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CLINICAL RESEARCH



Ethylene glycol determination in serum: comparison between enzymatic assay and GC–MS on real samples

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ABSTRACT

Introduction: Ethylene glycol intoxication can be life-threatening, but clinical signs lack sensitivity and specificity. Hence, the diagnosis relies on the detection of this compound in serum. Chromatographic methods are the gold standard, but they are hard to routinely apply. As a result, we implemented an enzymatic assay on automated analyzers. The aim of this study is to review the results of real samples and compare both methods over 10 years.

Methods: The enzymatic assay relies on oxidation of ethylene glycol to glycolaldehyde. All results were confirmed by gas chromatography coupled to mass spectrometry. Both methods share a lower limit of quantification of 50 mg/L.

Results: During the study period, 405 unique patient samples were analyzed: 305 samples tested negative by both methods (75.3% true negative) while 34 tested positive on both instruments (8.4% true positive). Only four samples tested negative by enzymatic assay were positive with chromatography (<1% false negative) and chromatography failed to confirm 62 samples that screened positive by enzymatic assay (15.3% false positive), yielding a sensitivity of 89% and a specificity of 83%.

Discussion: The sensitivity and specificity of the enzymatic assay are high. Most of the false positive samples were below a treatment threshold (200 mg/L). Some false positive results could be explained by high blood concentrations of lactate and/or high lactate dehydrogenase activity but a small proportion remained unexplained. The main advantage of the enzymatic reagent is a significant reduction of turnaround times compared to chromatography.

Conclusions: A rapid enzymatic assay for ethylene glycol allows for quick adjustments to patient care, avoiding unnecessary treatment or, conversely, insufficient treatment. However, any positive result should be confirmed by chromatography and interpreted in the context of the patient's medical history and clinical findings.

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Introduction

Ethylene glycol is mainly used as a component of various antifreeze products, and other industrial applications [1]. In case of ingestion, ethylene glycol as a parent molecule is relatively non-toxic on its own, initially producing clinical findings resembling ethanol intoxication. Serious symptoms appear after a delay corresponding to metabolite formation [2]. The first step of ethylene glycol metabolism is its conversion via alcohol dehydrogenase to glycolaldehyde, which is rapidly metabolized to glycolic acid. This last compound is responsible for metabolic acidosis with elevated anion gap [3,4], the typical biological sign of ethylene glycol intoxication. Glycolic acid is further

metabolized to glyoxylic acid, which is in turn converted to oxalic acid. Crystals of calcium oxalate are formed and can precipitate, notably in the kidneys, leading to renal failure. Major clinical symptoms also include cardiopulmonary failure and seizures, and death may occur in the absence of medical intervention [2].

As metabolites are responsible for toxicity, treatment consists of preventing their formation, by administering a product that competes with alcohol dehydrogenase, the enzyme involved in the first step of the metabolism. Fomepizole or ethanol can be administered for this purpose [5,6]. Hemodialysis can also be applied to remove ethylene glycol and its metabolites [7,8].

Whether accidental or intentional, intoxication can be life threatening and requires urgent medical care. Unless the medical history clearly confirms ingestion, diagnosis can only be made once the product has been detected in blood. Due to their high specificity, chromatographic methods are the gold standard, whether they use a flame ionization detector or mass spectrometry to improve selectivity [9]. However, they are time consuming and require highly qualified staff, who are not always available. In our institution, we use gas chromatography–mass spectrometry (GC–MS) to detect ethylene glycol in serum. In January 2014, we implemented enzymatic testing on Corelab analyzers following the methodology of Juenke et al. [10]. The main strengths of this assay are ease of use and speed: results can be obtained quickly, 24 h a day, seven days a week, with the staff who are on duty on site. As the reagent was initially sold for veterinary use, chromatographic confirmation was still performed during office hours, and it still is today. After more than 10 years of practice, our aim was to make a retrospective analysis of the results obtained by both methods, trying to explain the discrepancies and discuss the advantages and drawbacks of the methods. Although a few studies have already been published on the evaluation of this assay in clinical practice [11,12], given the rarity of positive samples, our findings complement previous research by providing further evidence on the discriminating ability of the enzymatic assay.

Methods

Data collection and statistical analysis

This is a retrospective observational study comparing the results of enzymatic assay and GC–MS. Samples submitted for simultaneous analysis by both methods between 1 January 2014 and 30 June 2025 were included in this study, whether they were taken at our hospital or at another hospital affiliated with a laboratory that does not perform this analysis. Data processing and graphic conception were performed with MS Office 2016 (Excel and Power Point). Agreement between the methods was evaluated using Bland–Altman's plot analysis.

Turnaround time (TAT) was calculated with the laboratory information system (GLIMS 10 from CliniSys).

Reagents

Ethylene glycol and 1,3-propanediol were purchased from Merck (Darmstadt, Germany) whereas phenylboronic acid

was purchased from T.C.I. Europe (Paris, France). Acetonitrile LC–MS grade was supplied by J.T. Backer (Phillipsburg, NJ).

Enzymatic assay

Ethylene glycol tests kits are purchased from Catachem (Oxford, CT). One kit allows carrying out 80 tests and contains two bottles of sample diluent (to reconstitute with water), and ready-to-use reagents: one bottle of activator reagent, one bottle of calibrator and two levels of quality controls.

The test consists of the oxidation of ethylene glycol by glycerol dehydrogenase, using nicotinamide adenine dinucleotide and producing glycolaldehyde and reduced nicotinamide adenine dinucleotide, which is detected by spectrophotometry (340 nm).

From January 2014 to April 2019, the assay was running on Cobas 8000 (Roche, Basel, Switzerland) which was replaced by Alinity ci (Abbott, Chicago, IL). The assay was validated with a lower limit of quantification of 50 mg/L.

Potential cross reactivity of the reagent was assessed by analysis of blank serum to which 0.25, 0.5, 1, 2 and 3 g/L of various solvents have been added: 1,3-butanediol, 2,3-butanediol, ethanol, methanol, propylene glycol, 1-octanol, 1,3-propanediol, 1-butanol, 2-butanol, isobutanol, 1-propanol, 2-propanol and acetone.

Chromatographic confirmation

After addition of the internal standard (526.5 mg/L of 1,3-propanediol in acetonitrile), 700 μ L of acetonitrile are added to 25 μ L of plasma sample to lead to protein precipitation. After vortex mixing and centrifugation, derivatization is performed by adding 50 μ L of phenylboronic acid 40 mM to 100 μ L of supernatant. After 10 min, extracts are injected on a GC–MS QP-2020 system from Shimadzu (Kyoto, Japan). The temperatures of ion source and interface are set at 230 and 250 $^{\circ}$ C, respectively. The column is an HP-5MS (30 m $\times$ 0.25 mm internal diameter, 0.25 μ m film thickness) from Agilent (Santa Clara, CA). Helium is used as carrier gas at a constant flow of 1.2 mL/min. The oven program begins at 95 $^{\circ}$ C for 5 min, then increases at 30 $^{\circ}$ C/min to 300 $^{\circ}$ C, held for 5 min. Ethylene glycol is detected in SIM (single ion monitoring) mode, using ions 148 as quantifier and 118 as qualifier. For the internal standard, ions 104 and 162 are monitored. Retention times of ethylene glycol and 1,3-propanediol are respectively of 6.80 and 8.00 min.

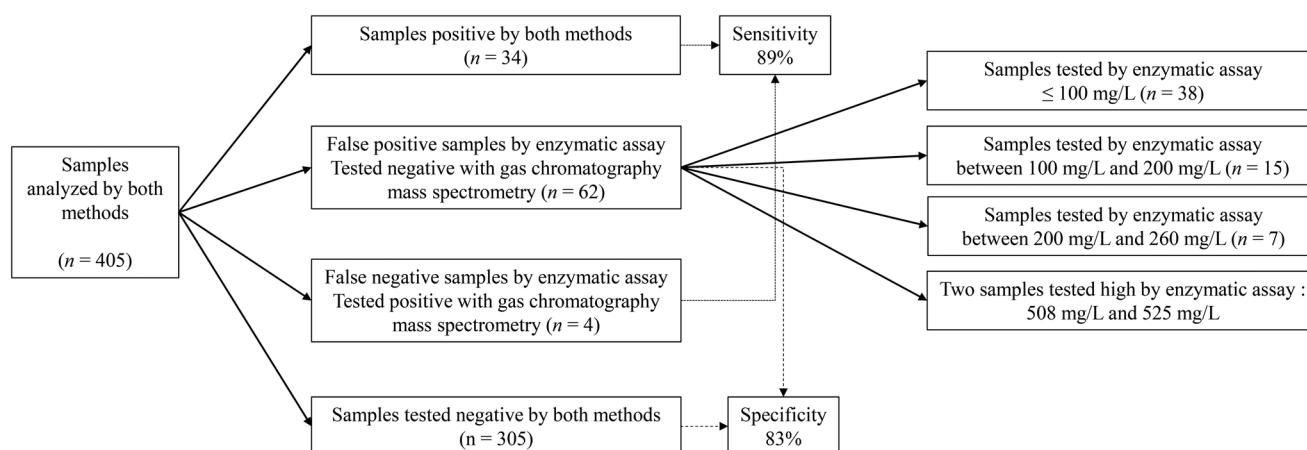


Figure 1. Flowchart of positive and negative samples identified by enzymatic and gas chromatography mass spectrometry testing.

The calibration curve used for quantification is prepared by mixing the appropriate volume of a 2 g/L solution of ethylene glycol in serum (prepared by dilution of a 10 g/L solution in water) to obtain a range from 50 to 500 mg/L. The lower limit of quantification is 50 mg/L.

Lactate and lactate dehydrogenase determination

To explore a relationship between lactate concentration, lactate dehydrogenase activity, and false positive ethylene glycol concentration, we serially measured ethylene glycol concentrations in available (non-ethylene glycol exposed) samples with known elevated lactate concentration and lactate dehydrogenase activity. To do this, we collected samples from nine patients for whom lactate levels and lactate dehydrogenase activity had been measured as part of their treatment, with high results. Instead of discarding the samples, we collected them to measure ethylene glycol.

Lactate levels and lactate dehydrogenase activity were initially measured on Cobas 8000, and then on Alinity ci, simultaneously with the change of analyzer for ethylene glycol. Both tests consist of an enzymatic reaction with photometric detection.

Results

During the study period, 405 samples were analyzed by both methods: 305 tested negative (75.3% true negative) while 34 tested positive on both instruments (8.40% true positive). Only four samples that tested negative with the enzymatic assay were revealed to be positive with GC–MS.

On the other hand, GC–MS failed to confirm 62 samples with a positive screening result. This yields a sensitivity of 89% and a specificity of 83%. Data are

Table 1. Patient demographics.

	All samples combined	Positive samples (excluded control analyses)
Number of distinct patients	340	13
Mean patient age (years)	50.0	44.8
Patient age range (years)	0.5–94	21–68
Gender (male, %)	57.4	69.2

summarized in [Figure 1](#), whereas patient demographics are shown in [Table 1](#).

Considering true positive results, the 34 serum samples were taken from 13 different patients, as some tests are carried out after diagnosis to check that ethylene glycol blood concentration is decreasing correctly with treatment. Only two of the 13 requests for analysis confirming ethylene glycol poisoning were received on a weekday morning; all others were received at night or on weekends. Concentrations obtained by enzymatic assay ranged from 75.9 mg/L to 2,820 mg/L. Values obtained with enzymatic assay were higher than those measured with GC–MS, as illustrated by the Bland–Altman plot ([Figure 2](#)).

False positive results were observed in 62 samples, representing 15.3% of the requests. Results between 50 mg/L and 100 mg/L represented more than half of the false positive samples. In fact, only one sample showing screening results below 100 mg/L (75.9 mg/L) was confirmed with GC–MS, and it was the fourth serum control for a patient with a real ethylene glycol intoxication. Majority (86%) of the false positive results showed a screening result lower than 200 mg/L, but two outliers were observed (508 mg/L and 525 mg/L). Both patients shared elevated lactate concentrations (16.4 mmol/L and 20.0 mmol/L, normal: 0.555–1.39 mmol/L), and lactate dehydrogenase

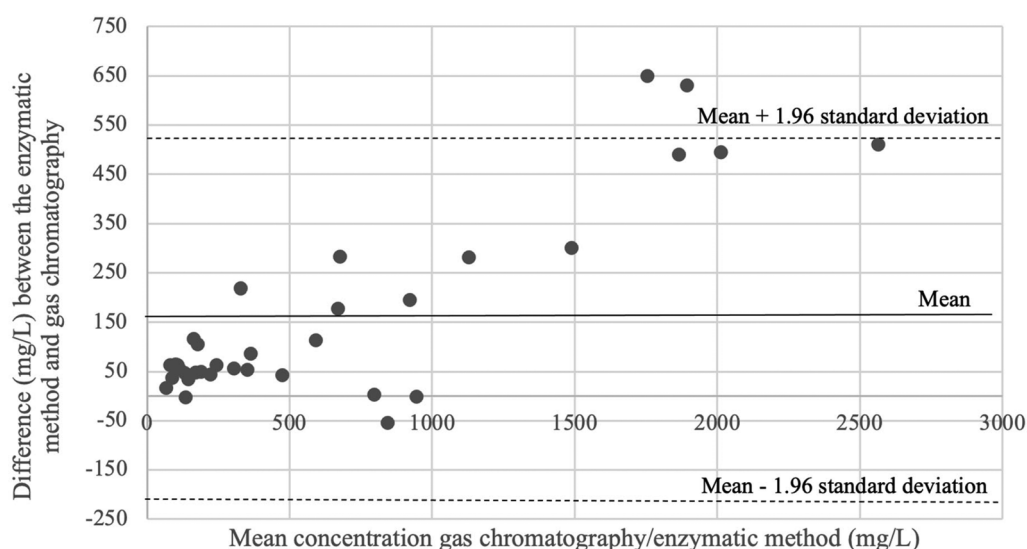


Figure 2. Bland–Altman's plot of mean ethylene glycol concentration measured using gas chromatography and the enzymatic method (X-axis) against the difference between ethylene glycol concentrations measured by both methods (Y-axis). Samples included between the dashed lines are within the ± 1.96 standard deviation acceptance range, and the enzymatic result is greater than the one obtained by gas chromatography.

Table 2. Enzymatic ethylene glycol determination in nine control patients with elevated blood lactate concentrations and lactate dehydrogenase activities, but no suspicion of ethylene glycol poisoning.

	Blood lactate dehydrogenase activity (U/L) 136–273	Blood lactate concentration (mmol/L) 0.555–1.39	Blood ethylene glycol concentration (mg/L)
Control patient 1	1,106	3.44	50
Control patient 2	2,239	Not determined	<50
Control patient 3	2,574	Not determined	61
Control patient 4	2,896	Not determined	80
Control patient 5	3,409	2.11	60
Control patient 6	4,143	2.44	122
Control patient 7	5,477	Not determined	<50
Control patient 8	7,943	>20.0	260
Control patient 9	>7,325	8.99	186
False positive case 1	1,480	Not determined	508
False positive case 2	1,800	Not determined	525

Table 3. Blood ethylene glycol concentration, blood lactate concentration and blood lactate dehydrogenase activity over time measured in a 55 year old man with cirrhosis who denied ethylene glycol consumption.

	Hospital admission	8.5 h post-admission	14 h post-admission	27 h post-admission	38.5 h post-admission	50.5 h post-admission
Blood ethylene glycol concentration by enzymatic assay (mg/L)	252	244	224	178	162	146
Blood ethylene glycol concentration by gas chromatography mass spectrometry (mg/L)	<50	<50	<50	<50	<50	<50
Blood lactate concentration (mmol/L)	1.67	1.11	0.777	0.888	0.666	0.888
Blood lactate dehydrogenase activity (U/L)	339	Not determined	353	Not determined	277	Not determined

activity could not be quantified due to hemolysis, which may suggest a high result. Results of the cross-reactivity study between lactate concentration, lactate dehydrogenase activity, and ethylene glycol concentration are described in Table 2.

Ten other false positive samples corresponded to two patients who were sampled several times. One of them was sampled six times as reported in Table 3.

From the cross-reactivity study, we observed that propylene glycol and 2,3-butanediol were likely to lead to false positive results.

One hundred and seventy-five analysis requests were received using the Cobas system, and 230 were analyzed using Alinity. Of the 62 false positive samples, 44 were measured with Alinity (half of them were lower than 100 mg/L), corresponding to a false

Table 4. Sensitivity and specificity of Cobas and Alinity analyzers, using a cutoff of 50 mg/L.

	Cobas	Alinity
Sensitivity (%)	95	82
Specificity (%)	88	79

positive rate of 19%, compared to 10% on Cobas. The sensitivity and specificity of both instruments are shown in Table 4.

False negative results were observed only four times (Cobas: 1; Alinity: 3). Chromatographic results were relatively low: 71.8 mg/L, 95.5 mg/L, 102 mg/L, and 119 mg/L.

Discussion

For more than 10 years, we have been using a reagent commercialized by Catachem, and all results are confirmed by GC–MS once the chromatography laboratory is open. During this study period, most of the samples were negative by both methods, which is not surprising as ethylene glycol intoxication is unusual; it occurs in one case a year in our laboratory. Metabolic acidosis is a critical feature of ethylene glycol toxicity, and the most common clinical sign that motivates the analysis. Whether positive or negative, it is important to obtain the serum concentration of ethylene glycol in a timely manner. Thanks to the enzymatic assay, rapid exclusion of the diagnosis of ethylene glycol intoxication helps avoid unnecessary and expensive treatments. It is interesting to note that the majority of established poisoning cases occurred outside office hours, confirming the need for a method that operates 24/7, which is not always possible with chromatography. Moreover, the slight overestimation of results observed with the enzymatic method has no clinical significance in our cohort.

The majority of false positive results were between 50 mg/L and 100 mg/L. An automatic comment warning about the elevated risk of false positive sample close to the lower limit of quantification goes along every validated result, avoiding misleading interpretation and unnecessary treatment. Increasing the positivity threshold to 100 mg/L could be another – more straightforward – option, reducing the false positive rate by a factor of three. One drawback of this threshold increase is that patients who are in the early stages of absorption may be missed. Moreover, any result above the positivity threshold should be reanalyzed, especially if the chosen threshold is 50 mg/L.

It is striking to note that the majority of false positive samples (>100 mg/L) were measured on Alinity, as only two false positive in this range of values were

reported on Cobas. Furthermore, across all values, the false positive rate is twice as high on Alinity (19% versus 10%). Unfortunately, no satisfactory explanation can be given.

On the other hand, two particularly high values obtained with the enzymatic assay, i.e., 508 mg/L and 525 mg/L were not confirmed by GC–MS. The first one was observed in a female patient released from jail, who initially recovered from a cardiac arrest at home. She had a fatal outcome, and the most likely cause of death was an overdose. Methadone was detected in serum 1,246 µg/L; benzoylcegonine in urine >2,400 µg/L; 6-monoacetylmorphine in urine >48 µg/L.

The second one was observed in a bedridden patient suffering from a chronic obstructive pulmonary disease who was admitted to the emergency room in a critical state. He finally died from cardiac arrest. A normal value of oxalic acid was found in urine, which is an additional argument for ruling out ethylene glycol intoxication.

These last two patients exhibited elevated lactate levels and, presumably, elevated lactate dehydrogenase activity.

Potential interference from lactate and lactate dehydrogenase was already observed by Eder et al. [13]. From our data (Table 2), this interference does not appear to be either proportional or systematic, suggesting that another factor is involved. In return, falsely elevated point-of-care lactate measurement after ethylene glycol ingestion has already been described on some instruments, but not all [14,15]. This interference can be explained by the structural similarity between lactate and ethylene glycol metabolites (glycolate and glyoxylate) which are confused by lactate oxidase.

Another 22 positive samples not confirmed by GC–MS showed an enzymatic result between 100 mg/L and 260 mg/L while GC–MS was negative. Ten samples corresponded to two patients who were sampled several times for verification. This cascade of samples erroneously reduced specificity. The main issue with these false positive and elevated results is the risk of initiating unnecessary treatment and leading the diagnosis down the wrong path.

One of the patients was undomiciled man who was sampled twice (diagnosis and control), on two occasions, with one year interval between the occurrences. Each of the four results was between 100 mg/L and 200 mg/L. The other patient (Table 3) was 55-years old man with cirrhosis, admitted for confusion and walking difficulties having caused a fall. Sepsis was diagnosed after prostatitis. Table 3 shows a very slow decrease in ethylene glycol concentration in this patient. The half-life of ethylene glycol is around 6 h,

and can prolong to 20 h when antidote is administered [16], as was the case with our patient. Altered kidney function would be another explanation of the slow decrease of concentration over time in this case, if it really was ethylene glycol poisoning. However, the patient strictly denied any ethylene glycol consumption, suggesting an unexplained interference, as expected considering negative GC-MS.

A false positive result below 200 mg/L should not be of any consequence since the toxicity threshold of ethylene glycol is 200 mg/L [16]. Similarly, the American Academy of Clinical Toxicology recommends treating ethylene glycol poisoning with an antidote when serum concentration is higher than 200 mg/L [7]. Other criteria to treat include arterial pH <7.3 combined with a serum bicarbonate concentration <20 mEq/L when there is a strong clinical suspicion of poisoning.

For the remaining false positive samples, anamnesis seems to confirm that this is a screening test error and that the negative GC-MS result is correct (methadone or cocaine overdose, among others). However, this proportion of false positives remains higher than that described by Filip et al. [11] who did not observe interference in the 118 tested patient samples.

As confirmed with our cross-reactivity study, propylene glycol (notably found in some intravenous medications) and 2,3-butanediol (which is found in serum of alcoholic patients [17]) are known to generate an interference that can be detected by inspecting the reaction curve [12,18]. When working on Cobas analyzers, an error flag was configured to inform the user. Unfortunately, this could not be applied on Abbott analyzers, and the potential interference of these solvents cannot therefore be excluded.

In the end, the specificity of the enzymatic assay is 83%. It can be raised to 93% by increasing the detection threshold at 100 mg/L.

At first glance, unexpected false negative results were observed four times for relatively low chromatographic values: 71.8 mg/L, 95.5 mg/L, 102 mg/L and 119 mg/L. This results in a sensitivity of 89%. These values were observed in psychiatric patients with metabolic acidosis, explaining the request of analysis. However, no history of ethylene glycol poisoning was documented. The possibility of false positive results obtained by GC-MS cannot be excluded. Given the low concentrations observed and the medical history pointing to another cause, these patients were not treated for ethylene glycol poisoning. Even if GC-MS specificity is high, due to ion ratio calculation and retention time selectivity, interferences are still possible, but sparse (less than 1% of analyzed samples in our case). If these

are indeed false positive GC-MS results, we could therefore consider the sensitivity of the enzymatic assay to be 100%. On the contrary, assuming that the GC-MS results are true positives, the potential 95% CI miss rate can be estimated around 3.3%.

Beyond specificity and sensitivity, other interesting parameters to consider when implementing a new test in a laboratory are the price and TAT.

Ethylene glycol test kit costs 450 United States dollars (excluding value-added tax) for approximately 80 tests, which may seem inexpensive. However, reagent stability is only 60 days, and the mean number of requests is three times a month, so reagents expire much faster than they are used. This drawback may not outweigh the significantly improved TAT. At the hospital level, further cost savings are achieved by avoiding unnecessary treatments by ruling out ethylene glycol poisoning. Indeed, the fomepizole loading dose alone costs around 2,000 United States dollars [19]. Median calculated TAT is 75 min for the enzymatic assay, which is acceptable and clearly better than GC-MS in our laboratory. Indeed, with the GC-MS method, not only the patient sample but also the calibration curve and quality controls are subjected to sample preparation. Once the extracts are ready to inject into GC-MS, the run-time lasts 10 min for each sample. In practice, results are available on the day of arrival only for samples that reach the laboratory in the morning and the median TAT exceeds 24 h.

Chromatographic methods are not available in all clinical laboratories, as they require special instrumentation and skills. By contrast, the enzymatic assay can be suitable to all laboratories, including in developing countries, as it can be installed on automated analyzer. In our institution, 400 patients present to the emergency room every day. However, 65% of ethylene glycol analysis requests are coming from other hospitals in the area. For these samples, transferring them to another hospital extends the TAT, but requests are so rare in small hospitals that it seems logical to concentrate the analyses in a single laboratory.

Finally, our study suffers from some limitations. The first one is related to the retrospective nature of the study, which means that serum samples are no longer available for further analysis to explain any differences. For example, propylene glycol analysis would have been interesting. Second, as we do not have access to all medical records, since some samples come from other hospitals, the search for explanations is also sometimes incomplete. Finally, changing the analyzer during the study introduced a systematic error, as the second analyzer was less accurate, but the results were nevertheless pooled.

Conclusions

Ethylene glycol poisoning, although rare, is a medical emergency. Unlike GC–MS, the enzymatic assay can easily be implemented 24/7 by staff who is not trained in chromatographic methods. The results observed over the last 10 years confirm that this is a reliable method: accounting for suspected false-positives in the gold-standard GC–MS, the sensitivity and specificity of the screening test could be as high as 100% and 93%, respectively. The positive threshold can be fixed at 100 mg/L and any positive result must be confirmed by chromatography, or at least interpreted in the context of the patient's medical history and other biological parameters such as pH, anion gap, etc.

Ethical approval

This study does not fall within the scope of the national law of 7 May 2004 on experiments on human subjects.

Disclosure statement

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