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Reviving classical *Bawl* (urine) diagnostics in Unani medicine via artificial intelligence and digital tools: toward integrative informatics for traditional systems

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ABSTRACT

In Unani medicine, *Bawl* (urine) is recognized as a key diagnostic tool, with humoural imbalances assessed via parameters like color, consistency, sediment, clarity, froth, odor, and volume. This conceptual review explores how these classical diagnostic indicators may be contextualized alongside modern urinalysis markers (e.g., bilirubin, protein, ketones, and sedimentation) and examined through emerging artificial intelligence (AI) frameworks. Potential applications include ResNet-18 for color classification, You Only Look Once version 8 (YOLOv8) for sediment detection, long short-term memory (LSTM) for viscosity estimation, and EfficientDet for froth analysis, with standardized urine images/videos forming the basis of future datasets. Additionally, a comparative ontology is proposed to align Unani perspectives with diagnostic approaches in traditional Chinese medicine, encouraging cross-system integration. By synthesizing classical epistemology with computational intelligence, this review highlights pathways for developing AI-based decision support systems to promote personalized, accessible, and telemedicine-enabled healthcare.

1 Introduction

The Unani system of medicine, deeply rooted in humoral theory, conceives health as a state of equilibrium among the four bodily *Akhlāt* (humours) *Dam* (blood), *Balgham* (phlegm), *Ṣafrā* (yellow bile), and *Sawdā* (black bile) [1]. Qualitative or quantitative derangement in these *Akhlāt* gives rise to *Maraḍ* (disease), and identifying these imbalances is fundamental to diagnosis and treatment in Unani practice [2].

Bawl (urine) holds a significant role among multiple classical diagnostic methods. It is regarded as a non-invasive, rational, and perceptible indicator of the body's internal milieu. Urine analysis transcends its role as an excretory product, serving as a reflection of the functional status of internal organs, especially the liver, kidneys, and bladder. It also reveals insights into the quality and consistency of the humours, thus helping in determining the *Mizāj* (patients' temperament), whether *Ḥārr* (hot), *Bārid* (cold), *Yābis* (dry), and *Raṭb* (moist), and *Ḥālāt-e-Maraḍ* (disease condition) [1, 3, 4].

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Historical Unani literature highlighted that urine examination ranked among the earliest diagnostic tools employed in traditional medical systems. The concept traces its origins to Ancient Mesopotamia and Egypt, but it was Hippocrates (460 – 370 BCE) who first proposed that urine is a filtrate of the humours and can reflect bodily imbalances. Galen (129 – 200 CE) further advanced this understanding by describing kidneys' role in urine formation and suggested that urine output should align with fluid intake under normal conditions [3]. In Unani medicine, these concepts were later systematically elaborated by scholars, such as *Ibn Sīnā* (Avicenna) in *Al-Qānūn fī al-Ṭibb* (the canon of medicine), wherein *Bawl* is enumerated as one of the three fundamental diagnostic signs, along with *Nabz* (pulse) and *Barāz* (stool) [4]. According to *Ibn Sīnā*, *Bawl* carries critical clues regarding the stage, severity, and prognosis of illness, particularly in cases involving digestive disorders, liver malfunction, phlegmatic conditions, and febrile illnesses [3].

These practices were conceptually advanced, but inherently subjective, which mostly rely on a Hakim's visual and olfactory assessments. This introduces variability and limits reproducibility, especially when assessed through the lens of contemporary evidence-based medicine. Despite their enduring clinical value, Unani urine diagnostics lack digitized, validated, and standardized methodologies for integration into modern healthcare frameworks.

In the emerging technologies, artificial intelligence (AI) offers an optimal platform to standardize these perceptual methods. With advancements in deep learning models and computer vision tools, it is now feasible to analyze traditional visual parameters, such as colour, sediment, turbidity, and froth with smartphone cameras and algorithmic interpretation. AI-based models, including residual network (ResNet), You Only Look Once version 8 (YOLOv8), and long short-term memory (LSTM), have already demonstrated high accuracy for interpreting similar features in modern urinalysis, as mentioned in Figure 1 [5, 6]. These innovations could transform Unani diagnostics into digitally assisted, scalable solutions suitable for telemedicine, remote health monitoring, and primary care.

Similarly, traditional Chinese medicine (TCM) also relies on urine analysis to assess organ imbalances, including hepatic and renal dysfunctions, using qualitative parameters (e.g., colour, volume, and odour). TCM diagnostic logic shares foundational similarities with Unani theory in its reliance on non-invasive, perceptible signs rooted in holistic system thinking [7]. This conceptual alignment can develop cross-system diagnostic ontologies, enabling the unification of AI-driven tools in medical knowledge systems.

Despite these philosophical and technological alignments, no previous study has systematically mapped Unani urine indicators to biomedical parameters, nor developed a technical AI framework for digitizing and analyzing these features in accordance with traditional epistemology.

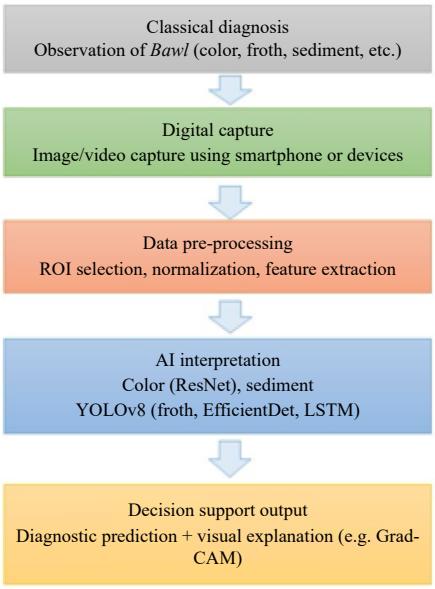

Figure 1 Workflow for integrating classical Unani urine diagnostics with AI systems

Therefore, the present review aims to: (i) examine and correlate classical Unani urine diagnostic indicators with their corresponding modern biomedical parameters; (ii) explore the potential application of AI tools including models (e.g., ResNet, YOLOv8, LSTM, and EfficientDet) for traditional *Bawl* analysis; (iii) highlight opportunities for cross-system integration between Unani and TCM through ontology-driven informatics frameworks. This review contributes to the expanding field of AI-assisted traditional medicine, proposing an interdisciplinary pathway to revive, validate, and digitally integrate Unani urine diagnostics into modern healthcare.

2 Theoretical foundations and urine formation in Unani medicine

In Unani medicine, diagnosis is founded on detecting disturbances in *Mizāj* (temperament) and the balance of bodily *Akhlāt* (humours). The medical framework is classified into two branches: (i) *Tibb-e-'Ilmi* (theoretical medicine), which covers *Umūr Ṭabī'iyya* (natural elements), *Asbāb* (causative factors), *Mizāj*, and *'Alāmāt* (signs and symptoms); and (ii) *Tibb-e-'Amali* (practical medicine), applies these principles in clinical evaluation and treatment [8].

Among classical diagnostic tools, *Bawl* is considered a non-invasive, perceptible indicator of internal health. *Ibn Sīnā* classified it as a principal *Fuḍlāt-e-Badan* (metabolic waste), offering insights into liver, kidney, and urinary tract function [4, 9]. The diagnostic significance of *Bawl* (urine) stems from its *Kayfiyāt* (qualitative attributes),

including colour, consistency, odor, and *Kamiyāt* (quantitative features), including volume, frequency, and sedimentation. These characteristics provide critical insights into *Su' Mizāj* (humoural imbalances) and organ function, often uncovering subtle pathological changes prior to the onset of clinical symptoms [10].

Examples include pale, excessive, and thin urine, indicating *Ghalba-e-Balgham* (phlegmatic dominance), suggesting a cold temperament or hepatic underactivity. And scanty, dark, thick urine is reflective of *Ghalba-e-Ṣafrā* (biliary excess), often seen in febrile or inflammatory conditions. The presence of froth or sediment may signal renal dysfunction or *Ghalba-e-Sawdā* (melancholic excess) [9]. Beyond its diagnostic use, *Bawl* has prognostic significance. Variations in its features are employed to monitor disease progression, assess *Buḥrān* (crisis), and guide treatment strategies. Physicians rely on this analysis to select temperament-specific therapies, such as *Munzij* (concoctive), *Mushil* (purgative), or *Muqawwī* (tonic) regimens [11].

Tameez-e-Bawl (urine formation) is described as a component of a four-stage digestive and metabolic framework. These stages includes *Hazm-e-Ma'idī* (gastric digestion) in the stomach, *Hazm-e-Kabadī* (hepatic digestion) in the liver, *Hazm-e-'Urūqī* (vascular digestion) in blood vessels, and *Hazm-e-Azā'ī* (tissue-level digestion) in organs and tissues [1]. During *Hazm-e-Kabadī* (hepatic digestion), nutrients from digested food are converted into blood, while *Fuḍlāt* (waste products) are generated. These waste products include *Raghwah* (frothy/gaseous waste), *Talchat* (a dense fecal waste), and *Bawl* (a liquid metabolic waste) filtered by the kidneys and excreted as urine [4].

Ibn Sīnā noted that the kidneys function as refined filters, extracting morbid matter from the blood while preserving useful elements. *Bawl* thus reflects internal states including humoural interactions, digestive function, and early pathological signals. *Razi* and *Ali Ibn Abbas Majoosi* emphasized that *Bawl* embodies dynamic metabolic processes, carrying traces of systemic and organ-level function [12].

From a modern biomedical perspective, urine is formed through glomerular filtration**,** tubular reabsorption, and secretion in the nephron. Blood plasma filtered in the glomerulus is modified along the renal tubules to generate final urine, which contains water, urea, creatinine, electrolytes, and potential pathological elements (e.g., proteins, glucose, or cells) that reflect conditions of the kidneys, liver, or systemic physiology.

Unani and modern views share a core conceptual similarity: both regard urine as a dynamic by-product of systemic metabolism. However, Unani theory views *Bawl* a more holistically entity beyond a mere waste product. It serves as a diagnostic mirror of *Mizāj*, humoural balance, and *Harārat-e-Gharīziyya* (internal heat). Disruption of this heat manifests as abnormal urine traits, such as turbidity, foul odor, or altered consistency, which parallel signs of hepatic or renal dysfunction in modern pathology [9, 11].

Understanding *Tameez-e-Bawl* is essential for linking diagnostic indicators to physiological processes in both classical and modern systems. It provides the mechanistic foundation upon which diagnostic interpretation of urine characteristics is constructed, reinforcing its role as a central tool in Unani diagnostics.

3 *Sharā'iṭ-e-Mu'āyana Bawl & Dalā'il-e-Bawl* (principles and diagnostic indicators in Unani urine examination)

Unani medicine proposed significant emphasis on a detailed and structured approach for *Mu'āyana Bawl* (urine examination) in diagnostic and prognostic applications. Classical physicians, including *Ibn Sīnā, Maseehi,* and *Ali Ibn Abbas Majoosi,* outlined *Sharā'iṭ* (principles) to ensure the reliability of observations and minimize diagnostic error.

3.1 *Sharā'iṭ-e-Mu'āyana Bawl* (principles of urine examination)

3.1.1 Collection of the early morning *Bawl* (urine) sample It is recommended that the first voided *Bawl* (urine) after waking is used for examination, and considered more concentrated and reflective of overnight metabolic processes. *Ibn Sīnā* noted that this sample represents the body's internal state with minimal interference from recent diet or activities [1, 4].

3.1.2 Avoidance of food, drinks, or medications before sampling Ingestion of colored substances (like beetroot, saffron, or drugs) may alter *Bawl* (urine) color and mislead the physician. Thus, the patient should be in a fasting state [4, 9].

3.1.3 Use of a clean, transparent glass vessel A transparent container allows for accurate visual assessment of *Bawl* (urine) color, clarity, sedimentation, and froth. The vessel should be washed thoroughly and be free of any residues from prior samples [4].

3.1.4 Timely examination within 1 – 2 h of voiding Delayed examination may result in chemical changes (oxidation and bacterial activity) that alter the original nature of *Bawl* (urine), leading to inaccurate interpretation [1].

3.1.5 Avoidance of physical or mental exertion before sample collection Emotional stress, fatigue, anger, exercise, or medication can affect the *Bawl* (urine)'s temperature, concentration, and composition. These influences can mask the humoral balance or imbalance condition [9].

These classical guidelines ensured that *Bawl* (urine) serves as a reliable indicator of the patient's intrinsic

Mizāj (temperament) classified as hot, cold, moist, or dry, and their overall *Ḥālāt-e-Badan* (physiological status). When these conditions are adhered to, physicians gain enhanced capacity to assess *Su' Mizāj* (humoural imbalances) and underlying pathology with diagnostic precision.

Building on these fundational principles, classical Unani physicians such as *Ibn Sīnā* (Avicenna) and *Jalīnūs* (Galen) formulated a structured and observational methodology for urine examination, known as *Dalā'il-e-Bawl* (diagnostic signs of urine). They emphasized that *Bawl* transcends its role as a metabolic waste product; rather, it serves as a perceptible reflection of internal states, capturing both the *Kayfiyāt* (qualitative attributes) of the humours and the condition of vital organs, including the liver, kidneys, bladders, and heart. These indicators, primarily assessed through macroscopic observation, offer valuable diagnostic and prognostic insights, enabling clinicians to evaluate disease severity, stage, and progression [8].

3.2 *Dalā'il-e-Bawl* (diagnostic signs of urine)

Building on these foundational principles, classical Unani physicians such as *Ibn Sīnā* (Avicenna) and *Jal īnūs* (Galen) formulated a structured methodology for urine examination, known as *Dalā'il-e-Bawl* (diagnostic signs of urine). They emphasized that Bawl is not merely a metabolic waste product but a perceptible reflection of internal states, capturing both the *Kayfiyāt* (qualitative attributes) of the humours and the condition of vital organs, including the liver, kidneys, bladder, and heart. To streamline, the diagnostic indicators can be grouped as follows.

3.2.1 *Alwān al-Bawl* (color of urine) *Bawl* (urine) color is considered one of the most significant diagnostic parameters in Unani medicine and reflects humoural dominance and organ function.

(i) *Bawl Asfar Tibnī* (straw yellow): this is considered the sign of *Tabayi Bawl* (normal urine) and reflects a balanced *Dam* and *Ṣafrā* [8].

(ii) *Bawl Ahmar Qānī* (dark red/vermilion): indicative of dominance of *Dam* (blood) may lead to reddish discoloration in *Bawl* or liver congestion. And it can be seen in acute fevers and hemorrhagic states [1].

(iii) *Bawl Abyaz Mukhātī* (white, mucous-like): suggesting *Ghalba-e-Balgham* (phlegmatic predominance), poor digestion, or renal albuminuria [11].

(iv) *Bawl Akhzar Zangārī* (verdigris green): associated with toxic states, jaundice, or food poisoning, and considered a grave sign when unaccompanied by sediments [11].

(v) *Bawl Aswad* (black): seen in *Shadeed Ehtraq* (severe oxidative stress) or *Saudāwi* conditions, such as melancholia and advanced liver disease. It also interpreted as a sign of *Buḥrān* (crisis) or even death [1].

Color not only indicates humoural excess but also aids in predicting disease stages and outcomes.

3.2.2 *Miqdār* (volume of urine) Urine volume is vital for assessing renal function and systemic hydration. (i) Polyuria (> 2 000 mL/d): seen in diabetes mellitus, diabetes insipidus, or nephropathy. (ii) Oliguria (< 500 mL/d): may suggest dehydration, shock, or cardiac failure. (iii) Anuria (< 200 mL/d): associated with acute renal shutdown or urinary tract obstruction [8]. Measurements were typically done over 24 h. Unani scholars would assess it regarding the relative output and fluid intake.

3.2.3 *Qiwām* (consistency) The texture or viscosity of *Bawl* (urine) is a sign of metabolic health. (i) *Bawl Ghaleez* (thick): denotes effective *Nuḍj* (maturation of humours), often a positive sign during disease resolution. (ii) *Bawl Raqeeq* (thin): may indicate weak digestion, *Barid Mizāj* (cold temperament), or poor liver function [13]. Thick *Bawl* (urine) with turbidity suggests humoural maturation, whereas persistently thin *Bawl* (urine) may denote constitutional weakness.

3.2.4 *Rasūb* (sediments) Sediments settle at the bottom or float on the surface after voiding. (i) *Ṭabī'ī Ras ūb* (physiological sediment): white, fine, and homogeneous, reflects complete digestion and balanced humoural elimination. (ii) *Ghair Ṭabī'ī Rasūb* (pathological sediment): it includes *Mukhātī* (mucoid) → excess phlegm, *Laḥmī* (fleshy) → possible renal or bladder pathology, *Ramlī* (sandy) → urinary calculus, and *Khamīrī* (fermented/yeast-like) → disturbed digestion or infection [14].

3.2.5 *Bū* (odour) Unani physicians used smell to identify internal imbalances. (i) Normal: slightly aromatic. (ii) Ammoniacal: indicates bacterial decomposition or UTI. (iii) Fruity: ketonuria or diabetic acidosis. (iv) Fishy: presence of *Proteus* bacteria or severe infection [14].

3.2.6 *Kaf/Jhāg* (froth) Froth is related to *Rīḥ* (gas) or excessive viscosity of body fluids. (i) Black froth: seen in *Yarqān-e-Aswad* (black Jaundice). (ii) Orange froth: in *Yarqān-e-Asfar* (yellow Jaundice). Froth size and persistence suggest the consistency of *Bawl* (urine) and level of *Lazūjat* (viscidity or thickness of the fluid) [12].

3.2.7 *Ṣafā'ī wa Kadūrat* (clarity and turbidity) (i) *Ṣafā'ī* (clear): sign of normal metabolism or *ba'da buḥrān* (post-recovery state). (ii) *Kadūrat* (cloudy): presence of pus, phlegm, or undigested materials—common in phlegmatic disorders or infections [4].

3.2.8 *Nuḍj* (concoction) and *Bawl* (urine) color change The concept of *Nuḍj* (maturation or ripening of morbid matter) lies at the core of Unani pathophysiology. It refers to the transformation of abnormal humours into a form suitable for evacuation. This process is supported by *Munzij* drugs, which prepare morbid matter for expulsion through natural routes like *Bawl* (urine), stool, and sweat. According to *Ibn Sīnā,* concoction reflects the

Ghalba (strength) of *Tabi'at* (medicatrix naturae). Signs of *Nuḍj* in *Bawl* (urine) include color change (often lighter in phlegmatic disorders), reduced turbidity, formation of homogenous sediment, and shift from thick to thinner consistency over time [1, 4].

A recent observational study conducted by SUBHAN et al. [15] confirmed that administration of *Munzij-e-Balgham* [e.g., decoction of *Glycyrrhiza glabra* Linn. (Aslussoos), *Foeniculum Vulgare* Mill. (Badiyan), *Cichorium intybus* Linn. (Beekh-Kasni)] in patients with phlegmatic conditions resulted in a statistically significant reduction in *Bawl* (urine) color intensity, as measured by a photoelectric colorimeter at 580 nm. This modern validation supports the classical view that *Bawl* (urine) changes reflect the efficacy of concoction and sign readiness for evacuation.

3.3 Evidence gaps and limitations of classical indicators

Despite rich clinical descriptions, classical indicators often lack reproducibility and objective validation. Visual interpretations are subject to perceptual bias. Recent approaches using AI and digital tools show promise in addressing this limitation by enabling quantifiable, consistent assessment. Despite the richness of classical observations, many Unani diagnostic indicators are subject to perceptual variability. Visual parameters like assessment of color, sediment, and froth are interpreted based on physician experience, lighting conditions, and the container transparency. For instance, categories such as *Bawl Asfar* or *Bawl Akhzar* failed to define using standardized color charts, further limiting reproducibility.

Moreover, these indicators lack formal statistical validation. There are no sensitivity/specificity values or inter-observer agreement studies to verify their diagnostic accuracy. This gap constrains their acceptance in evidence-based clinical settings.

Recently however, emerging studies have begun to address the limitations. SUBHAN et al. [15] used photoelectric colorimeters to correlate traditional color classifications with humoural states, demonstrating the feasibility of modern quantification. These pilot observations pave the way for integrating AI models that can objectively analyze and classify these traditional parameters. By introducing AI-assisted quantification, Unani diagnostics can achieve enhanced consistency, validation, and clinical relevance while preserving its epistemological roots.

3.4 Integrated table: mapping Unani indicators to modern biomarkers

Table 1 integrates classical Unani indicators with their modern biomedical equivalents to support cross-system diagnosis and future AI applications. Beyond the above comparative mapping, several Unani diagnostic terms required precise understanding to ensure consistency for interdisciplinary readers and to support integration with AI-based diagnostic models. Therefore, a glossary of key Unani terms used in *Bawl* (urine) examination is provided in Table 2.

4 Conceptual and technical integration of AI tools for Unani urine analysis

The diagnostic methodology established by classical Unani physicians for examining *Bawl* (urine) is inherently perceptual and holistic, grounded in the observation of physical characteristics such as colour, clarity, froth, consistency, and odour. These macroscopic features were interpreted in the *Su' Mizāj* (humoral imbalances) and *Tabayyur-e-Mizāj* (temperamental deviations), allowing the *Ḥakīm* (physician) to deduce underlying organ dysfunctions or disease stages.

Today, the perceptible attributes once evaluated by ancient *Ḥukamā',* previously assessed through experience and sensory acuity—can be captured and quantified using modern biomedical tools. This convergence of traditional observation and contemporary technology provides a fertile ground for integrating AI into Unani diagnostics. Rather than replacing classical principles, AI enhances their consistency, reproducibility, and diagnostic value in contemporary clinical settings.

4.1 Alignment of classical indicators with modern tools

A meaningful alignment can be drawn between traditional *Mu'āyana Bawl* and modern clinical urinalysis in the following core areas.

Table 1 Comparative overview of classical Unani indicators and modern biomarkers

Unani indicator	Classical description	Modern equivalent/biomarker
Bawl Asfar Tibnī	Straw-yellow, normal humoral balance	Normal urobilin and bilirubin levels
Bawl Ahmar Qānī	Dark red, excess *Dam* or hepatic inflammation	Hematuria, bilirubinuria
Bawl Abyaz Mukhātī	White, mucous-like; *Ghalba-e-Balgham* (excess *Balgham)*	Proteinuria, leukocytes in urine
Bawl Akhzar Zangārī	Verdigris green; toxic or infectious states	Biliverdin presence, severe infections
Bawl Aswad	Black; advanced melancholia or crisis state	Hemoglobinuria, myoglobinuria
Rasūb Ramlī	Sandy sediment indicating urinary calculus	Crystals, calculi (uric acid, oxalates)
Jhāg (froth)	Froth linked to *Lazūjat or Su' Mizāj* (viscosity)	Proteinuria, foamy urine
Bū (odour)	Fruity, fishy, ammoniacal smells	UTI (ammonia), ketoacidosis, *Proteus* spp.
Qiwām (consistency)	Thick/thin urine indicating *Nuḍj* or digestion status	Specific gravity, urine viscosity

Table 2 Glossary of key Unani diagnostic terms

No.	Term	Definition
1	*Bawl*	Urine; considered a major excretory product in Unani diagnostics, reflecting internal humoural and organ states
2	*Kayfiyāt*	Qualitative properties of the body or humour, such as *ḥarārat* (heat), *burūdat* (cold), *rutūbat* (moisture), and *yubūsat* (dryness)
3	*Nuḍj*	The process of maturation of humours, indicating readiness of pathological materials for expulsion; crucial in *Buḥrān* (crisis) prediction
4	*Su' Mizāj*	Dystemperament; an abnormal state of temperament caused by humoural imbalance, affecting organ function or systemic health
5	*Lazūjat*	Viscidity or thickness of the body fluids, associated with increased froth in urine and resistance to flow
6	*Dam*	Blood; one of the four cardinal humours, associated with warmth and moisture; dominance can reflect hyperemia or inflammatory states
7	*Ṣafrā*	Yellow bile; a hot and dry humour; excess is linked with fevers, jaundice, and hypermetabolic conditions
8	*Balgham*	Phlegm; a cold and moist humour; excessive accumulation is associated with white urine, sluggish metabolism, and chronic conditions
9	*Saudā*	Black bile; a cold and dry humour; its dominance may manifest in dark urine and melancholic or degenerative states
10	*Rīḥ*	Wind or gas; formed during digestion; abnormal increase is associated with bloating, frothy urine, or discomfort
11	*Mizāj*	Temperament; the unique humoral constitution of a person (e.g., hot-cold and dry-moist), foundational to Unani diagnosis and therapy
12	*Hālat-e-Badan*	General physical condition or systemic state of health at a given moment

4.1.1 Macroscopic features Classical signs like *Bawl Asfar Tibnī* (straw-yellow urine indicating health or mild *Ṣafrā* excess), *Jhāg* (froth indicating humoural viscosity), or *Rasūb* (sediments reflecting metabolic imbalance or organ dysfunction) can be digitized using imaging sensors, and classified with AI-powered computer vision tools. This mirrors the interpretive logic of Unani physicians, preserving the diagnostic essence while improving objectivity.

4.1.2 Chemical attributes Modern urinalysis includes pH, specific gravity, glucose, protein, and bilirubin levels—parameters that correlate with Unani concepts of humoural excess (e.g., acidic urine with *Ṣafrā*, proteinuria with *Balgham*). AI algorithms can interpret these values in real time using smartphone-integrated dipstick readers.

4.1.3 Microscopic insights *Rasūb Ghair Ṭabīʿī* (pathological sediments), such as *Rasūb Ramlī* (sandy particles) or mucoid discharges, traditionally associated with kidney stones or *Balgham* dominance, align well with microscopic sediment analysis in modern medicine. These can be digitally recognized and categorized via AI-based detection.

4.2 AI-driven applications rooted in Unani logic

By mimicking the layered reasoning of classical *Ḥakīmān*, AI models can offer interpretive support in various aspects of Unani urine examination [5, 6].

4.2.1 Color classification Digital imaging combined with CNN architectures (e.g., ResNet-18) can identify and classify urine colors corresponding to humoural states—*Ṣafrā* (yellow), *Balgham* (white), *Dam* (red), and *Saudā or severe pathology* (green/black).

4.2.2 Froth and sediment analysis Object detection algorithms, such as YOLOv8 or EfficientDet can evaluate *Jhāg* (froth) and *Rasūb* (sediments) to infer internal *Lazūjat* (viscosity) or pathological deposits—mimicking classical pattern recognition.

4.2.3 Viscosity evaluation Using temporal models like LSTM, the flow of *Bawl* captured in short videos can assess thickness or stickiness, echoing Unani inferences about incomplete *Nuḍj* (concoction) or humoural stagnation.

4.2.4 Olfactory and volume indicators Emerging biosensors and smart urinalysis devices can detect chemical *Bū* (odours) or *Miqdār* (urine volume anomalies), both key indicators in Unani diagnostics.

By contextualizing AI tools within this diagnostic framework, the role of AI model transcends mere data processing—they emerge as critical aids in interpreting *Kayfiyāt* (qualities) and *Kamiyāt* (quantities), which is central to Unani diagnosis [16].

4.3 Proposed technical framework for AI-based *Bawl* analysis

To digitize classical Unani *Bawl* (urine) diagnostics into digital, machine-readable formats, a multi-stage AI-driven pipeline is proposed. This framework integrates image processing, deep learning models, and clinical domain knowledge to enhance analytical objectivity.

4.3.1 Data acquisition Urine samples are captured in transparent containers under standardized lighting conditions using smartphone cameras or webcam-based imaging systems. Short video clips (5 – 10 s) are recorded to assess dynamic parameters such as flow and viscosity.

4.3.2 Image pre-processing Captured images undergo color normalization (e.g., gray world algorithm), region-of-interest (ROI) extraction using edge detection or semantic segmentation (e.g., U-Net), and denoising. For videos, key frames are extracted at regular intervals.

4.3.3 AI model components (i) Color classification: CNN architectures like ResNet-18 or MobileNetV2 are for classifying *Bawl* (urine) into categories, such as straw yellow, *Akhzar Zangārī* (verdigris green), blackish, etc., corresponding to traditional indicators.

(ii) Sediment detection: YOLOv8 or Single Shot MultiBox Detector (SSD) object detection algorithms may identify and quantify visible sediments at the container's base.

(iii) Flow analysis/viscosity estimation: LSTM-based temporal models can analyze flow consistency across video frames to infer fluid resistance and thickness.

(iv) Froth classification: models, such as EfficientDet, are applied to categorize froth levels into light, moderate, or dense, corresponding to phlegmatic or safrawi indicators to infer *Lazūjat* (humoral thickening).

4.3.4 Model training and validation Datasets are annotated by traditional physicians and trained with stratified data split. Metrics such as accuracy, precision, recall, F1 score, and confusion matrix analyses are employed for model validation.

4.3.5 Explainable AI (XAI) To enhance clinician trust and transparency, visual explanation methods, including Grad-CAM and SHapley Additive exPlanations (SHAP) are incorporated to highlight key features that influence AI decision-making. This pipeline serves as the basis for developing intelligent mobile or desktop applications for real-time urine analysis in Unani healthcare settings.

4.4 Broader implications and cross-system integration

This AI-integrated system not only preserves the diagnostic philosophy of Unani medicine but also improves its clinical application. Parallel advancements in TCM, such as tongue and pulse image classification, confirm the feasibility of transforming perceptual diagnostic practices into structured, data-driven systems. Such integrative approaches could serve as a model for revitalizing traditional diagnostic systems through responsible digital innovation, balancing epistemological integrity with technological advancements.

5 Cross-system informatics: Unani and TCM integration through AI

Unani medicine and TCM are traditional healing systems with deep historical roots and share notable diagnostic parallels, especially in urine-based assessments. Both systems emphasize perceptible macroscopic features of urine including color, clarity, froth, odor, volume, and sediment as vital indicators for internal physiological imbalances and disease progression. For instance: (i) in Unani medicine, *Bawl Asfar Tibnī* (straw-yellow urine) is considered as a sign of normal temperament with mild *Safrā* dominance. In TCM, a similar yellow hue is linked to a "heat syndrome", particularly when it was accompanied by scanty urine and dryness, normally indicating the associations with internal heat or liver dysfunction. (ii) *Bawl Abyaz Mukhātī* (whitish mucous-like urine) in Unani suggests a *Ghalba-e-Balgham* (phlegmatic excess) or weak digestion. In TCM, this corresponds with fluid retention from spleen-kidney yang deficiency, both reflecting hypo-metabolism and internal cold. (iii) *Bawl Aswad* (blackish urine) is considered a dangerous sign in both systems. In Unani Medicine, it reflects severe *Su' Mizāj* (melancholic imbalance) or *Buḥrān* (crisis), while in TCM, it may point to blood stasis or advanced Yin deficiency with internal heat, often signaling a critical or end-stage condition.

These conceptual parallels support the development of cross-system AI-based diagnostic platforms. The following framework outlines the applications of this integration with informatics and machine learning tools.

5.1 Annotated dataset harmonization

To advance this endeavor, standardized, high-resolution image datasets should be curated and annotated by experienced Unani and TCM practitioners. These datasets will capture macroscopic urine features (color, froth, clarity, etc.), and dual-label to support the training of AI models across both diagnostic traditions. Specifically, classical urine indicators such as *Rasūb* (sediment layering), *Jhāg* (froth), or *Kadūrat* (turbidity) will be systematically documented and co-annotated by Unani *ḥakīms* and TCM practitioners. For instance, a urine sample showing frothy, pale characteristics may receive dual labels: *Ghalba-e-Balgham* in Unani and cold-dampness accumulation in TCM. This allows deep learning models to identify visual features relevant to both diagnostic systems [17].

5.2 Ontological mapping of diagnostic concepts

A unified digital ontology using RDF/OWL or similar semantic web standards was constructed. This would align diagnostic categories across systems of *Bawl Akhzar*

Zangārī (verdigris green urine in Unani) with TCM's "liver-gallbladder damp-heat" syndrome or *Ghalba-e-Safrā* (yellow bile excess) with TCM's Yang excess or liver fire.

The ontology can power knowledge graphs for AI reasoning and differential diagnosis across systems. A unified ontology can power integrative diagnostic systems and traditional knowledge graphs [17].

5.3 Cross-traditional diagnostic platforms

AI-assisted mobile and desktop applications allowing data input from both Unani and TCM parameters should be designed. For example, a physician could input urine that is "cloudy, thick, and odorous", and receive Unani interpretations (e.g., *Ghalba-e-Safrā* with *Su-e-Hazm*) alongside TCM interpretations (e.g., heat-damp accumulation in the bladder). Users can toggle between system-specific or integrated diagnostic outputs, enhancing collaborative care and cross-referencing [18].

5.4 XAI for trust and interpretability

To enhance clinical trust, AI models should incorporate interpretability, such as SHAP values, which explicitly demonstrate how specific features (e.g., color gradients or sediment density), influence predictive outcomes. Additionally, Grad-CAM heatmaps can visualize the spatial regions of the image that drive the classification of *Bawl Akhzar*. These tools align with the traditional pattern-recognition approaches of Unani and TCM physicians, preserving the underlying diagnostic logic while enhancing transparency. By making AI decision-making processes interpretable, this approach ensures that algorithmic suggestions remain trustworthy, facilitating validation by traditional practitioners through the lens of their respective philosophies [19].

5.5 Digital twins for personalized Unani-TCM integration

Constructing digital twin models that simulate patient health status based on traditional diagnostic parameters (urine characteristics, *Mizāj* or body constitution, tongue diagnosis, pulse manifestations, etc.) can enhance clinical decision-making. For instance, a patient's recurrent *Bawl Aswad* readings combined with lethargic symptoms may generate alerts in the system for *Buḥrān* (crisis progression) in Unani medicine and Yin deficiency in TCM, thereby guiding real-time treatment adjustment [20].

Standardizing and integrating urine diagnostic indicators across Unani and TCM through AI-driven approaches offers a transformative approach in the era of digital traditional medicine. It not only retains the philosophical essence of both systems, but also builds evidence-based, reproducible, and interoperable diagnostic infrastructures [21].

Future research should prioritize the development of large-scale, multicenter datasets, annotated by experts from both disciplines, followed by model validation using hybrid metrics that reflect both traditional insights and biomedical accuracy. Such efforts can lay the foundation for a globally integrative diagnostic platform, enhancing the relevance and sustainability of Unani and TCM in modern precision healthcare.

6 Future prospects and validation

To ensure the successful integration of AI into Unani urine diagnostics, a phased roadmap is essential. The following strategic plan categorizes the developmental pathway into short-term, mid-term, and long-term objectives, promoting clarity, coherence, and actionable progression.

6.1 Short-term objectives: foundation and feasibility studies

Priority should first be on the concept and technical feasibility through foundational studies. (i) Clinical validation studies: pilot studies are conducted for providing comparison on AI-generated analyses of *Bawl* (urine) features with assessments by experienced *ḥakīms* and conventional biomedical diagnostics. Parameters, such as sensitivity, specificity, and inter-rater reliability, should be measured to evaluate diagnostic validity and reproducibility. (ii) Dataset development and annotation: creating well-labeled image and video datasets of *Bawl* (urine), annotated with classical Unani descriptors like *Bawl Abyaz Mukhātī* (milky white) and *Rasūb Ramlī* (sandy sediment). These curated datasets will serve as the backbone for supervised machine learning training and algorithm validation. (iii) Awareness and training initiatives: begin orienting Unani physicians and postgraduate scholars through workshops and introductory modules on AI integration, digital health tools, and ethical considerations.

6.2 Mid-term objectives: tool development and deployment

Building upon early validation, the mid-term goals focus on translating models into accessible diagnostic tools.

6.2.1 Development of real-time diagnostic tools Smartphone-integrated applications and point-of-care diagnostic devices based on the proposed deep learning models, including ResNet (for color classification), YOLOv8 (for sediment detection), EfficientDet (for froth quantification), and LSTM (for viscosity estimation) are developed. These tools will enable rapid, standardized, and reproducible real-time interpretation of urine features,

especially valuable in low-resource and telemedicine settings. A stepwise workflow illustrating the integration of classical Unani diagnostics with AI systems is depicted in Figure 2.

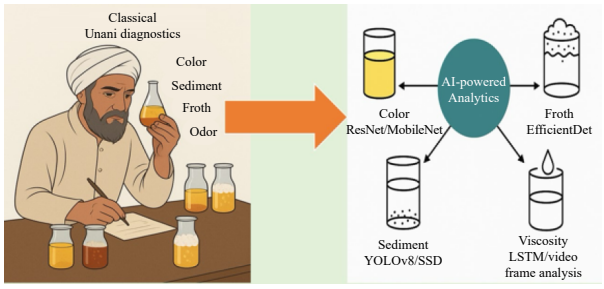

Figure 2 AI-powered interpretation of Unani urine indicators using deep learning pipelines

Classical parameters are linked with computer vision models to facilitate diagnostic automation.

6.2.2 Interoperable integration with TCM systems Collaborating with TCM researchers to co-develop shared ontologies and AI models capable of interpreting diagnostic concepts from both Unani and TCM. Unified platforms will allow system-specific as well as cross-traditional diagnostic perspectives. At the same time, ethical and regulatory compliance must be ensured by initiating dialogues with regulatory agencies to standardize these tools under Clinical Decision Support System (CDSS) frameworks, including the incorporation of privacy safeguards, data protection, transparency, and informed consent mechanisms as part of the deployment protocol.

6.3 Long-term objectives: institutionalization and global integration

To achieve sustainable impact and global relevance, long-term objectives should aim at institutional adoption and international visibility.

(i) Curriculum integration and capacity building: embed AI literacy and digital diagnostic competencies into formal Unani curricula across academic institutions. Develop specialized certificate and diploma programs focused on AI in traditional medicine to cultivate a new generation of hybrid practitioners with expertise in both classical Unani knowledge and modern computational tools.

(ii) Multicenter trials and evidence synthesis: conduct multicenter trials across Unani and integrative health institutions to assess the real-world efficacy of AI-assisted urine diagnostics. Publish comparative outcomes and meta-analyses to inform the development of evidence-based clinical guidelines and the modernization of traditional diagnostic practice.

(iii) Global digital repository and knowledge exchange: establish an open-access, multilingual platform curated to host annotated datasets, standardized diagnostic frameworks, validated clinical protocols, and AI model architectures from Unani and related traditional medical systems. This digital knowledge base can catalyze international collaborations and policy advocacy for the recognition of AI-enhanced traditional medicine.

7 Conclusion

The classical Unani method of *Bawl* (urine) examination offers a nuanced, non-invasive diagnostic framework grounded in perceptible signs. Re-evaluating these indicators, such as color, sediment, and consistency through the lens of modern biomedical tools and AI technologies allows for their standardization, validation, and clinical reapplication. Integrating AI with traditional diagnostic logic not only preserves Unani epistemology but also expands its relevance in contemporary healthcare. This convergence paves promising pathways for personalized, accessible, and holistic diagnostics in the evolving landscape of integrative medicine.

Competing interests

The authors declare no conflict of interest.

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通过人工智能与数字工具复兴尤纳尼医学的经典尿液诊断：迈向传统医学体系的整合信息学

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【摘要】在尤纳尼医学中，*Bawl*（尿液）被视为一项关键诊断工具，借助颜色、黏稠度、沉淀物、清澈度、泡沫、气味与排量等参数来评估体液失衡。本文为概念性综述，探讨如何将这些经典诊断指标与现代尿液分析标志物（如胆红素、蛋白、酮体、沉淀物等）结合，并通过新兴的人工智能（AI）框架加以研究。潜在应用包括使用 ResNet-18 进行颜色分类、YOLOv8 进行沉淀物检测、长短期记忆网络（LSTM）估算黏度、以及使用 EfficientDet 进行泡沫分析，并以标准化的尿液图像/视频作为未来数据集的基础。此外，我们提出一种比较本体论，以将尤纳尼诊断视角与传统中医的诊断方法相对照，促进跨体系整合。通过将经典诊断学认识论与计算智能相结合，本文强调了开发基于 AI 的决策支持系统的路径，以促进个性化、可及性强且支持远程医疗发展的健康服务。

【关键词】尤纳尼医学；*Bawl*（尿液）诊断法；人工智能；深度学习；ResNet；YOLOv8；尿液生物标志物