EtS blood (mg/L)	EtG urine (mg/L)	EtS urine (mg/L)	Putrefaction of the corpse?	*n*-propanol detected?
0.2	0.3	n.d	n.d	n.a	n.a	N	Y
0.5	0.1	n.d	n.d	n.d	n.d	N	Y
0.9	0.3	n.d	n.d	n.d	n.d	N	Y
0.2	0.4	n.d	n.d	n.d	n.d	Y	N
n.d	0.1	n.d	n.d	n.d	n.d	N	N
0.1	0.1	n.d	n.d	n.d	n.d	N	N
0.2	0.1	n.d	n.d	n.d	n.d	Y	N
1.0	n.a	n.d	n.d	n.a	n.a	Y	N
n.d	0.2	n.a	n.a	n.d	n.d	N	N
0.8	0.8	n.d	n.d	n.a	n.a	Y	Y
0.1	0.3	n.a	n.a	n.d	n.d	N	N
n.d	n.d	n.d	n.d	n.d	n.d	N	N
0.3	n.d	n.d	n.d	n.d	n.d	Y	N
n.d	0.1	n.a	n.a	n.d	n.d	N	N
0.2	0.2	n.a	n.a	n.d	n.d	N	Y
0.6	0.7	n.d	n.d	n.d	n.d	N	Y

n.d not detected, *n.a* not available, *Y* yes, *N* no

before death. This is accordingly one example of superior quality of EtS and shows that degradation of EtG could occur in routine forensic autopsy cases.

The situation where EtG was negative in blood and positive in urine was in accordance with our previous study, where only EtG was studied [16]. We then assumed that this was caused by total degradation of EtG from blood, but not from urine, a theory that was supported by the present study. In such cases, EtS yielded valuable information.

An interesting aspect is the ratio between EtG and EtS. Most previous studies addressing this question have found higher molar concentrations for EtG [29, 30]. Interestingly, the single case in which EtS has been measured postmortem found the opposite [23]. Lowering of the EtG concentration due to instability could be an explanation. This was further strengthened by the present results, as the ratio EtG/EtS in the present study was lower than previous results from living subjects in blood [20, 31]. For urine, there was no such difference [29, 30, 32], and a better stability of EtG in urine compared to blood could be hypothesized.

In the present material, instability of EtG resulting in total degradation from blood or urine was a relatively small problem, as there was only one case negative for EtG, but positive for EtS. The studies which reported instability of EtG have used extreme conditions [14–16, 28], which was apparently not the situation for more than one of these real cases. The amount of bacteria could have been too low, the temperature not sufficiently high, or the bacteria did not contain ß-glucuronidase, which is necessary for degradation of EtG to occur [14, 15]. On the other hand, bacteria and temperature were apparently sufficient for postmortem formation of ethanol to happen. This could indicate that postmortem affection of EtG stability demands more extreme conditions than ethanol formation or that the bacterial flora present is more likely to cause alcohol formation than degradation of EtG. The practical problem of EtG stability in routine materials was previously studied for clinical urine samples, and the findings were in accordance with ours as only four of 354 cases were negative for EtG and positive for EtS [30]. On the other hand, the number of cases in the present study was quite small, and including more cases could possibly reveal other findings. Also, we could not totally exclude that both EtG and EtS was lost because of instability, especially when considering the very recent publication reporting instability of EtS [19]. On the other hand, the reports of enhanced stability of EtS are more numerous [14, 15, 17, 18].

One result of the present study was an impression of the magnitude of cases in which EtG and EtS analyses could be valuable. During the 18-month study period, we suspected postmortem alcohol formation in 36 cases only, constituting approximately 5% of all ethanol positive forensic autopsy cases. One could also argue that all cases with low ethanol levels should be analyzed for EtG and EtS, increasing the use of these ethanol metabolites. In addition, it is important to suspect postmortem alcohol formation also in cases where the level of ethanol is higher, but when other factors speak against alcohol ingestion before death.

In conclusion, this study reported the use of EtG and EtS as markers of antemortem alcohol ingestion in routine forensic autopsies. Of the 36 cases in which postmortem alcohol formation was suspected, this was very unlikely in 19 cases and highly probable in 16, according to consistent results of EtG and EtS. In the last case, there were inconsistency between EtG and EtS results, and interpretation was therefore more complicated.

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