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Multidimensional Data Visualization to Evaluate the Post-treatment Prognosis of Patients Presenting with Methanol Intoxication: Chernoff Faces

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ABSTRACT

Objective: Methanol intoxication is life-threatening and often needs urgent intervention due to severe metabolic disturbances. This study aims to evaluate Chernoff faces (CF) as a visual tool for representing patient prognosis. It also aims to support rapid clinical decision-making in cases of methanol intoxication.

Methods: This retrospective study included 81 patients who presented to the emergency department with methanol intoxication. Key biochemical parameters—pH, bicarbonate (HCO₃), base excess, and creatinine—were recorded before and after dialysis. CF, a graphical method for displaying multidimensional data, were used to visualize these values. The technique illustrated both individual—and group—level changes in metabolic status.

Results: The cohort comprised 81 patients (6 females, 75 males; mean age: 52.9 years). After dialysis, significant improvements were observed: pH and HCO₃ levels increased, while blood urea nitrogen and creatinine levels decreased. Chernoff's facial features clearly depict these changes. Pre-dialysis patients exhibited distressed facial expressions, reflecting severe acidosis. Post-dialysis faces appeared more harmonious and "smiling", suggesting metabolic recovery. This visual shift was consistent across the entire group and in selected individuals. The method effectively and intuitively demonstrated clinical improvement.

Conclusion: CF provides a practical, visually intuitive method for monitoring metabolic recovery in methanol intoxication. By enabling rapid assessment of complex data, this tool enhances decision-making, particularly in time-sensitive settings like mass poisonings. Further studies will expand its use to other clinical contexts requiring the swift interpretation of multidimensional parameters.

Keywords: Methanol intoxication, Chernoff faces, multidimensional data, data visualization, emergency medicine

INTRODUCTION

Methanol is a clear, colourless, and odourless solvent widely used in industry as an antifreeze and cleaning agent; it is produced via wood distillation. It is often mistaken for ethanol and illegally added to cheap alcoholic beverages, leading to accidental and intentional poisonings. While ingestion is the most common route, transdermal and inhalation exposures have also been reported (1-4). Methanol is rapidly absorbed from the gastrointestinal tract, reaching peak serum levels within 30-60 minutes. Its toxicity stems from its metabolites-formaldehyde and formic acid. Formic acid inhibits mitochondrial oxidative phosphorylation, leading to high-

anion-gap metabolic acidosis (5). Clinically, methanol poisoning progresses through three phases: an early phase with non-specific symptoms (nausea, headache, vomiting), a latent phase with few or no symptoms, and a late phase marked by severe metabolic acidosis, visual disturbances (blurred vision, photophobia, diplopia), and central nervous system depression (6,7).

Treatment involves stabilization, antidotal therapy, and extracorporeal elimination. Airway, breathing, and circulation are secured with oxygen and IV fluids. Antidotes (ethanol or fomepizole) inhibit alcohol dehydrogenase, thereby preventing the formation of toxic metabolites. A loading dose followed by a

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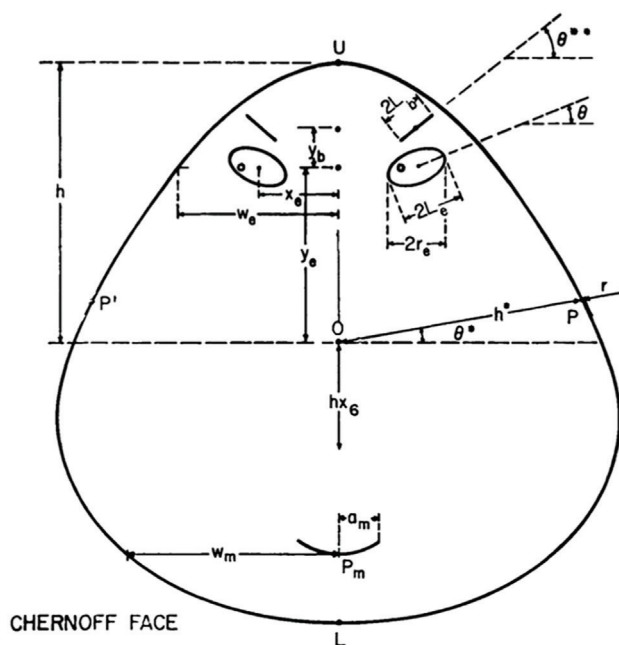
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maintenance infusion aims to achieve serum levels of 100-150 mg/dL. Fomepizole is given at 15 mg/kg IV every 12 hours, adjusted by response and labs to minimize side effects (8,9).

In severe cases, hemodialysis rapidly eliminates methanol and its metabolites while correcting acidosis (10). Folate and sodium bicarbonate (HCO_3^-) support formatted metabolism and acid-base balance (11). In the busy emergency department, clinicians must evaluate multiple biochemical parameters to guide treatment. Complex interactions may not be easily understood using numerical data. Alternative visualization methods can help interpret multidimensional data. Chernoff faces (CF), invented by Chernoff (12) in 1973, are widely used to visualize complex datasets by mapping multiple variables to facial features such as eye size, mouth curvature, and nose length. This technique, developed for general data analysis, has been used in psychology, social sciences, engineering, and finance to find patterns, clusters, and anomalies in large datasets (13). CF enables medical researchers to visually represent clinical data and compare multiple variables in an intuitive, interpretable format.

Computational algorithms generate CF. Each facial feature represents a variable in a multidimensional dataset. Any change in the 18 parameters alters the facial structure; therefore, each face visually encodes a unique, 18-dimensional data point. For datasets with fewer variables, missing dimensions are filled with fixed values to maintain consistency (12). Stata, Python, MATLAB, and R can create CF. These tools make complex datasets visual. Trends and relationships are easier to identify than when presented in tables or as numerical data. This method helps researchers and clinicians interpret large-scale data more easily and holistically.

This study examined CF as a multidimensional data visualization tool in emergency medicine, particularly for interpreting metabolic parameters and guiding clinical management. The parameters and facial features of the original CF are presented in Table 1 and Figure 1.



CHERNOFF FACE

Figure 1. The original Chernoff face

Table 1. Parameters and facial features represented in the original Chernoff face

Parameter (X)	Feature	Description
X1	Face width (h^*)	Horizontal width of the face, low values correspond to narrower faces
X2	Ear level (θ^*)	Horizontal level of the ears based on distance from the face center
X3	Face height (h)	Vertical height of the face
X4	Upper face eccentricity	Roundness or ellipticity of the upper half of the face
X5	Lower face eccentricity	Roundness or ellipticity of the lower half of the face
X6	Nose length	Length of the nose, high values indicate longer noses
X7	Mouth center (P_m)	Vertical position of the mouth
X8	Mouth curvature	Curvature of the mouth, indicating positive or negative expressions
X9	Mouth length	Width of the mouth
X10	Height of eye center (Y_e)	Vertical position of the eyes
X11	Eye separation (X_e)	Distance between the two eyes
X12	Eye slant (θ)	Horizontal slant of the eyes
X13	Eye eccentricity	Ovality or roundness of the eyes
X14	Eye length (L_e)	Size of the eyes
X15	Pupil position	Position of the pupil within the eye
X16	Eyebrow height (Y_b)	Vertical position of the eyebrows
X17	Eyebrow angle (θ^{**})	Angle of the eyebrows
X18	Eyebrow length	Length of the eyebrows

h^* : A normalized (standardized) measure representing facial width. It expresses a relative (proportional) value rather than an absolute length,

θ^* : An angular parameter indicating the position of features (e.g., ear level) relative to the facial center,

P_m : A normalized parameter representing the vertical position of the mouth center,

** (double asterisk): A derived angular measurement, particularly used for parameters such as eyebrow angle that define facial expressions

METHODS

Study Design

This research was conducted as a retrospective, observational study and was approved by the İzmir Katip Çelebi University Ethics Committee on March 21, 2024, under decision number 0175. It was conducted in accordance with ethical and scientific standards and was approved unanimously by the committee.

Study Population

Patients aged 18 years and older with methanol intoxication who received dialysis between November 1, 2015, and September 1, 2022 were included. Eligible patients were identified in the hospital database using international classification of diseases codes F10 (alcoholic mental and behavioral disorders) and T51.1 (methanol toxicity). Confirmation was obtained by reviewing nephrology and internal medicine consultations. Of the 92 patients initially identified, 6 were excluded due to missing data and 5 were excluded because they did not receive dialysis. For the final study, clinical and laboratory data from 81 patients were extracted from records and stored in a structured database.

Variables

The collected data included demographics (age, gender) and mode of hospital arrival (ambulance or self-admission).

Clinical symptoms: blurred vision, altered mental status, suspected alcohol intake, nausea/vomiting, syncope, dyspnea

Laboratory parameters: blood urea nitrogen (BUN), creatinine, sodium, potassium, chloride, calcium, pH, partial pressure of carbon dioxide (PaCO₂), HCO₃, lactate, ethanol, base excess, amylase, total bilirubin, international normalized ratio (INR).

These laboratory values were mapped to different facial features in a multidimensional visualization using CF.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics (Standard Concurrent User, v. 27; IBM Corp., Armonk, New York, USA). Descriptive statistics were presented as the number of units (n), percentage (%), mean ± standard deviation, median, minimum, and maximum values. The normality of the numerical variables was assessed using the Shapiro-Wilk normality test. Values that met the prerequisites for parametric tests were analyzed using the paired t-test; otherwise, the Wilcoxon signed-rank test was used. A p-value <0.05 was considered significant. Each laboratory parameter was mapped to a facial feature for CF visualizations. Assignments included: face—height (BUN), width (PaCO₂), and shape (lactate); mouth—height (sodium, HCO₃) and curvature (smile; pH); eye—height (base excess) and width (ethanol); hair—height (potassium, chloride, calcium); nose—height (creatinine, amylase); and ear—width (total bilirubin) and height (INR). This variable-feature mapping is shown in Table 2.

Data visual data visualization was performed in RStudio version 2024.04.2 using the “aplpack” package for CF representation. This study used CF to visualize pre- and post-dialysis laboratory

parameters in patients with methanol intoxication. Representations of metabolic changes after treatment made it easy to understand these changes.

RESULTS

This study included 81 patients: 6 women and 75 men. The average age was 52.9 years, ranging from 18 to 77. The emergency department received 38 walk-ins and 43 ambulance arrivals. Blurred vision (20 patients) and altered mental status (37 patients) were the most common symptoms. Overall, 54.3% of patients required intensive care. 12.3% of ED patients died (exitus), while 13.6% were discharged. The descriptive statistics for the patients are presented in Table 3.

Post-dialysis laboratory values showed a significant decrease in BUN and creatinine levels (p<0.01). While sodium levels remained unchanged (p=0.815), potassium levels significantly decreased (p<0.001). Treatment resulted in a significant increase in pH, indicating an improvement in metabolic acidosis (p<0.001). Lactate levels decreased slightly after treatment (p=0.053). Additionally, levels of base excess, HCO₃, INR, and total bilirubin significantly improved (p<0.001). Laboratory values and data visualization before and after dialysis are presented in Table 4 and Figure 2.

Data visualization and CF were generated from the average laboratory data of all patients, collected before and after dialysis. The CF technique effectively demonstrated the variations in biochemical parameters pre- and post-dialysis. The pH levels associated with the “smile” feature of the faces increased significantly post-treatment, from 7.04±0.23 to 7.17±0.24

Table 2. Laboratory parameters mapped to Chernoff face features in our study

Chernoff face parameter	Corresponding laboratory value
Face height	BUN
Face width	PaCO ₂
Face structure	Lactate
Mouth height	Sodium
Mouth width	HCO ₃
Smile	pH
Eye height	Base deficit
Eye width	Ethanol
Hair height	Potassium
Hair width	Chloride
Hair style	Calcium
Nose height	Creatinine
Nose width	Amylase
Ear width	Total bilirubin
Ear height	INR

BUN: Blood urea nitrogen, INR: International normalized ratio, PaCO₂: Partial pressure of carbon dioxide, HCO₃: Bicarbonate

($p < 0.001$). The change was visually evident in the post-treatment facial appearance, with a more pronounced smile, signifying improvement in metabolic acidosis. BUN levels decreased from 16.33 ± 14.29 to 14.71 ± 12.05 ($p = 0.010$), indicating a corresponding

Table 3. Demographic and clinical features of all patients

Variables	n	%
Gender		
Female	6	7.4
Male	75	92.6
Age		
$\bar{x} \pm SD$	52.90 ± 14.33	
M (min-max)	56 (18-77)	
Admission type		
Walk-in	38	46.9
Ambulance	43	53.1
Presenting symptoms		
Blurred vision	20	24.7
Altered mental status	37	45.7
Suspected alcohol intake	16	19.8
Nausea/vomiting	3	3.7
Syncope	2	2.5
Dyspnea	3	3.7
Mortality		
Exitus	18	22.2
Survive	63	77.8
Outcome		
Exitus	10	12.3
Intensive care	44	54.3
Inpatient ward	12	14.8
Left against medical advice	4	4.9
Discharged	11	13.6

∞: Mean, SD: Standard deviation, M: Median

reduction in face height in the CF. This visual alteration indicated an improvement in renal function. Creatinine levels demonstrated a significant reduction (from 1.33 ± 0.52 to 1.21 ± 0.56 , $p = 0.004$), which correlated with a decrease in nose height in the visual representation. HCO_3^- levels, correlated with mouth width, increased from 11.31 ± 6.88 to 15.55 ± 7.31 ($p < 0.001$), indicating a wider mouth in post-treatment faces, which visually reflected the correction of metabolic acidosis. Ethanol levels, indicated by eye width, decreased from 65.22 ± 103.44 to 52.17 ± 89.63 ($p = 0.028$), resulting in narrower eyes in post-treatment faces. The base deficit, associated with eye height, improved significantly from -17.87 ± 9.85 to -7.35 ± 8.26 ($p < 0.001$), resulting in elevated eye positions in the post-treatment faces. Potassium levels, correlated with hair height, decreased from 4.94 ± 1.16 to 4.23 ± 1.19 ($p < 0.001$), resulting in shorter hair in the visual representation.

Total bilirubin levels, indicated by ear width, rose from 0.66 ± 0.62 to 1.01 ± 0.75 ($p < 0.001$), leading to an increase in ear width in post-treatment subjects.

The pre-dialysis CF depicted features consistent with impaired metabolic and renal function, including elongated facial features and reduced pH. In contrast, the post-dialysis facial appearance demonstrates significant changes: a shorter, broader structure; a noticeable smile indicating pH normalization; and wider eyes suggesting improved metabolic status.

Case Examples

CF is shown in four randomly selected patients to demonstrate their clinical features. To ensure impartial representation of the study population, these patients were selected without selection criteria. The comparison of pre- and post-dialysis biochemical

Table 4. Laboratory values before and after dialysis

Variable	Measurement times		Test statistic	
	Before	After	Test value	p-value
BUN	13 (9)	11 (7.50)	2.593	0.010 [∞]
Creatinine	1.24 (0.63)	1.11 (0.69)	2.898	0.004[∞]
Sodium	137.33 ± 5.59	137.23 ± 5.01	0.235	0.815 ^f
Potassium	4.80 (1.60)	3.90 (1.40)	5.080	<0.001[∞]
Chloride	102.0 (6.50)	103.0 (6.50)	0.869	0.385 [∞]
Calcium	8.78 ± 0.86	8.66 ± 0.88	1.524	0.131 ^f
pH	7.10 (0.37)	7.30 (0.36)	5.144	<0.001[∞]
PaCO ₂	32.5 (21.05)	34.10 (14.05)	1.505	0.132 [∞]
HCO ₃ ⁻	8.90 (7.60)	16.90 (13.50)	5.143	<0.001[∞]
Lactate	4.30 (8.20)	3.0 (7.05)	1.936	0.053 [∞]
Ethanol	10.0 (76.0)	10.0 (25.0)	2.194	0.028[∞]
Base excess	-21.0 (11.50)	-6.0 (11)	6.538	<0.001[∞]
Amylase	75.0 (57.50)	68.0 (80)	1.715	0.086 [∞]
Total bilirubin	0.46 (0.50)	0.84 (0.97)	4.480	<0.001[∞]
INR	0.97 (0.14)	1.04 (0.23)	4.061	<0.001[∞]

Data are expressed as mean \pm standard deviation or median (interquartile range)
[∞]: Wilcoxon signed-rank test, ^f: Paired samples t-test, PaCO₂: Partial pressure of carbon dioxide, HCO₃⁻: Bicarbonate

parameters in the case series and CF, based on individual data from four selected patients, is shown in Table 5 and Figure 3.

In the first patient, the pre-dialysis facial appearance was tense and asymmetrical, reflecting severe metabolic derangement. Elevated lactate (15.0) and PaCO₂ (36.0) distorted the facial structure, while extreme acidosis (pH 6.60) created a pronounced frown. Post-dialysis, normalized values (lactate 1.2, pH 7.49, HCO₃ 25.1) produced a more symmetrical, smiling facial appearance, visually confirming an improved acid-base balance.

Similarly, the second patient's face narrowed after PaCO₂ dropped from 50.7 to 31.6, and the frown softened as pH improved from 6.8 to 7.3. An increase in HCO₃ (5.9 to 15.3) and a reduction in lactate (13.6 to 8.7) further normalized facial features. These changes reflected respiratory and metabolic recovery.

The third patient showed subtle but meaningful improvements: pH increased from 7.33 to 7.37, base excess from -3 to 3, and HCO₃ from 21.4 to 25.5; a sharp drop in ethanol (286 to 10) and narrowing of the pupils, indicating detoxification after methanol

poisoning. The patient initially presented with a severely distorted facial appearance due to extreme acidosis (pH 6.60, base deficit -27). After treatment, facial balance improved; however, residual acidosis (pH 7.19, base deficit -11) left the mouth relatively narrow. Overall, CF offered a unique visual summary of patients' clinical progression. Changes in smile, eye position, and facial symmetry corresponded to key biochemical improvements, enabling rapid and intuitive assessment of treatment effectiveness.

DISCUSSION

Methanol poisoning, a rare but serious medical condition, is caused by industrial or illegal alcohol consumption (1,2). Outbreaks can strain healthcare systems. Managing complex metabolic disturbances during crises requires timely and accurate clinical decision-making. Methanol intoxication causes rapid fluctuations in pH, base deficit, HCO₃, and lactate, making real-time assessment crucial for patient outcomes.

CF has been studied and applied in epidemiology, environmental sciences, and social sciences since Hermann Chernoff introduced it in 1973, but its use in clinical medicine remains limited. One study has compared them to star plots and profile graphs (14). Some researchers have shown that CF elicits rapid visual awareness, but data analysis has mostly focused on detecting psychological states and on depicting heart rate and other physiological data in evaluations of adolescent social anxiety, enabling non-experts to accurately discern patterns and deviations from established norms (15-18). In this study, we aim to understand not only patients' central state but also their metabolic state upon arrival at emergency services. Because the facial results are binary (white or black), more facial-point variables are needed to better understand the severity of patients. In a 1992 study by Phillipou (19),

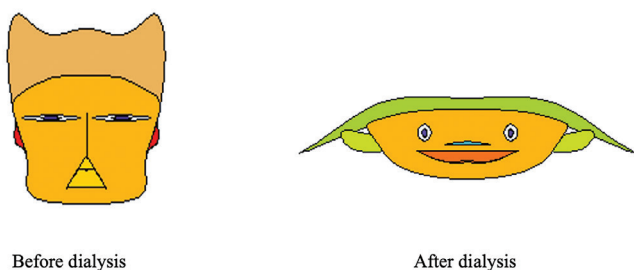


Figure 2. Chernoff face derived from pre- and post-dialysis mean data

Table 5. Comparison of pre- and post-dialysis biochemical parameters in case series

Parameter	Patient 1		Patient 2		Patient 3		Patient 4	
	Before	After	Before	After	Before	After	Before	After
BUN	12	12	21.0	21.0	10	12	8	8
PaCO ₂	36.0	29.7	50.7	31.6	41.5	48.3	53.9	43.6
Lactate	15.0	1.2	13.6	8.7	2.1	1.4	8	5.5
Sodium	140	134	138.0	139.0	143	144	135	132
HCO ₃	3.8	25.1	5.9	15.3	21.4	25.5	10.6	15.6
pH	6.60	7.49	6.8	7.3	7.33	7.37	6.60	7.19
Base excess	-26	-1	-24.2	-10.7	-3	3	-27	-11
Ethanol	10	10	10	10	286	10	397	10
Potassium	4.7	3.7	5.4	3.2	3.7	3.8	5.9	3.6
Chloride	105	105	105	105	99	104	102	104
Calcium	9.1	8.7	9.3	9.3	9.1	9.4	7.5	6.5
Creatinine	1.29	1.62	1.8	1.8	0.81	0.82	1.53	1.45
Amylase	283	181	78	78	77	63	175	116
Total bilirubin	0.85	1.00	0.4	0.4	0.31	0.50	0.18	0.18
INR	1.07	0.97	1.0	1.0	0.93	0.95	0.97	1.41

BUN: Blood urea nitrogen, INR: International normalized ratio, PaCO₂: Partial pressure of carbon dioxide, HCO₃: Bicarbonate

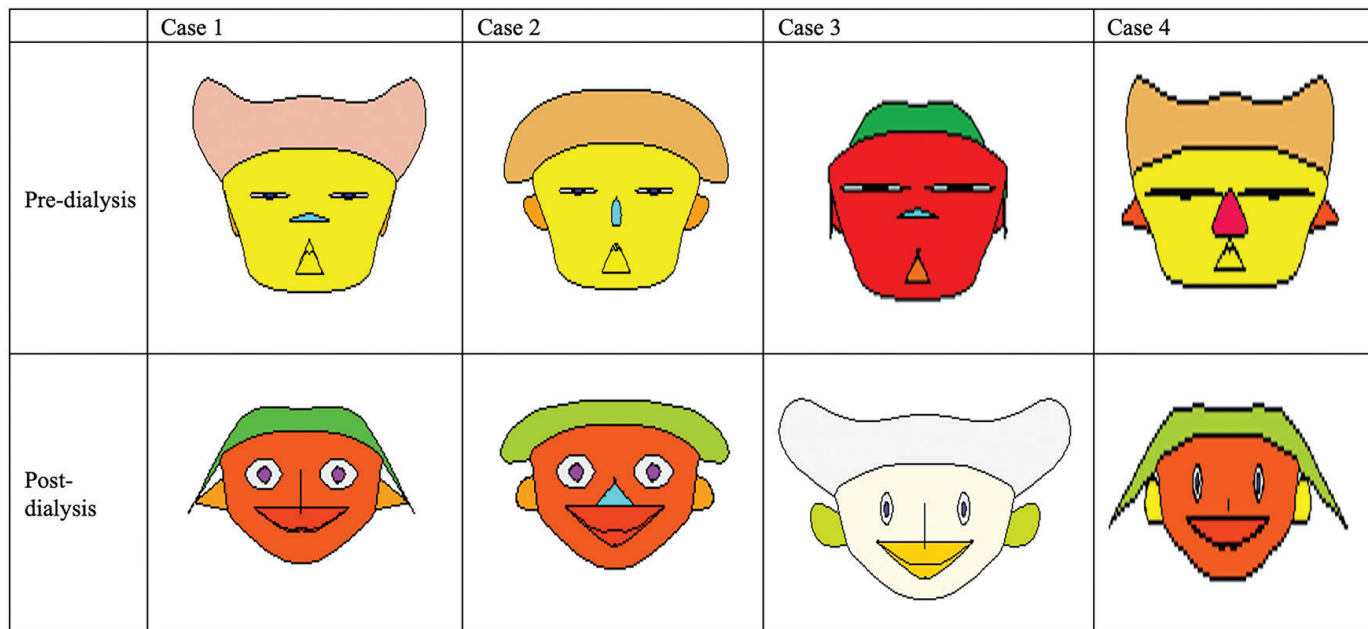


Figure 3. Chernoff faces based on individual data from four selected patients

CF was used to visually represent capillary blood glucose levels in diabetic individuals, facilitating rapid assessment of glucose regulation and temporal trends. This method enables both patients and healthcare providers to comprehend complex data more effectively than with conventional charts or tables. In studies by He et al. (20) and Shi et al. (21), the authors claim that machine learning, specifically RNN-LSTM, can precisely forecast the onset of acute kidney disease in patients with sepsis-associated acute kidney injury. Moreover, flexible machine learning techniques are widely used for predicting acute kidney injury, yet more complex deep learning models are emerging (22). As CF is a machine learning starter model, and among its advantages, rapid results are the most important, it can be used in emergency services in triage areas for multiple illnesses, such as methanol intoxication. CF has been used to visually represent cancer incidence rates and to interpret large-scale health data in epidemiology (23). Lott and Durbridge (24) demonstrated how CF could be employed to track metabolic and biochemical changes in critically ill patients, thereby facilitating the interpretation of complex laboratory trends. In orthodontic research, CF has been utilized to visualize morphological changes before and after treatment (25). In this study, the pre- and post-treatment data of patients who presented to the emergency department with methanol intoxication were visualized, and their potential contributions to clinical decision-making were examined. The results indicated that facial visualizations generated from key laboratory parameters commonly monitored in methanol intoxication could serve as effective tools to support clinical decision-making before and after treatment. Although this study focused specifically on CF—one of the most widely used methods of data visualization—the findings underscore the broader value of data visualization in enhancing diagnostic and therapeutic processes. Previous studies

have reported that CF is an effective tool for displaying trends in laboratory data and assisting in the recognition of abnormalities in acute care settings (24,26,27). Considering advances in technology and artificial intelligence, it is increasingly apparent that data visualization can be used more effectively. The conclusion that data visualization may be a useful tool in acute conditions such as methanol intoxication, which require urgent treatment and close monitoring, is therefore particularly significant. More research has examined which facial features are most perceptually informative (27,28). Eye size and mouth width are more intuitively recognized by observers, making them effective for visually encoding critical variables, while nose length and ear width had less impact on information retention (27). This study linked metabolic markers to distinct facial features, such as pH (smiling expression), HCO_3 (mouth width), base deficit (eye height), and ethanol (eye width), highlighting treatment-related changes. Pre- and post-dialysis average laboratory values for all patients showed a striking difference in CF values. Post-treatment, the face showed improved metabolic stability, whereas the pre-treatment face showed severe metabolic derangement. Individual case analyses showed clear correlations between laboratory improvements and facial transformations, supporting the clinical use of CF.

Study Limitations

CFs have limitations despite their benefits. As the number of variables increases, facial representation becomes more complex, potentially causing cognitive overload. Chernoff noted that exceeding 18 variables could reduce interpretability and reduce the technique's ability to convey nuanced details (12). Graphical representations simplify data interpretation, but they may obscure numerical subtleties and require additional analytical methods for high-precision evaluations. Integrating CF into

clinical applications requires appropriate software and technical infrastructure, which may pose logistical and financial challenges for healthcare institutions. The retrospective single-center design of our study limits it. Future research should validate these findings in larger, prospective cohorts to investigate the potential of CF for real-time clinical decision-making. Researchers and clinicians can assign facial features to parameters based on their study, thereby enabling highly adaptable data representation. This flexibility may limit study comparability due to the lack of a standardized feature-variable mapping method. Each study must explicitly define its parameter assignments, as a map legend does, because there is no universal framework. Implementation in clinical settings may require additional training to ensure that healthcare professionals accurately interpret visualized data.

CONCLUSION

CF visualizes multivariate data by mapping variables to facial features, thereby facilitating pattern recognition and comparison. They work well in clinical and emergency medicine. We found that CF may benefit emergency medicine, particularly during mass-casualty events in which rapid patient assessment is essential. It visualizes complex metabolic changes to improve triage, prioritize treatment, and monitor patients. More standardization and validation of CF are needed to help healthcare professionals manage critical cases.

Ethics

Ethics Committee Approval: The study was approved by the İzmir Katip Çelebi University Ethics Committee on March 21, 2024, under decision number 0175.

Informed Consent: This research was conducted as a retrospective study.

Footnotes

Author Contributions: Concept - E.S.B., M.G.E.; Design - E.S.B.; Data Collection and/or Processing - M.A.T., E.K.; Analysis and/or Interpretation - M.G.E.; Literature Search - M.A.T., E.K.; Writing - E.S.B., M.G.E.

Conflict of Interest: The authors have no conflicts of interest to declare.

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