International Journal of
Medical Toxicology & Forensic Medicine
October 2024, Volume 14, Number 4

Review Paper

Differentiation of Suspected Methanol Poisoning From Ethanol Poisoning: A Review Study and Consensus Statement

Mansour Deylami[1], Maryam Ziyaei[2], Elham Pishbin[3], Hamid Zamani Moghadam[3], Roohie Farzaneh[3], Behrang Rezvani Kakhki[3], Arman Hakemi[4], Mohammad Sadegh Sanie Jahromi[5*], Fatemeh Maleki[6], Navid Kalani[7], Davood Soroosh[8], Mehrdad Malekshoar[9], Tayyebeh Zarei[9]

1. Department of Anesthesiology and Critical Care, Faculty of Medicine, Golestan University of Medical Sciences, Gorgan, Iran.
2. Department of Emergency Medicine, School of Medicine, Zahedan University of Medical Sciences, Zahedan, Iran.
3. Department of Emergency Medicine, School of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran.
4. Department of Emergency Medicine, Faculty of Medicine, Bahar Hospital, Shahroud University of Medical Sciences, Shahroud, Iran.
5. Department of Anesthesiology, School of Medicine, Jahrom University of Medical Sciences, Jahrom, Iran.
6. Department of Emergency Medicine, School of Medicine, Birjand University of Medical Sciences, Birjand, Iran.
7. Research Center for Social Determinants of Health, Jahrom University of Medical Sciences, Jahrom, Iran.
8. Department of Forensic Medicine, Faculty of Medicine, Sabzevar University of Medical Sciences, Sabzevar, Iran.
9. Anesthesiology, Critical Care and Pain Management Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran.

Use your device to scan and read the article online

Citation Deylami M, Ziyaei M, Zamani Moghadam H, Farzaneh R, Rezvani Kakhki B, Hakemi A, et al. Differentiation of Suspected Methanol Poisoning From Ethanol Poisoning: A Review Study and Consensus Statement. International Journal of Medical Toxicology and Forensic Medicine. 2024; 14(4):E45359. https://doi.org/10.32598/ijmtfm.v14i4.45359

https://doi.org/10.32598/ijmtfm.v14i4.45359

Article info:
Received: 18 May 2024
First Revision: 22 May 2024
Accepted: 30 Aug 2024
Published: 09 Oct 2024

Keywords:
Methanol, Poisoning, Ethanol, Intoxication

ABSTRACT

Background: Ethanol and methanol poisoning pose significant clinical challenges due to their overlapping clinical presentations. This literature review and consensus statement aim to provide evidence-based guidelines for differentiating these two poisonings.

Methods: We conducted a comprehensive literature review of relevant literature, including individual patient data (IPD) meta-analysis, to assess clinical, laboratory, and diagnostic findings in cases with ethanol and methanol poisoning. A literature review was also performed to gather case series of electrocardiograms of ethanol and methanol poisoning. We synthesized the evidence and convened an expert panel to develop consensus-based recommendations.

Results: Based on the literature review and IPD analysis, cases of methanol poisoning often present later than 24 hours after alcohol consumption, emphasizing the importance of assessing patients with delayed referrals. Methanol-poisoned patients are frequently awake and responsive after 12 hours of ingestion, but symptoms alone do not reliably differentiate between the two poisonings. Declines in visual acuity and symptoms are strongly associated with methanol poisoning and should prompt immediate hospitalization and ophthalmic examination. Oliguria and anuria are more common in cases of methanol poisoning, warranting detailed urinary symptom assessment and close monitoring of urinary output. Electrocardiograms are essential for all alcohol poisoning patients, with non-sinus rhythm suggesting methanol poisoning. Arterial blood gas analysis, with low pH values, favors methanol poisoning. However, blood

*** Corresponding Author:**
Mohammad Sadegh Sanie Jahromi, Associate Professor.
Address: *Department of Anesthesiology, School of Medicine, Jahrom University of Medical Sciences, Jahrom, Iran.*
Tel: *+98 (917) 7002599*
E-mail: *m.sadeghsanie@gmail.com*

sugar levels alone cannot definitively determine the type of poisoning. Laboratory point-of-care tests to diagnose methanol in serum are urgently needed.

Conclusion: This literature review and consensus statement offer guidance for healthcare providers facing cases of alcohol poisoning where point-of-care testing methods of blood alcohol concentrations are unavailable. A comprehensive assessment, considering clinical history, physical examination, laboratory data, and specialized evaluations such as ophthalmic examination and electrocardiograms, is essential for accurately differentiating ethanol and methanol poisoning.

Introduction

Contaminated alcoholic beverages and industrial or household products can contain methanol and cause methanol toxicity in case of human consumption [1]. Illicit production is responsible for most methanol poisoning outbreaks [2], which have been reported in the USA [3], Malaysia [4], Norway [5], Libya, Kenya [6], and Iran [7]. Methanol poisoning can cause various symptoms, such as nausea, vomiting, headache, dizziness, abdominal pain, and visual disturbances. In severe cases, it can cause metabolic acidosis, central nervous system depression, coma, seizures, and even death [8]. The treatment for methanol poisoning involves administering ethanol or fomepizole [9]. At the same time, as there are few cases of this toxication worldwide and most are limited to Asian countries with boundaries on alcohol roles, the current practices are not well structured. While some outdated guidelines are available, like American [10], Iranian health authorities have faced this thread. Here, we aim to prepare a guideline based on the expertise of Iranian experts in the field. Differentiating ethanol from methanol poisoning is challenging for physicians in Iran due to the lack of available methanol detection measures in most centers [11].

Scope and purpose

The overall objective of the Iranian methanol poisoning guideline is to establish an evidence-based guide for the prevention, diagnosis, and treatment of methanol poisoning. This instruction will be developed based on the appraisal of guidelines for research & evaluation (AGREE) recommendations for writing clinical guidelines [12]. Expected benefits include early diagnosis and improved treatment. This study does not focus on preventative measures or legislation to stop a methanol poisoning outbreak.

Based on this, the population, intervention, comparison, outcome (PICO) method was used to structure study questions.

Population (P):

What are the differences between ethanol and methanol poisoning based on clinical presentation at arrival and time of consumption to referral?

What are the differences in physical examination findings between patients with ethanol and methanol poisoning on arrival?

What are the differences in laboratory results between patients with ethanol and methanol poisoning on arrival?

Intervention (I):

What are the most effective diagnostic interventions for individuals with methanol poisoning?

Comparison (C):

How does diagnosis differ from ethanol and methanol poisoning?

Outcome (O):

How reliable is evidence to differentiate the methanol poisoning from methanol poisoning?

Materials and Methods

Stakeholder involvement

A team of experts was enrolled in this study. The steering group members provided strategic guidance in the subject area. Focus group discussions were conducted with these stakeholders. The research team was responsible for selecting and reviewing the evidence. Some other experts formulated the final recommendations for synthesizing them into actionable guidance.

Specialists in relevant medical fields, such as toxicology, emergency medicine, and critical care, are a primary target audience. Health policymakers and regulators may also be part of the audience.

Search methods

This section will determine the methodologies used to integrate evidence for study questions. For questions about symptoms and clinical presentations, as epidemiologists only report the proportion of symptoms that could not be used as a source for differentiating patients, our objective would be gathering individual cases for individual patient data (IPD) meta-analysis with the primary aim of comparing ethanol and methanol poisoning symptoms, stratified based on the time from toxication. So, the inclusion criteria for studies were methanol poisoning in individual reported cases. Performing case-control studies based on IPD meta-analysis is previously used in the literature [13]. A MeaSurement tool to assess systematic reviews (AMSTAR2) guidelines were observed when performing the IPD meta-analysis [14]. The search was conducted using the following databases: PubMed, Embase, Scopus, and Google Scholar. PubMed search strategy would be as follows: ("Methanol poisoning" OR "methyl alcohol poisoning") AND ("clinical presentations" OR "symptoms" OR "signs" OR "manifestations") AND ("case series" OR "case report"); and same for ethanol poisoning: ("Ethanol poisoning" OR "ethyl alcohol poisoning") AND ("clinical presentations" OR "symptoms" OR "signs" OR "manifestations") AND ("case series" OR "case report").

Two independent reviewers screened the search results based on titles and abstracts. Full texts of potentially relevant articles were retrieved for further assessment. Any discrepancies in inclusion were resolved through discussion. Data were extracted from the included case reports using a standardized data extraction form. Two independent reviewers delicately extracted data and compared results.

In the case of ethanol poisonings, studies with concomitant intoxications or interacting medications were not sought. Only case reports of severe ethanol poisoning were included where admission was required, and three were high values of blood alcohol concentrations .

Demographic data included age and gender, while clinical data encompassed clinical status (e.g. coma, somnolent, lethargic/drowsy, awake), vital signs (e.g. heart rate, respiratory rate, systolic and diastolic blood pressure, temperature), and blood gas analysis, specifically pH levels. Clinical symptoms such as unconsciousness, abdominal pain, nausea and vomiting, diarrhea, decreased level of consciousness (LOC), aggressive behavior, visual symptoms, dyspnea, chest pain, headache (H/A), and the presence of asymptomatic cases were also recorded.

For questions about ECG findings of ethanol and methanol poisoning cases, our approach primarily focuses on a literature review. To achieve this, our inclusion criteria were centered on methanol poisoning ECG findings reports. There was a previous systematic review and meta-analysis; our study will be updated on the mentioned study [15]. This methodology follows a sub-group meta-analysis of proportional data. Data extraction included both demographic and clinical aspects. Demographic data included age and gender, and ECG findings were extracted.

CAse REport (CARE) guidelines were used to assess the risk of bias in case reports and case series studies [16]. The Newcastle-Ottawa scale was used to determine the quality of non-randomized studies [17].

Evidence was synthesized based on the statistical analyses in SPSS software, version 21. Descriptive statistics were used to summarize the data, including Mean±SD for continuous variables and frequency and percentage for categorical variables. Differences between the ethanol and methanol poisoning groups were assessed using appropriate statistical tests. For continuous variables (e.g. age), the independent samples t test or Mann-Whitney U test was employed based on the data distribution. Categorical variables (e.g. gender, clinical status) were compared using the chi-square test or Fisher exact test when appropriate. Subgroup analyses were performed for variables of interest, such as age groups or time since poisoning. Logistic regression analysis was conducted to investigate associations between specific clinical symptoms or outcomes (e.g. mortality) and poisoning type, adjusting for potential confounding variables. Receiver operating characteristic (ROC) analysis assessed the discriminatory power of pH levels in differentiating between severe ethanol and methanol poisoning. A significance level of $P<0.05$ was used to determine statistical significance. We used the Python programming language, along with the Pandas, Seaborn, and Matplotlib libraries, to create a heatmap using Seaborn.

Synthesized evidence was evaluated using the grading of recommendations assessment, development, and evaluation (GRADE) tool [18].

Results

Table 1 provides included studies in the individual patient level (IPD) meta-analysis related to symptoms and clinical presentation in cases of alcohol poisoning. There were 18 case reports of severe ethanol poisoning and 5 case series of methanol poisoning. The Table lists vari-

Table 1. Included studies in IPD meta-analysis of symptoms and clinical presentation

Author(s)	Study Design	Cases (No.)	Type of Poisoning	Country	(RoB)
Atassi et al. [19]	Case report	1	Ethanol	United States	++
Elliott & Hunter [20]	Case report	1	Ethanol	United States	+++
Pereska et al. [21]	Case report	1	Ethanol	Macedonia	+
Morgan et al. [22]	Case report	1	Ethanol	United States	++
Johnson et al. [23]	Case report	1	Ethanol	United States	++
Berild & Hasselbalch [24]	Case report	1	Ethanol	Denmark	+++
Sanap & Chapman [25]	Case report	1	Ethanol	Australia	+
Quispe et al. [26]	Case report	1	Ethanol	Valladolid	+
Nagashima et al. [27]	Case report	1	Ethanol	Japan	+
Wilson & Waring [28]	Case report	1	Ethanol	United Kingdom	+
Doyon & Welsh [29]	Case report	1	Ethanol	United States	+
Roberts et al. [30]	Case report	1	Ethanol	United Kingdom	++
Meyer et al. [31]	Case report	1	Ethanol	United Kingdom	++
Henry-Lagarrigue et al. [32]	Case report	1	Ethanol	United States	++
Bookstaver et al. [33]	Case report	1	Ethanol	France	+++
Tavolacci et al. [34]	Case report	1	Ethanol	Columbia	+
Brvar & Bunc [35]	Case report	1	Ethanol	France	+++
Piccini & Zaas [36]	Case report	1	Ethanol	Slovenia	+++
Alqurashi et al. [37]	Case series	6	Methanol	Saudi Arabia	+
Eskandrani et al. [38]	Case series	9	Methanol	Saudi Arabia	++
Kabli et al. [39]	Case series	9	Methanol	Saudi Arabia	++
Amin et al. [40]	Case series	8	Methanol	Bangladesh	+++
Liu et al. [41]	Case series	50	Methanol	United States	+++

RoB: Risk of bias; IPD: Individual patient data.

International Journal of Medical Toxicology & Forensic Medicine

+: Low; ++: Moderate; +++: High.

ous case reports and case series, the number of cases, the country of origin, and the assessed risk of bias for each study.

Table 2, on the other hand, presents an overview of additional studies, each with its number of cases, study design, and risk of bias assessment. These studies encompass a range of study designs, including case-control, crossover, cross-sectional, prospective cohort, and retrospective studies, contributing to a comprehensive analysis.

In our study comparing ethanol poisoning (n=18) and methanol poisoning (n=82) patients, ethanol poisoning patients had a similar mean age (45.55±20.53 years) compared to methanol poisoning patients (37.67±12.693 years), with no statistically significant (P=0.134). Gender distribution showed a higher proportion of males in both groups (61.11% in ethanol, 76.83% in methanol), but the difference was not statistically significant (P=0.234). In terms of clinical status, ethanol poisoning patients were more likely to present in an uncon-

Table 2. Additional studies for the analysis of electrocardiogram findings

Author(s)	No.	Study Design	Risk of Bias
Cardy et al. [42]	10	Case-control	+
Priest et al. [43]	37	Case-control	+
Uyarel et al. [44]	10	Crossover study	+
Aasebo et al. [45]	84	Case-control	+
Drooshi et al. [46]	250	Cross-sectional	+
Brunner et al. [47]	3028	Prospective cohort	+
Total	3419		
Nikoo et al. [48]	356	Cross-sectional	+
Tabatabaiei et al. [49]	114	Cross-sectional	+
Jaff et al. [50]	9	Retrospective	+
Sanaei-Zadeh et al. [51]	42	Retrospective	+
Total	521		

+: Low; ++: Moderate; +++: High.

scious state (66.67%) compared to methanol poisoning patients (15.85%), and this difference was statistically significant (P=0.087). Other clinical parameters, such as heart rate (HR), respiratory rate (RR), systolic blood pressure (SBP), and temperature, showed no differences between the two groups (P>0.05). However, diastolic blood pressure (DBP) was significantly lower in ethanol-poisoning patients (P=0.024). Notably, the pH levels were significantly lower in the methanol poisoning group (7.082857±0.254) compared to the ethanol group (7.26±0.104) (P=0.002). Additionally, the mortality rate was significantly higher in the methanol poisoning group (39.02%) compared to the ethanol group (5.56%) (P=0.0001) (Table 3).

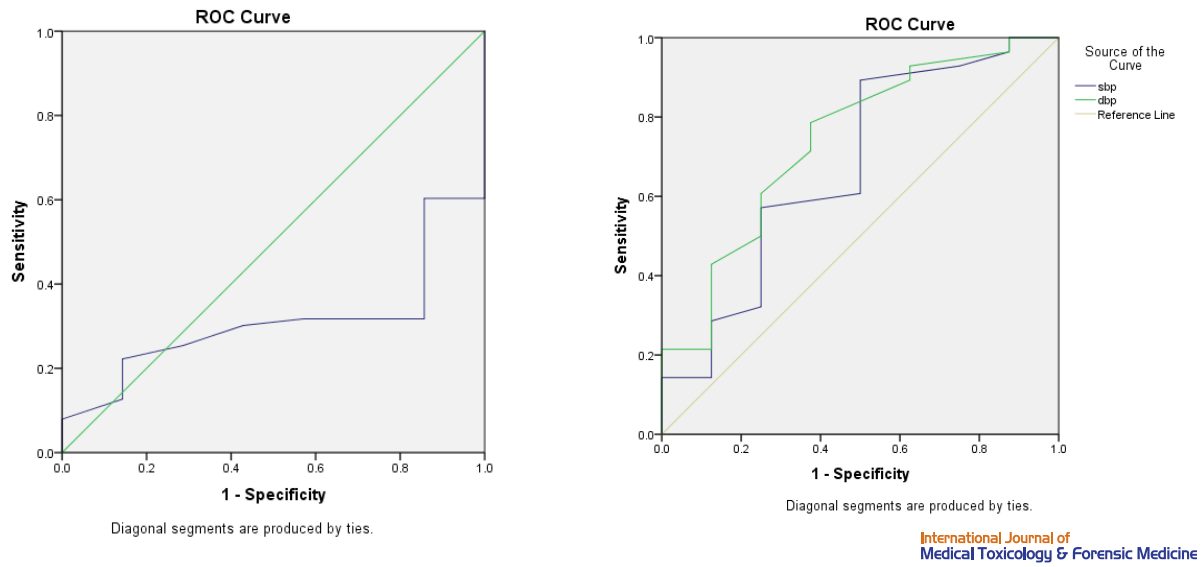


Figure 1. ROC analysis of pH (left side) and blood pressure (right side) for differentiation between methanol and ethanol poisoning

ROC: Receiver operating characteristic.

Table 3. Characteristics of the study populations

Characteristics		Mean±SD/No. (%)		P
		Ethanol Poisoning (n=18)	Methanol Poisoning (n=82)	
Age (y)		45.55±20.53	37.67±12.693	0.134*
Gender	Male	11(61.11)	63(76.83)	0.234
	Female	7(38.89)	19(23.17)	
Status	Coma	12(66.67)	13(15.85)	0.087
	Somnolent	3(16.67)	3(3.66)	
	Lethargic/Drowsy	2(11.11)	3(3.66)	
	Awake	1(5.56)	12(14.63)	
Weight (kg)		58.5±10.847	NR	-
HR (bpm) [35 data]		92.14286±25.3	93.60714±20.11	0.871
RR (breaths/min) [20 data]		17.25±7.80	24.5±10.9	0.234
SBP (mm Hg) [36 data]		104.37±33.85	126.4286±28.82	0.075
DBP (mm Hg) [36 data]		61.375±19.07	78.07143±17.16	0.024
Temperature (°C) [16 data]		35.09±1.93	36.68333±1.135	0.09
Bs [10 data]		133±36.51	108.9000±36.08	-
pH [70 data]		7.26±0.104	7.082857±0.254	0.002
Death		1(5.56)	32(39.02)	0.0001

International Journal of Medical Toxicology & Forensic Medicine

Abbreviations: HR: Heart rate; RR: Respiratory rate; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; Bs: Blood sugar; NR: Not reported.

There are statistically significant differences in the distribution of the presenting pattern of poisoning among different types of alcohol poisoning categories based on chi-square (P=0.047). It seems that methanol poisoning patients are more frequently presenting awake and responsive than ethanol poisoning patients, later than 12 hours after first ingestion (P=0.025) (Table 4).

Significant differences were observed between the two groups in several key symptoms. Notably, a significantly higher proportion of patients with ethanol poisoning presented with unconsciousness (66.67%) compared to those with methanol poisoning (14.63%) (P<0.001). Additionally, the prevalence of aggressive behavior was significantly higher in the methanol poisoning group (29.27%) compared to the ethanol poisoning group (5.56%) (P=0.038). Visual symptoms were absent in the ethanol poisoning group but were present in 26.83% of methanol poisoning cases, showing a significant difference (P=0.010). Other symptoms, such as abdominal pain, nausea and vomiting, diarrhea, decreased LOC, dyspnea, chest pain, and headache, did not exhibit statistically significant differences between the two groups (P>0.05) (Table 5).

Based on a ROC analysis of pH for differentiation of severe ethanol poisoning and methanol poisoning, pH had an area under the curve (AUC) of 0.310 (P=0.10). It cannot be utilized for differentiation, as well as the systolic blood pressure with an AUC of 674 (P=0.128) (Figure 1). Meanwhile, diastolic blood pressure had an AUC of 0.739 (P=0.049), showing promising differentiating performance.

Discussion

Based on the provided literature review, IPD meta-analysis, and literature review of studies on electrocar-

Table 4. Crosstabulation of clinical presentation, timing of referral, and type of toxicity

Status		As Time Passed the Poisoning (h)			P
		<12	12-24	24-72	
Coma	Ethanol	7	1	1	0.508
	Methanol	6	0	2	
Somnolent	Ethanol	2	0	0	-
	Methanol	0	0	0	
Lethargic/Drowsy	Ethanol	3	0	0	-
	Methanol	1	0	0	
Awake	Ethanol	0	1	0	0.025
	Methanol	0	0	4	
Total	Ethanol	10	2	1	0.047
	Methanol	7	0	6	

International Journal of
Medical Toxicology & Forensic Medicine

diogram findings, we will offer recommendations for differentiating ethanol poisoning from methanol poisoning.

The low quality of evidence suggests that these recommendations should be considered, but they may benefit from further research and validation. Our first recommendation is in line with the body of literature. Williams et al. reported that most patients with methanol poisoning start having symptoms 24 hours later, and mixed ethanol poisoning might delay the symptom's manifestation [55]. A literature review and meta-analysis of 2327 patients in 67 studies showed that the time from methanol

Table 5. Comparison of symptoms between ethanol and methanol poisoning patients

Symptoms	No. (%)		P
	Ethanol Poisoning (n=18)	Methanol Poisoning (n=82)	
Unconsciousness	12(66.67)	12(14.63)	<0.001
Abdomen	2(11.11)	7(8.54)	0.257
Nausea and Vomiting	3(16.67)	16(19.51)	0.847
Diarrhea	1(5.56)	0(0)	0.969
LOC decrease	3(16.67)	25(30.49)	0.384
Getting aggressive	1(5.56)	24(29.27)	0.038
Visual symptoms	0(0)	22(26.83)	0.010
Dyspnea	0(0)	7(8.54)	0.128
Chest pain	0(0)	3(3.66)	0.463
Headache	0(0)	1(1.22)	0.987
Asymptomatic	0(0)	10(12.2)	0.201

International Journal of
Medical Toxicology & Forensic Medicine

Q1. What are the differences between ethanol and methanol poisoning based on the clinical picture on arrival and time of drinking to referral?
1. Based on the review of results of individual patient level (IPD) meta-analysis, a higher percentage of methanol poisoning cases present later than the first day passing the drink compared to ethanol poisoning cases. **Recommendation:** Healthcare providers should carefully assess patients referred to the hospital for more than 24 hours for alcohol consumption. **Quality of evidence:** ⊖⊖OO
2. Methanol poisoning patients are more frequently presenting awake and responsive than ethanol poisoning patients, later than 12 hours of first ingestion. **Recommendation:** Being awake and responsive could not be observed as a good clinical picture, and all patients with a history of alcohol consumption should be further evaluated in cases of symptoms, timings, and clinical findings. **Quality of evidence:** ⊖⊖OO
3. Our IPD analysis did not show robust evidence for symptomatology, and there is no subjective sign for differentiating methanol poisoning from ethanol poisoning, except for the visual impairment symptoms. **Recommendation:** A detailed history of exposure, timing, and sources of alcohol is needed to interpret the signs of the patient to decide on the diagnosis of ethanol or methanol poisoning. **Quality of evidence:** ⊖⊖OO
4. Symptoms of oliguria and anuria are frequently seen in methanol poisoning cases. In contrast, ethanol poisoning may rarely manifest with these symptoms (only in some cases reports of rhabdomyolysis after ethanol poisoning [52] and concurrent NSAID and ethanol consumption [53] or chiroptic chronic alcohol users [54]). **Quality of evidence:** ⊖OOO **Recommendation:** A detailed history should be obtained from patients with alcohol poisoning focusing on the urinary symptoms, and urinary output should be closely documented. Further laboratory exams should be considered to manage any acute renal failure.

Symbol: ⊖⊖⊖⊖: High; ⊖⊖⊖O: Moderate; ⊖⊖OO: Low; ⊖OOO: Very low.

poisoning to hospital referral ranges between 3 to more than 48 hours [56]. While there is a substantial number of studies on ethanol and methanol poisoning individually, there is limited direct comparative research on the symptomatology of these two types of poisoning cases in human patients. Most studies separately focus on each poison's characteristics, treatment, and outcomes. However, there was an animal model study that found that methanol is more lethal than ethanol, particularly when ingested in its pure form [57]. In the case of the clinical picture on arrival, Methanol's central nervous system (CNS) depressive effects are primarily attributed to its metabolites. However, ethanol has direct effects on neurotransmitters and causes direct CNS depression [58].

Ocular examination with assessments of visual acuity, pupillary abnormalities, fundoscopic examinations, and monitoring for visual symptoms is critical for all patients who have a history of alcohol exposure. For alert patients, a detailed examination is needed, including assessing visual acuity, vision and color vision testing

Q2. What are the differences in physical examinations of patients with ethanol and methanol poisoning on arrival?
1. Vital signs evaluation is a critical step in facing alcohol poisoning patients, while normal blood pressure could not be related, as even methanol poisoning cases might have a higher DBP than ethanol poisoning cases but have similar systolic blood pressures. **Recommendation:** A normal blood pressure reading alone may not reliably distinguish between methanol and ethanol poisoning cases. **Quality of evidence:** ⊖⊖OO
2. Visual acuity decreases or visual symptoms are directly associated with methanol poisoning. Recommendation 1: Any patient reporting visual disturbances or experiencing a decline in visual acuity after alcohol consumption should be hospitalized promptly and be treated for potential methanol exposure. **Recommendation 2:** Ocular examination should not be limited to patients with ocular symptoms. All patients with suspected methanol poisoning should undergo a detailed ophthalmic examination. **Quality of evidence**: ⊖⊖⊖O
3. Based on our literature review of observational studies, it's evident that ethanol poisoning cases predominantly show symptoms related to sinus rhythm abnormalities, particularly Sinus bradycardia, and tachycardia, while methanol poisoning cases are more characterized by abnormalities in QTc interval duration, ST-segment depressions/elevation, and T-wave changes. Additionally, methanol poisoning cases exhibit a broader range of ECG abnormalities compared to ethanol poisoning cases. **Recommendation**: Electrocardiogram is required for all patients with alcohol poisoning referring to hospitals. In patients with non-sinus rhythm, physicians should be suspected of methanol poisoning. **Quality of evidence:** ⊖⊖OO

Notes: High; ⊖⊖⊖O: Moderate; ⊖⊖OO: Low; ⊖OOO: Very low.

Q3. What are the differences in laboratory analyses of patients with ethanol and methanol poisoning on arrival?
1. Based on our IPD meta-analysis, atrial blood gas analyses with low PH values favor methanol poisoning, while our data was not satisfactory in bringing a clinically usable cut-off point. Based on the literature, ethanol poisoning mostly manifests as mild metabolic acidosis, while acidosis in methanol poisoning is severe [11]. **Recommendation:** An atrial blood gas analysis is crucial laboratory data needed for all alcohol poisoning patients. **Quality of evidence:** ⊖⊖OO 2. Ethanol poisoning is known to be associated with hypoglycemia [11, 63], but we only found 10 cases with available blood sugar levels for analysis. **Recommendation:** Literature shows more frequent hypoglycemia in ethanol poisoning and hyperglycemia in methanol poisoning; this is not reliable as no case-control or comparative studies exist. While blood sugar assessment is a necessary part of alcohol poisoning assessment, we cannot use it as a diagnostic tool. **Quality of evidence:** ⊖OOO 3. Methods of diagnosing methanol poisoning in blood are recently developed but are not widely available or approved for clinical application. **Quality of evidence:** ⊖OOO

Notes: High; ⊖⊖⊖O: Moderate; ⊖⊖OO: Low; ⊖OOO: Very low.

chart, eye movements, measuring intraocular pressure, pupillary reactions, and conducting a fundoscopic examination. For unconscious patients, a swinging flashlight test, a fundus examination, and pupillary reaction examinations should be performed at the bedside [59]. Point-of-care ocular ultrasonography can be used for both types of patients [60]. Studies have proposed daily examinations for patients hospitalized with methanol poisoning [59]. Optic disc atrophy was found in all one hundred patients reviewed in a retrospective study [61]. In case of positive findings, magnetic resonance imaging should be used to assess optic fiber nerves and potential brain edema [62] (Figure 2).

Ten observational studies were included studies in the literature review of ECG findings, with 3419 ethanol poisoning and 521 methanol poisoning cases. In the groups of ethanol poisoning (n=3419) and methanol poisoning (n=521), the most frequent ECG finding varies significantly. In the ethanol poisoning group, the most frequent finding is sinus bradycardia, with a prevalence of 63.73%, followed by sinus tachycardia at 24.10%. In contrast, the methanol poisoning group exhibits a higher prevalence of QTc prolongation at 19.58%, followed by ST-segment depressions/elevation and T changes at 14.59% and 8.06%, respectively (Figure 3).

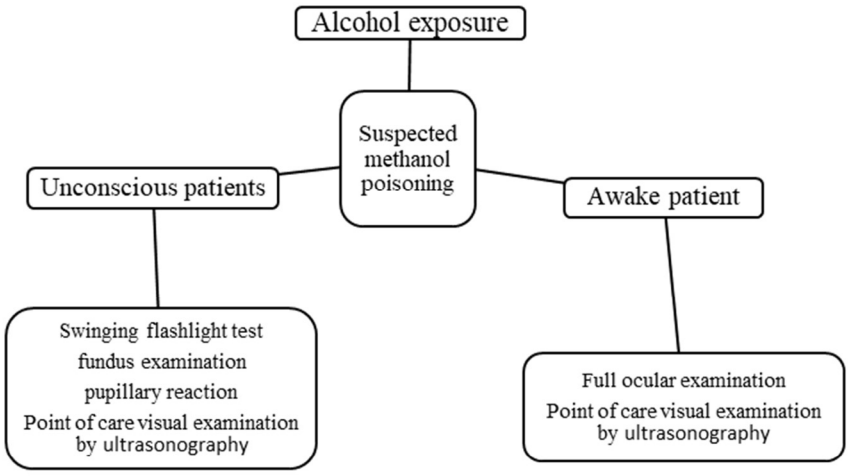
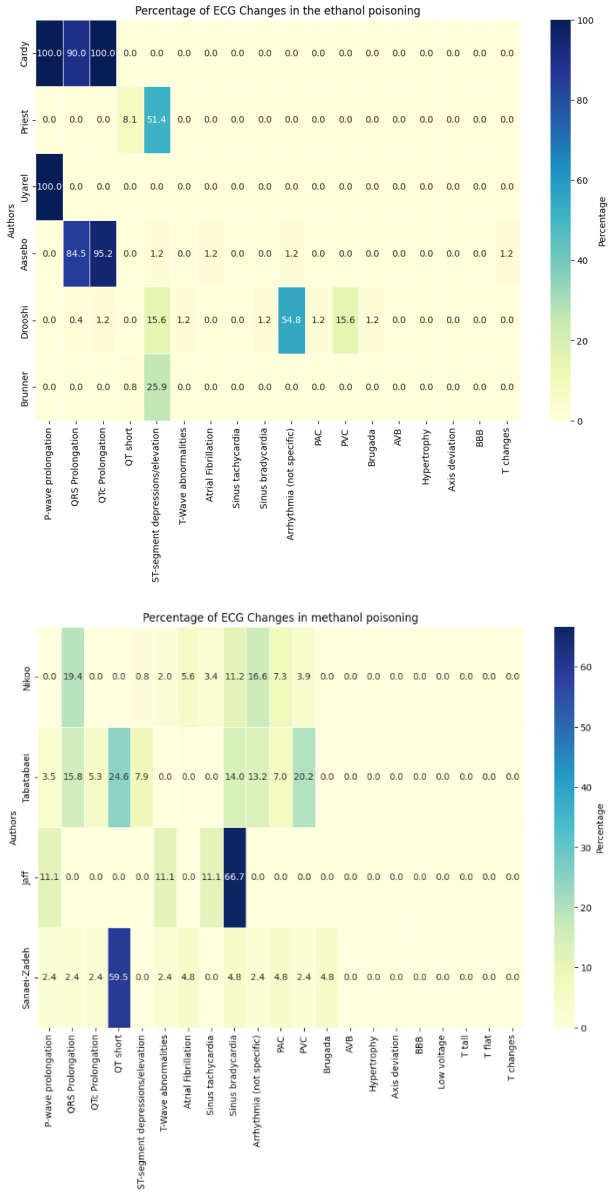


Figure 2. Schematic diagnostic approach for visual assessment of suspected cases



International Journal of Medical Toxicology & Forensic Medicine

Figure 3. ECG findings of methanol and ethanol poisoning cases from the IPD meta-analysis

Notes: Each cell in the heatmap represents the intersection of a row and column and is colored based on its value. The color intensity reflects the magnitude of the value. Numbers indicate the actual values for that combination of author and ECG change.

Methanol is metabolized in the body to formaldehyde and formic acid, which can disrupt glucose metabolism and increase blood sugar levels. Hypoglycemia is not commonly associated with methanol poisoning. Methanol poisoning more often leads to hyperglycemia and is known to be a prognostic factor in methanol poisoning [64]. Even in some circumstances, it might lead to diabetic ketoacidosis [65, 66].

Researchers have developed a simple and rapid diagnostic test for methanol poisoning using an enzyme called formate oxidase (FOX), which can detect formate in the blood. The test showed high sensitivity and specificity, with no false positives detected, making it a promising tool for point-of-care diagnosis, especially in low-resource settings where laboratory equipment may not be readily available [67]. Researchers have developed a bedside test strip that can detect formate, a toxic metabolite of methanol, from a single drop of blood, providing

a rapid and simple diagnosis of methanol poisoning. In a clinical trial, the test strip correctly identified a 61-year-old patient with methanol poisoning, allowing for prompt treatment and confirming the potential of this technology to revolutionize the management of methanol poisoning worldwide [68]. In another study, a commercially available dipstick test, originally designed to detect ethanol in saliva, was found to rapidly and reliably detect methanol in the serum of mice at concentrations as low as 5 mg/dL, offering a potential rapid diagnostic tool for emergency physicians [69]. Kubáň and colleagues developed a rapid and direct method for detecting formate in blood serum using capillary electrophoresis with contactless conductometric detection, which can diagnose methanol intoxication in approximately 1 minute with high sensitivity [70]. Gas chromatography/mass is also used to detect and quantify methanol in blood [71]. But these methods are not broadly investigated for clinic or are so expensive.

Ethanol's impact on blood sugar levels involves inhibiting the release of glucose from the liver and enhancing insulin secretion, which can lead to a drop in blood sugar levels. A study [72] shows that hypoglycemia can occur in children following ethanol ingestion. Research in rural Uganda [73] has shown instances of alcohol-related hypoglycemia, particularly in communities where alcohol consumption is prevalent.

Conclusion

In conclusion, the differentiation between ethanol and methanol poisoning presents a clinical challenge, and several key clinical and laboratory factors must be considered. Methanol poisoning cases tend to present later than the first day after alcohol consumption and are often characterized by awake and responsive patients, especially after 12 hours of ingestion. Notably, symptoms alone do not provide a reliable means of differentiation, emphasizing the importance of obtaining a detailed history of exposure, timing, and alcohol sources. Physical examinations may not reliably distinguish between the two types of poisoning, with vital signs such as blood pressure showing limited discriminatory value. Visual acuity and ophthalmic examinations are critical in cases of suspected methanol poisoning. Electrocardiograms are essential for all alcohol poisoning patients, particularly those with non-sinus rhythm, as methanol poisoning is associated with a broader range of ECG abnormalities. Laboratory analyses, including arterial blood gas measurements and blood sugar assessments, are valuable in the evaluation, but blood sugar levels alone cannot definitively diagnose the type of poisoning. A comprehensive evaluation combining clinical history, physical examination, and laboratory data is crucial for accurately differentiating ethanol and methanol poisoning.

Study limitations

The study's reliance on case reports and case series of severe ethanol and methanol poisoning may introduce selection bias, as these cases may not be representative of all alcohol poisoning presentations. This may lead to an overemphasis on statistical significance rather than clinical relevance. Furthermore, the sample size of ethanol poisoning cases (n=18) was relatively small compared to methanol poisoning cases (n=82), which may limit the power to detect significant differences between the two groups.

Ethical Considerations

Compliance with ethical guidelines

This article is a review with no human or animal sample.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgements

The authors thank the Clinical Research Development Unit of Peymanieh Educational and Research and Therapeutic Center of Jahrom University of Medical Sciences for revising the manuscript.

References

[1] Becker CE. Methanol poisoning. The Journal of Emergency Medicine. 1983; 1(1):51-8. [DOI:10.1016/0736-4679(83)90009-4] [PMID]

[2] Kruse JA. Methanol poisoning. Intensive Care Medicine. 1992; 18(7):391-7. [DOI:10.1007/BF01694340] [PMID]

[3] Veras-Estévez BA, Chapman HJ. Methanol toxicity outbreaks in the Americas: Strengthening national prevention and response measures. MEDICC Review. 2022; 24(2):43-44. [DOI:10.37757/mr2022.v24.n2.8] [PMID]

[4] Md Noor J, Hawari R, Mokhtar MF, Yussof SJ, Chew N, Norzan NA, et al. Methanol outbreak: A Malaysian tertiary hospital experience. International Journal of Emergency Medicine. 2020; 13(1):6. [DOI:10.1186/s12245-020-0264-5] [PMID] [PMCID]

[5] Hovda KE, Hunderi OH, Tafjord AB, Dunlop O, Rudberg N, Jacobsen D. Methanol outbreak in Norway 2002-2004: Epidemiology, clinical features and prognostic signs. Journal of Internal Medicine. 2005; 258(2):181-90. [DOI:10.1111/j.1365-2796.2005.01521.x] [PMID]

[6] Rostrup M, Edwards JK, Abukalish M, Ezzabi M, Some D, Ritter H, et al. The methanol poisoning outbreaks in Libya 2013 and Kenya 2014. Plos One. 2016; 11(3):e0152676. [DOI:10.1371/journal.pone.0152676] [PMID] [PMCID]

[7] Mahdavi SA, Zamani N, McDonald R, Akhgari M, Kolahi AA, Gheshlaghi F, et al. A cross-sectional multicenter linkage study of hospital admissions and mortality due to methanol poisoning in Iranian adults during the COVID-19 pandemic. Scientific Reports. 2022; 12(1):9741. [DOI:10.1038/s41598-022-14007-1] [PMID] [PMCID]

[8] Meyer RJ, Beard ME, Ardagh MW, Henderson S. Methanol poisoning. The New Zealand Medical Journal. 2000; 113(1102):11-3. [PMID]

[9] Brent J, McMartin K, Phillips S, Aaron C, Kulig K; Methylpyrazole for Toxic Alcohols Study Group. Fomepizole for the treatment of methanol poisoning. The New England Journal of Medicine. 2001; 344(6):424-9. [DOI:10.1056/NEJM200102083440605] [PMID]

[10] Barceloux DG, Krenzelok EP, Olson K, Watson W. American academy of clinical toxicology practice guidelines on the treatment of ethylene glycol poisoning. ad hoc committee. Journal of Toxicology. Clinical Toxicology. 1999; 37(5):537-60. [DOI:10.1081/CLT-100102445] [PMID]

[11] Sanaei-Zadeh H. The case files: Methanol or ethanol poisoning? Correct diagnosis influences treatment. Emergency Medicine News. 2012; 34(9B). [DOI:10.1097/01.EEM.0000421442.47327.b3]

[12] Brouwers MC, Kerkvliet K, Spithoff K; AGREE Next Steps Consortium. The AGREE reporting checklist: A tool to improve reporting of clinical practice guidelines. BMJ. 2016; 352:i1152. [DOI:10.1136/bmj.i1152] [PMID] [PMCID]

[13] Aibana O, Huang CC, Aboud S, Arnedo-Pena A, Becerra MC, Bellido-Blasco JB, et al. Vitamin D status and risk of incident tuberculosis disease: A nested case-control study, systematic review, and individual-participant data meta-analysis. Plos Medicine. 2019; 16(9):e1002907. [DOI:10.1371/journal.pmed.1002907] [PMID] [PMCID]

[14] Shea BJ, Reeves BC, Wells G, Thuku M, Hamel C, Moran J, et al. AMSTAR 2: A critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ. 2017; 358:j4008. [DOI:10.1136/bmj.j4008] [PMID] [PMCID]

[15] Raheja H, Namana V, Chopra K, Sinha A, Gupta SS, Kamholz S, et al. Electrocardiogram changes with acute alcohol intoxication: A systematic review. The Open Cardiovascular Medicine Journal. 2018; 12:1-6. [DOI:10.2174/1874192401812010001] [PMID] [PMCID]

[16] Gagnier JJ, Kienle G, Altman DG, Moher D, Sox H, Riley D, et al. The CARE guidelines: Consensus-based clinical case report guideline development. Journal of Dietary Supplements. 2013; 10(4):381-90. [DOI:10.3109/19390211.2013.830679] [PMID]

[17] Peterson J, Welch V, Losos M, Tugwell PJ. The newcastle-ottawa scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Ottawa: Ottawa Hospital Research Institute. 2011; 2(1):1-2. [Link]

[18] Atkins D, Best D, Briss PA, Eccles M, Falck-Ytter Y, Flottorp S, et al. Grading quality of evidence and strength of recommendations. BMJ. 2004; 328(7454):1490. [DOI:10.1136/bmj.328.7454.1490] [PMID] [PMCID]

[19] Atassi WA, Noghnogh AA, Hariman R, Jayanthi S, Cheung SF, Kjellstrand CM, et al. Hemodialysis as a treatment of severe ethanol poisoning. The International Journal of Artificial Organs. 1999; 22(1):18-20. [DOI:10.1177/039139889902200105] [PMID]

[20] Elliott RW, Hunter PR. Acute ethanol poisoning treated by haemodialysis. Postgraduate Medical Journal. 1974; 50(586):515-7. [DOI:10.1136/pgmj.50.586.515] [PMID] [PMCID]

[21] Pereska Z, Simonovska N, Babulovska A, Berat-Huseini A, Naumoski K, Kostadinoski K. Acute severe poisoning with disinfectant in senior aged patient-case report and overview of literature considering age influence on treatment decision in alcohol-based intoxications. SAGE Open Medical Case Reports. 2021; 9:2050313X211047717. [DOI:10.1177/2050313X211047717] [PMID] [PMCID]

[22] Morgan DL, Durso MH, Rich BK, Kurt TL. Severe ethanol intoxication in an adolescent. The American Journal of Emergency Medicine. 1995; 13(4):416-8. [DOI:10.1016/0735-6757(95)90127-2] [PMID]

[23] Johnson RA, Noll EC, Rodney WM. Survival after a serum ethanol concentration of 1 1/2%. Lancet. 1982; 2(8312):1394. [DOI:10.1016/S0140-6736(82)91285-5] [PMID]

[24] Berild D, Hasselbalch H. Survival after a blood alcohol of 1127 mg/dl. Lancet. 1981; 2(8242):363. [DOI:10.1016/S0140-6736(81)90674-7] [PMID]

[25] Sanap M, Chapman MJ. Severe ethanol poisoning: A case report and brief review. Critical Care and Resuscitation. 2003; 5(2):106-8. [DOI:10.1016/S1441-2772(23)00904-3] [PMID]

[26] Quispe Gonzales JO, Gomez Giralda B, Ruiz-Zorrilla López C, Acosta Ochoa MI, Ampuero Anachuri K, Molina Miguel A. Severe ethanol poisoning treated by haemodialysis. Nefrología. 2011; 31(2):226. [DOI:10.3265/Nefrologia.pre2010.Dec.10738]

[27] Nagashima G, Kamimura M, Kato A, Fukuda Y, Noda M, Morishima H, et al. A case of self-harm by alcohol intoxication resulted in unintended in-hospital death. Clinical Case Reports. 2014; 2(2):45-7. [DOI:10.1002/ccr3.51] [PMID] [PMCID]

[28] Wilson E, Waring WS. Severe hypotension and hypothermia caused by acute ethanol toxicity. Emergency Medicine Journal. 2007; 24(2):e7. [DOI:10.1136/emj.2006.041590] [PMID] [PMCID]

[29] Doyon S, Welsh C. Intoxication of a prison inmate with an ethyl alcohol-based hand sanitizer. The New England Journal of Medicine. 2007; 356(5):529-30. [DOI:10.1056/NEJMc063110] [PMID]

[30] Roberts HS, Self RJ, Coxon M. An unusual complication of hand hygiene. Anaesthesia. 2005; 60(1):100-1. [DOI:10.1111/j.1365-2044.2004.04055.x] [PMID]

[31] Meyer P, Baudel JL, Maury E, Offenstadt G. A surprising side effect of hand antisepsis. Intensive Care Medicine. 2005; 31(11):1600. [DOI:10.1007/s00134-005-2814-y] [PMID]

[32] Henry-Lagarrigue M, Charbonnier M, Bruneel F, Legriel S, Troche G, Ben Mokhtar H, et al. Severe alcohol hand rub overdose inducing coma, watch after H1N1 pandemic. Neurocrit Care. 2010; 12(3):400-2. [DOI:10.1007/s12028-009-9319-4] [PMID]

[33] Bookstaver PB, Norris LB, Michels JE. Ingestion of hand sanitizer by a hospitalized patient with a history of alcohol abuse. American Journal of Health-System Pharmacy. 2008; 65(23):2203-4. [DOI:10.2146/ajhp080320] [PMID]

[34] Tavolacci MP, Marini H, Vanheste S, Merle V, Coulon AM, Micaud G, Czernichow P. A voluntary ingestion of alcohol-based hand rub. The Journal of Hospital Infection. 2007; 66(1):86-7. [DOI:10.1016/j.jhin.2007.01.008] [PMID]

[35] Brvar M, Bunc M. High-degree atrioventricular block in acute ethanol poisoning: A case report. Cases Journal. 2009; 2:8559. [DOI:10.4076/1757-1626-2-8559] [PMID] [PMCID]

[36] Piccini J, Zaas A. Cases from the Osler Medical Service at Johns Hopkins University. Diffuse colonic angiodysplasia with chronic iron deficiency anemia. The American Journal of Medicine. 2003; 115(3):245-8. [DOI:10.1016/S0002-9343(03)00369-3] [PMID]

[37] Alqurashi GI, Alqurashi FS, Alhusayni KM, Falemban AH, Alhindi YZ, Alsanosi SM, et al. Case reports study on methanol poisoning in king abdul aziz specialist hospital, taif, Saudi Arabia. Journal of Clinical Medicine. 2023; 12(13):4282. [DOI:10.3390/jcm12134282] [PMID] [PMCID]

[38] Eskandrani R, Almulhim K, Altamimi A, Alhaj A, Alnasser S, Alawi L, et al. Methanol poisoning outbreak in Saudi Arabia: A case series. Journal of Medical Case Reportsp. 2022; 16(1):357. [DOI:10.1186/s13256-022-03600-7] [PMID] [PMCID]

[39] Kabli AO, Felemban AM, Nasri AK, Aljedani FA, Bedairi AM, Alghamdi MM, et al. Outcome of methanol toxicity outbreak in Saudi Arabia: Case series study. Cureus. 2023; 15(6). [DOI:10.7759/cureus.41108]

[40] Amin MR, Shohagh AB, Basher A, Rahman M, Faiz MA, Ahasan HA. Methanol poisoning with fatality-case series in Dhaka Medical College Hospital in Bangladesh. Toxicol Open Access. 2017; 3(121):2. [DOI: 10.4172/2476-2067.1000121]

[41] Liu JJ, Daya MR, Carrasquillo O, Kales SN. Prognostic factors in patients with methanol poisoning. Journal of Toxicology. Clinical Toxicology. 1998; 36(3):175-81. [DOI:10.3109/15563659809028937] [PMID]

[42] Cardy MA, Donnerstein RL, Kelly LF, Bittner NH, Palombo GM, Goldberg SJ. Acute effects of ethanol ingestion on signal-averaged electrocardiograms. The American Journal of Cardiology. 1996; 77(15):1356-7. [DOI:10.1016/S0002-9149(96)00205-6] [PMID]

[43] PPriest RG, Binns JK, Kitchin AH. Electrocardiogram in alcoholism and accompanying physical disease. British Medical Journal. 1966; 1(5501):1453-5. [DOI:10.1136/bmj.1.5501.1453] [PMID] [PMCID]

[44] Uyarel H, Ozdöl C, Karabulut A, Okmen E, Cam N. Acute alcohol intake and P-wave dispersion in healthy men. Anadolu kardiyoloji dergisi. 2005; 5(4):289-93. [PMID]

[45] Aasebø W, Erikssen J, Jonsbu J, Stavem K. ECG changes in patients with acute ethanol intoxication. Scandinavian Cardiovascular Journal. 2007; 41(2):79-84. [DOI:10.1080/14017430601091698] [PMID]

[46] Dorooshi G, Savari MA, Nayeri F, Meamar R, Tarrahi MJ, Eizadi-Mood N. Electrocardiogram changes in patients with acute ethanol poisoning. International Journal of Medical Toxicology and Forensic Medicine. 2021; 11(2):33353. [DOI:10.32598/ijmtfm.v11i2.33353]

[47] Brunner S, Herbel R, Drobesch C, Peters A, Massberg S, Kääb S, et al. Alcohol consumption, sinus tachycardia, and cardiac arrhythmias at the Munich Octoberfest: Results from the Munich beer related electrocardiogram workup study. European Heart Journal. 2017; 38(27):2100-6. [DOI:10.1093/eurheartj/ehx156] [PMID] [PMCID]

[48] Nikoo MH, Arjangzadeh A, Pakfetrat M, Boogar SS, Mohammadkarimi V, Ostovan VR, et al. Electrocardiographic findings of methanol toxicity: A cross-sectional study of 356 cases in Iran. BMC Cardiovascular Disorders. 2020; 20(1):415. [DOI:10.1186/s12872-020-01691-y] [PMID] [PMCID]

[49] Tabatabaiei MR, Yazdani S, Qorbani M, Shojaei L, Arani HF. [Evaluation of electrocardiogram changes in patients with methanol poisoning (Persian)]. Age. 2023; 28:9-21. [Link]

[50] Jaff Z, McIntyre WF, Yazdan-Ashoori P, Baranchuk A. Impact of methanol intoxication on the human electrocardiogram. Cardiology Journal. 2014; 21(2):170-5. [DOI:10.5603/CJ.a2013.0053] [PMID]

[51] Sanaei-Zadeh H, Emamhadi M, Farajidana H, Zamani N, Amirfarhangi A. Electrocardiographic manifestations in acute methanol poisoning cannot predict mortality. Arhiv za Higijenu Rada i Toksikologiju. 2013; 64(2):79-85. [DOI:10.2478/10004-1254-64-2013-2285] [PMID]

[52] Papadatos SS, Deligiannis G, Bazoukis G, Michelongona P, Spiliopoulou A, Mylonas S, et al. Nontraumatic rhabdomyolysis with short-term alcohol intoxication - A case report. Clinical Case Reports. 2015; 3(10):769-72. [DOI:10.1002/ccr3.326] [PMID] [PMCID]

[53] Calviño J, Bravo J, Millán B, Gonzalez-Tabares L. Flank pain and acute renal failure after binge drinking: A growing concern? Renal Failure. 2013; 35(3):421-4. [DOI:10.3109/0886022X.2013.764253] [PMID]

[54] Shweta K, Neelima C, Madhuri K. Study of clinical profile and outcome in patients of alcohol induced chronic liver disease with Hepato Renal Syndrome. MVP Journal of Medical Sciences. 2022; 8(2):240-8. [DOI:10.18311/mvpjms/2021/v8i2/307]

[55] Williams GF, Hatch FJ, Bradley MC. Methanol poisoning: A review and case study of four patients from central Australia. Australian Critical Care. 1997; 10(4):113-8. [DOI:10.1016/S1036-7314(97)70412-0] [PMID]

[56] Wang C, Hiremath S, Sikora L, Kanji S, Bugeja A, Samaha D, et al. Kidney outcomes after methanol and ethylene glycol poisoning: A systematic review and meta-analysis. Clinical Toxicology. 2023; 61(5):326-35. [DOI:10.1080/15563650.2023.2200547] [PMID]

[57] Youssef A, Madkour K, Cox C, Weiss B. Comparative lethality of methanol, ethanol and mixtures in female rats. Journal of Applied Toxicology. 1992; 12(3):193-7. [DOI:10.1002/jat.2550120308] [PMID]

[58] Cohier C, Chevillard L, Salle S, Risède P, Roussel O, Mégarbane B. Editor's highlight: Neurorespiratory effects of buprenorphine and ethanol in combination: A mechanistic study of drug-drug interactions in the rat. Toxicological Sciences. 2017; 155(2):389-99. [DOI:10.1093/toxsci/kfw221] [PMID]

[59] Desai T, Sudhalkar A, Vyas U, Khamar B. Methanol poisoning: Predictors of visual outcomes. JAMA Ophthalmology. 2013; 131(3):358-64. [DOI:10.1001/jamaophthalmol.2013.1463] [PMID]

[60] Propst SL, Kirschner JM, Strachan CC, Roumpf SK, Menard LM, Sarmiento EJ, et al. Ocular point-of-care ultrasonography to diagnose posterior chamber abnormalities: A systematic review and meta-analysis. JAMA Network Open. 2020; 3(2):e1921460. [DOI:10.1001/jamanetworkopen.2019.21460] [PMID]

[61] Galvez-Ruiz A, Elkhamary SM, Asghar N, Bosley TM. Visual and neurologic sequelae of methanol poisoning in Saudi Arabia. Saudi Medical Journal. 2015; 36(5):568-74. [DOI:10.15537/smj.2015.5.11142] [PMID] [PMCID]

[62] Yang CS, Tsai WJ, Lirng JF. Ocular manifestations and MRI findings in a case of methanol poisoning. Eye. 2005; 19(7):806-9. [DOI:10.1038/sj.eye.6701641] [PMID]

[63] Goldfrank LR. Goldfrank›s toxicologic emergencies. New York: Appleton-Century-Crofts; 1986. [Link]

[64] Sanaei-Zadeh H, Esfeh SK, Zamani N, Jamshidi F, Shadnia S. Hyperglycemia is a strong prognostic factor of lethality in methanol poisoning. Journal of Medical Toxicology. 2011; 7(3):189-94. [DOI:10.1007/s13181-011-0142-x] [PMID] [PMCID]

[65] Erfanifar A, Mahjani M, Salimpour S, Zamani N, Hassanian-Moghaddam H. Diabetic ketoacidosis as a complication of methanol poisoning; A case report. BMC Endocrine Disorders. 2022; 22(1):148. [DOI:10.1186/s12902-022-01037-z] [PMID] [PMCID]

[66] Freinkel N, Arky RA, Singer DL, Cohen AK, Bleicher SJ, Anderson JB, et al. Alcohol hypoglycemia. IV. current concepts of its pathogenesis. Diabetes. 1965; 14:350-61. [DOI:10.2337/diab.14.6.350] [PMID]

[67] Lao YE, Heyerdahl F, Jacobsen D, Hovda KE. An enzymatic assay with formate oxidase for point-of-care diagnosis of methanol poisoning. Basic & Clinical Pharmacology & Toxicology. 2022; 131(6):547-54. [DOI:10.1111/bcpt.13789] [PMID] [PMCID]

[68] Hovda KE, Lao YE, Gadeholt G, Jacobsen D. Formate test for bedside diagnosis of methanol poisoning. Basic & Clinical Pharmacology & Toxicology. 2021; 129(1):86-8. [DOI:10.1111/bcpt.13597] [PMID]

[69] Hack JB, Early J, Brewer KL. An alcohol oxidase dipstick rapidly detects methanol in the serum of mice. Academic Emergency Medicine. 2007; 14(12):1130-4. [DOI:10.1197/j.aem.2007.07.017] [PMID]

[70] Kubáň P, Foret F, Bocek R. Capillary electrophoresis with contactless conductometric detection for rapid screening of formate in blood serum after methanol intoxication. Journal of Chromatography. A. 2013; 1281:142-7. [DOI:10.1016/j.chroma.2013.01.035] [PMID]

[71] Islek D, Ramadanoglu S. Headspace-gas chromatography/mass spectrometry analysis of methanol in blood. Medicine Science International Medical Journal. 2017; 6(2):372-4. [DOI:10.5455/medscience.2017.06.8588]

[72] Yang CC, Yang LY, Deng JF. Hypoglycemia following ethanol ingestion in children: Report of a case. Journal of the Formosan Medical Association. 1995; 94(5):267-70. [PMID]

[73] Hammerstedt H, Chamberlain SL, Nelson SW, Bisanzo MC. Alcohol-related hypoglycemia in rural Uganda: Socioeconomic and physiologic contrasts. International Journal of Emergency Medicine. 2011 Feb 10;4:5. [DOI:10.1186/1865-1380-4-5] [PMID] [PMCID]