Saudi Journal of Medicine and Public Health

https://saudijmph.com/index.php/pub

https://doi.org/10.64483/202631830

From Biological Specimen to Clinical Decision: Integrating Forensic Toxicology, Emergency Medical Services, Nursing Documentation, Radiological Findings, Nutritional Confounders, and Social Context.

Faisal Abdullah Shaher Alqahtani[(1)] , Seham Abdu Ali Khafy[(2)] , Saad Abdulrahman Saad Alsahli[(3)] , Hashel Ali Saleh Al Abdullah[(4)] , Malak Yahya Ali Jraibi[(5)] , Maryam Hejji Bumozah[(6)] , Abdullah Ali Alawadh[(6)] ,Rashed Abdullah Almuhaini[(7)] , Maryam Saleh Al-Hafizi[(8)] , Faiz Ali Ahmed Kaabi[(9)]

(1)Ministry of Health,Saudi Arabia
(2)Abu Arish General Hospital, Ministry of Health, Saudi Arabia
(3)Ruwaidat Al-Ard General Hospital, Ministry of Health, Saudi Arabia
(4)Al-Hudn Health Center, Najran, Ministry of Health, Saudi Arabia
(5)King Fahd Central Hospital, Jazan,Ministry of health, Saudi Arabia
(6)Maternity and Children's Hospital, Al-Kharj, Ministry of Health, Saudi Arabia
(7)King Khalid Hospital, Al-Kharj – Ministry of Health, Riyadh First Health Cluster, Saudi Arabia
(8)Al-Ais Hospital, Al-Ais Governorate – Ministry of Health, Saudi Arabia
(9)Irada Mental Health Hospital, Jazan, Ministry of Health, Saudi Arabia

Abstract

Background: Toxicological results seldom reach clinical decisions as isolated facts; they emerge from a chain of prehospital, nursing, laboratory, imaging, and social processes. **Aim:** To synthesize evidence on how forensic toxicology, emergency medical services (EMS), nursing documentation, radiology, nutritional status, and social context jointly shape the interpretation of biological specimens. **Methods:** A narrative review of peer-reviewed literature and surveillance reports published between 2017 and 2024 was conducted, with thematic synthesis across six domains. **Results:** Interpretive error accumulates at handoffs. Specimen timing and matrix, incomplete prehospital and nursing records, uninformative imaging requisitions, unrecognized nutritional modifiers, and stigma-related or structural biases each alter inference. Analytical advances such as high-resolution mass spectrometry expand detection but increase interpretive demands. **Conclusion:** An integrated, documentation-anchored framework linking specimen provenance to contextual metadata may reduce misinterpretation and support more accurate and equitable decisions.

Keywords: forensic toxicology; emergency medical services; nursing documentation; postmortem imaging; social determinants of health.

Introduction

A toxicology result is often treated as a number that speaks for itself. In practice, that number is the end product of a chain of decisions made by people who rarely meet. A paramedic decides what to give, what to collect, and what to write down at the roadside. A nurse records when, where, and how a sample was drawn. A radiographer images the patient under a particular clinical question. A laboratory scientist selects a matrix and an analytical method. Finally, a clinician, medical examiner, or court must decide what the finding means for a living patient or a deceased person. Around this chain sit factors that are seldom captured in structured data: what the person had eaten or failed to eat, the social circumstances that shaped exposure and access to care, and the assumptions that health professionals bring to the encounter.

The urgency of integrating these elements is evident in the epidemiology of drug-related harm. Overdose mortality in the United States has risen steeply, driven largely by synthetic opioids (Hedegaard et al., 2021; Spencer et al., 2019), and the geographic and demographic footprint of polysubstance fentanyl deaths has continued to widen (Friedman & Shover, 2023). Globally, the supply of new psychoactive substances has outpaced the capacity of surveillance and control systems (Peacock et al., 2019; Merz, 2018). Each of these trends increases the number of cases in which clinicians and forensic scientists must interpret complex, multi-substance findings under time pressure and with incomplete information.

Diagnostic reasoning in such cases is vulnerable. Diagnostic error is a major source of preventable harm in acute care (Newman-Toker et al., 2021), and the conditions that foster it, including

*Corresponding author faisalabdullah@gmail.com (Faisal Abdullah Shaher Alqahtani).
Receive Date: 30 August 2026, Revise Date: 27 October 2026, Accept Date: 13 November 2026

fragmented information, time pressure, and reliance on partial histories, are characteristic of toxicological presentations. In forensic settings, cognitive and contextual biases can influence expert judgment even when analytical procedures are sound (Dror, 2020). What is missing from much of the literature is a view that follows a single specimen across disciplinary boundaries and asks where meaning is gained or lost.

This review therefore adopts a pathway perspective. It examines six domains that jointly determine how a biological specimen becomes a clinical decision: forensic toxicology, EMS, nursing documentation, radiology, nutritional confounders, and social context. The aim is to synthesize recent evidence for each domain, identify the points at which information is most likely to be degraded, and propose an integrative framework that links specimen provenance to contextual metadata. The review is intended for clinicians, forensic scientists, nurses, paramedics, radiologists, and policymakers who share responsibility for the interpretive chain but seldom view it whole.

2. Methods

This study is a narrative review, an approach suited to topics that span several professional literatures with heterogeneous designs and outcome measures. A systematic review with pooled estimates was judged inappropriate because the domains differ in study type, ranging from analytical chemistry validation studies to qualitative nursing research and population surveillance reports. The review followed general good-practice principles for narrative synthesis: explicit questions, transparent sourcing, and thematic organization.

The guiding questions were as follows. First, how do specimen characteristics and analytical choices shape toxicological inference? Second, how do prehospital and nursing records preserve or lose information essential to interpretation? Third, what do radiological findings add to, or complicate in, toxicological reasoning? Fourth, how do nutritional status and dietary exposures confound interpretation? Fifth, how do social context and professional bias influence exposure, care, and documentation?

Literature was identified through targeted searches of PubMed, Scopus, and Google Scholar, supplemented by official surveillance publications from public health agencies and international drug-monitoring bodies. Search terms combined concepts such as forensic toxicology, postmortem redistribution, high-resolution mass spectrometry, naloxone, prehospital care, nursing documentation, electronic health records, postmortem computed tomography, malnutrition, food–drug interaction, social determinants, stigma, and overdose. Publications from January 2017 to December 2024 in English were eligible. Primary studies, systematic reviews, consensus statements, and surveillance reports were included when they addressed one or more review questions. Opinion pieces without an evidence base, conference abstracts, and studies focused solely on pharmacological treatment were excluded.

Because the review is narrative, selection was purposive, and no formal quality scoring was applied. Instead, priority was given to studies with clear methods, adequate sample sizes, or recognized authority, such as national surveillance data and consensus guidance. Findings were organized thematically and then integrated into a pathway model. Limitations arising from this approach are discussed in Section 10.

3. Forensic Toxicology: From Specimen to Analytical Result

3.1 Specimen, matrix, and time

Forensic toxicology begins before the laboratory. The choice of matrix (whole blood, plasma, urine, vitreous humour, oral fluid, hair, or tissue) determines the detection window, the interpretive framework, and the risk of artefact. Blood remains the reference matrix for assessing recent exposure and impairment, whereas urine extends the detection window but correlates poorly with concentration at the time of an event. Hair provides a long retrospective window but is vulnerable to external contamination and variability in incorporation. Each matrix therefore answers a different question, and the question asked by the clinician or investigator should dictate the sample, not the reverse.

In postmortem cases, time is the dominant confounder. Postmortem redistribution, the movement of drugs from tissue reservoirs into blood after death, can raise measured concentrations of lipophilic and basic drugs, and the effect depends on the drug, the site of sampling, and the interval to collection. Controlled work on opioids has shown time-dependent changes in blood and alternative matrices after death, underscoring that a single concentration cannot be interpreted without knowing the sampling site and postmortem interval (Brockbals et al., 2018). For clinicians receiving postmortem findings in a family or public health context, this means that a reported concentration is not equivalent to the concentration at the time of death or, still less, at the time of the last clinical contact.

3.2 Analytical advances and their interpretive cost

High-resolution mass spectrometry (HRMS) has transformed forensic toxicology by allowing untargeted acquisition and retrospective data mining, which is particularly valuable when new compounds emerge faster than reference standards can be produced (Pasin et al., 2017). Laboratories can now reanalyse stored data when a novel substance is identified, a capability that was previously impossible with targeted methods. The same flexibility,

however, increases the burden of interpretation. A tentative identification without a reference standard, a metabolite without established pharmacokinetics, or a low-level finding of unknown significance may all appear in a report, and non-specialist readers may over- or underestimate their importance.

The novel psychoactive substance (NPS) market illustrates the problem. Peacock et al. (2019) described how the speed, diversity, and unpredictability of NPS challenge drug surveillance and public health response, and the Merz (2018) continues to document the persistence of this market. In the opioid sector, regulatory action against fentanyl-related substances was followed by the appearance of structurally distinct synthetic opioids in postmortem investigations (Papsun et al., 2019). Potent nitazene-class compounds, for example, have been quantified and characterized in authentic casework, with metabolite discovery guiding which analytes laboratories should target (Krotulski et al., 2020). For the clinician, the lesson is that a negative immunoassay or a limited panel does not exclude exposure to a synthetic opioid and that the clinical picture should be allowed to challenge the laboratory screen.

3.3 Impairment, facilitated crime, and alcohol markers

Interpretation also depends on the legal or clinical question. In drug-impaired driving, surveys of toxicological findings show that prescription medicines, cannabinoids, and NPS frequently co-occur, so that single-substance thresholds provide limited guidance (Wille et al., 2018). In suspected drug-facilitated sexual assault, delayed reporting and rapid elimination of many sedatives complicate detection, and systematic review evidence indicates that alcohol and a limited range of sedative-hypnotics account for most positive findings, though under-detection is likely (Anderson et al., 2017). The timing of sampling, and the documentation of that timing, therefore determines whether a negative result is informative.

For alcohol, direct biomarkers such as phosphatidylethanol (PEth) in whole blood offer a window of weeks and are not affected by postmortem or in-vitro ethanol formation in the way that ethanol itself may be, making them valuable for distinguishing sustained heavy use from recent isolated drinking (Ulwelling & Smith, 2018). Such markers are an example of how the choice of analyte can bypass confounders that would otherwise require extensive contextual reconstruction.

3.4 Cognitive bias and the forensic–clinical boundary

Analytical rigour does not eliminate cognitive bias. Dror (2020) argued that expert decision-making is vulnerable to several sources of bias, including exposure to irrelevant contextual information, base-rate expectations, and organizational pressures, and that experts commonly hold the fallacy that they are immune. In toxicology, this may arise when a laboratory is told that a death is a presumed overdose and therefore accepts a borderline finding more readily. The challenge is not to withhold all context, since clinical interpretation requires it, but to sequence information so that analytical judgments are made before potentially biasing narratives are introduced and to document what was known when. This tension between the need for context and the need for independence is central to the integrative framework developed later in this review.

4. Emergency Medical Services: The First Custodian of the Clinical Story

4.1 Prehospital observations and interventions

EMS clinicians are often the only professionals to witness the scene: the environment, paraphernalia, bystander accounts, the patient's initial level of consciousness, respiratory pattern, pupils, and skin findings. These observations are time-sensitive and irretrievable. Once the patient has been moved and treated, the scene is gone, and the first physiological picture is overwritten by interventions. In toxicological presentations, that first picture may be the most diagnostic information available, particularly when laboratory confirmation is delayed or negative.

Prehospital treatment itself modifies the presentation and the specimen. Naloxone administration by EMS has grown substantially, and national data show both an increase in the frequency of administration and a pattern of repeated dosing in a growing proportion of events (Cash, 2018; Faul et al., 2017). Repeated dosing may reflect more potent synthetic opioids, larger exposures, or mixed overdoses, but it also changes the clinical timeline. Pharmacological reviews emphasize that naloxone dosing and route influence the speed and completeness of reversal and the risk of precipitated withdrawal (Rzasa Lynn & Galinkin, 2018). Mechanistic work suggests that rapid-onset effects of fentanyl on chest wall rigidity and noradrenergic pathways may explain some cases in which naloxone appear to fail (Torralva & Janowsky, 2019). For a clinician later interpreting a toxicology result, therefore, the number and timing of doses given before arrival are essential contextual data, and their omission can lead to misattribution of the patient's response.

4.2 Time, geography, and access

The interval between collapse and treatment is a determinant of both outcome and interpretation. Studies of EMS response intervals show that response times are longer in rural than in suburban and urban settings (Mell et al., 2017), which may produce more severe hypoxic injury and different laboratory profiles in otherwise similar overdoses. In addition, the proportion of patients who are treated

and not transported, or who refuse transport after reversal, varies by locality and protocol. These patients may never produce a hospital specimen, so that the toxicological picture of a region, as reconstructed from hospital data, is systematically biased toward those who were transported.

4.3 The handoff as a point of loss

The transition from EMS to the emergency department is a structured moment of information transfer and a common point of loss. Interprofessional collaboration research indicates that structured communication tools and shared goals can improve professional practice and, in some contexts, patient outcomes, though effects vary and evidence quality is mixed (Reeves, 2018). In practice, a verbal handoff delivered in a busy resuscitation bay may omit the scene context, the exact times of drug administration, the paraphernalia found, or the bystander account. If the written prehospital record is completed later and made available only after the initial decisions have been taken, the receiving team works from memory and impression.

Surveillance programmes that link EMS, hospital, and medical examiner data have demonstrated the value of integrated records for characterizing overdose epidemiology, as shown in work combining multiple data sources to describe heroin and fentanyl overdoses at the state level (Slavova et al., 2017). The same logic applies at the individual level. A prehospital record that is accessible at the point of care, and that records timestamps, doses, observations, and scene findings in structured fields, is a form of toxicological evidence in its own right.

4.4 Implications for specimen integrity

Finally, EMS practice has implications for specimen integrity. Intravenous access sites, fluids, and drugs administered en route can contaminate or dilute subsequent blood samples, and a sample drawn from an arm receiving an infusion is not equivalent to one drawn from the contralateral side. Where EMS treatment precedes sampling, the order and timing of events must be recorded if the specimen is to be interpreted correctly. In forensic cases, this requirement extends to chain of custody, where each transfer of responsibility must be documented. The paramedic is therefore the first, not merely a peripheral, link in the chain on which toxicological interpretation depends.

5. Nursing Documentation: The Connective Tissue of the Chain

5.1 What the record must carry

Nurses are present at the bedside for the longest continuous interval of any professional group, and their documentation is often the only continuous record of the patient's course. In toxicological cases, this record should carry the time and site of each specimen collection, the container and preservative used, the identity of the collector, observations of consciousness, respiratory rate, pupils, temperature, and behaviour, medication administration times, and any statements made by the patient or companions. These data link the specimen to the patient and the patient's physiological state at the time of collection, and without them an analytical result floats free of its context.

Forensic nursing scholarship has formalized this role. Valentine et al. (2020) described the evolution of forensic nursing theory, highlighting the integration of clinical care with evidence preservation, including attention to documentation, specimen handling, and the interface between health and legal systems. Although much forensic nursing work concerns violence and abuse, the same principles apply to the toxicology specimen: it is both a clinical sample and a potential legal exhibit, and the nurse is often its first custodian in hospital.

5.2 Documentation quality and its determinants

Evidence on nursing documentation quality is sobering. A comparison of paper-based and electronic records found improvements with electronic systems in some dimensions, such as legibility and completeness of certain fields, but persistent gaps in the documentation of assessments and care planning (Akhu-Zaheya et al., 2018). A facility-based study in Ethiopia reported that documentation practice was associated with factors such as training, workload, availability of documentation tools, and organizational support, with substantial proportions of nurses documenting suboptimally (Tasew et al., 2019). These findings are not confined to resource-limited settings. Workload and system design are recurring determinants in all contexts.

The electronic health record (EHR) has also introduced new problems. A scoping review of documentation burden among physicians and nurses concluded that the time spent on documentation is substantial, that measures are inconsistent, and that burden is associated with dissatisfaction and potential harm (Moy et al., 2021). For toxicology, the risk is that the fields most relevant to interpretation, such as the exact time a sample was drawn or the number of naloxone doses given before arrival, are buried in free text or are not captured at all, whereas fields demanded for billing or compliance are completed reliably. Documentation burden is thus not simply an efficiency problem but a threat to interpretive validity.

5.3 From documentation to decision support

Clinical decision support offers a mechanism for embedding critical fields in the workflow. Reviews of decision support systems describe both benefits, including improved adherence to guidelines and reduced errors, and risks, such as alert fatigue and poor integration into clinical routines (Sutton et al., 2020). Applied to toxicology,

a decision-support design would prompt the nurse to record collection time, site, and relation to infusions at the moment the specimen is labelled, and would flag to the interpreting clinician when such data are missing. Such design should be co-developed with nurses, since externally imposed prompts that add to documentation burden are likely to fail.

5.4 Nursing documentation and bias

Documentation is not neutral. The language that nurses use to describe a patient who uses drugs may reflect, and then reinforce, stereotypes that influence later decisions. A systematic review of implicit bias among healthcare professionals found evidence of implicit bias in the majority of studies, with potential effects on communication and decision-making (FitzGerald & Hurst, 2017). Stigmatizing language in the chart can carry forward to other clinicians, who may read a patient's complaints through the lens of a prior label. This bears directly on toxicological interpretation, because a presumption of drug use can lead to premature closure, so that other causes of altered consciousness, such as infection, stroke, or metabolic disease, are not pursued. Objective, behaviourally specific, time-stamped documentation is both an ethical and a diagnostic safeguard.

6. Radiological Findings: Independent Evidence and Its Limits

Radiological findings supply objective evidence that is independent of the laboratory, but they are rarely specific for a toxic exposure. Their value lies in constraining the differential diagnosis, identifying complications, and sometimes explaining a discordance between clinical picture and chemistry. In living patients, aspiration pneumonitis, non-cardiogenic pulmonary oedema, and hypoxic-ischaemic brain injury may follow opioid or sedative overdose, whereas intracranial haemorrhage, infarction, or trauma may mimic intoxication or coexist with it. A positive urine screen for a sedative does not exclude a structural cause of coma, and cranial imaging therefore remains a counterweight to the anchoring that a positive toxicology result can induce. The same logic applies in reverse: a normal scan does not exclude toxic encephalopathy or metabolic coma.

The usefulness of imaging depends on the quality of the question put to the radiologist. A systematic review of the effect of clinical information on radiology reporting found that supplying clinical information generally improves the accuracy and relevance of reports, although the strength of the evidence varies and poorly completed requisitions are common (Castillo et al., 2021). In toxicological presentations, a requisition that reads only "altered mental state" omits the facts that would direct attention, such as suspected opioid exposure, prehospital naloxone, prolonged down-time, or a fall. The nursing and EMS records described above are the natural source of these details, which illustrates how failures in one domain propagate to another.

In the postmortem setting, imaging has become established as an adjunct or alternative to conventional autopsy. A prospective, masked comparison of postmortem computed tomography with targeted coronary angiography against autopsy for coroner-requested investigations reported that the imaging approach could identify a cause of death in a large proportion of cases and could reduce the need for invasive autopsy, though it was less reliable in certain categories (Rutty et al., 2017). For toxicology, the implication is twofold. Imaging can exclude or identify competing natural or traumatic causes, allowing the toxicological finding to be weighed appropriately, and it can guide sampling, for example by indicating gastric contents or aspiration. Conversely, imaging cannot attribute death to a drug, and the temptation to treat a negative scan as support for an overdose diagnosis should be resisted. The sequence in which imaging, sampling, and any invasive procedure occur should be recorded, because sampling after resuscitation, transfusion, or prolonged storage affects specimen interpretation.

7. Nutritional Confounders: The Overlooked Variable

Nutritional status modifies drug disposition, laboratory biochemistry, and the clinical presentation, yet it is seldom recorded in toxicological case files. Malnutrition, defined by consensus criteria that combine phenotypic and aetiological factors (Cederholm et al., 2019), is associated with altered body composition, reduced protein binding, and changes in hepatic metabolism. These changes can increase the free fraction of highly protein-bound drugs and prolong the effect of agents cleared by the liver. A patient who is cachectic, chronically alcohol-dependent, or food-insecure may therefore show a more profound or prolonged response at a given measured concentration than a well-nourished patient, and the concentration alone will not explain the difference.

Food and drug interactions further complicate matters. A comprehensive review of food effects on oral drug absorption described how meal composition, gastric emptying, and bile secretion can increase, decrease, or delay absorption depending on the drug's properties (Deng et al., 2017). When the time of the last meal is unknown, the interpretation of an apparently low or delayed concentration after oral ingestion is correspondingly uncertain. The gut microbiome adds a further layer: systematic mapping has shown that human gut bacteria metabolize a substantial proportion of tested drugs, which may contribute to inter-individual variability in exposure (Zimmermann et al., 2019). Because diet shapes the microbiome, nutritional status is plausibly linked to pharmacokinetic variability, though direct evidence in forensic cases remains limited.

Dietary substances can also produce analytical confounding. Consumption of poppy seed products is a well-recognized source of low-level morphine and codeine findings in urine, and in postmortem cases, microbial fermentation can generate ethanol in the presence of glucose, which complicates interpretation where decomposition or hyperglycaemia is present. In such cases, direct markers such as PEth, which are not produced by fermentation, help to resolve the question (Ulwelling & Smith, 2018). Fasting and ketosis alter biochemical markers that may be misread as evidence of metabolic disease or poisoning. Table 1 summarizes the principal nutritional confounders and their interpretive consequences.

Nutritional vulnerability is also social. Food insecurity is associated with a range of adverse health outcomes and is unevenly distributed, as reviewed in the United States literature (Gundersen & Ziliak, 2018). People who use drugs are disproportionately exposed to food insecurity, which may mean that malnutrition, rather than being incidental, is part of the causal context of both exposure and vulnerability. Recording a simple nutritional history, including recent intake, weight loss, alcohol use, and food access, takes minutes and can transform the interpretability of a result.

Table 1. Principal nutritional confounders in toxicological interpretation

Confounder	Mechanism	Interpretive consequence	Practical mitigation
Malnutrition or hypoalbuminaemia	Reduced protein binding and altered hepatic metabolism	Greater or longer effect at a given concentration	Record weight, intake history, and albumin; interpret total concentrations cautiously
Meal timing and composition	Altered gastric emptying and absorption	Delayed or variable peak after oral ingestion	Document time of last meal and ingestion
Dietary substances (e.g., poppy seeds)	Natural opiate content	Low-level morphine or codeine findings	Use confirmatory quantitation and ask about diet
Hyperglycaemia and decomposition	Microbial ethanol formation	False impression of antemortem drinking	Use vitreous or direct markers such as PEth
Fasting, ketosis, chronic alcohol use	Altered biochemistry and thiamine status	Metabolic findings mistaken for poisoning or disease	Obtain history; correlate with clinical course
Gut microbiome variability	Bacterial drug metabolism	Unexplained inter-individual variability	Acknowledge uncertainty; avoid over-precise inference

8. Social Context: The Conditions behind the Specimen

8.1 Structural drivers of exposure

A specimen is taken from a person embedded in a social world, and that world shapes both the exposure and the response to it. Case and Deaton (2017) documented rising mortality among middle-aged adults in the United States, linked to drugs, alcohol, and suicide, and associated with economic and social disadvantage. Dasgupta et al. (2018) argued that the opioid crisis has deep social and economic determinants and that supply-side or prescribing-focused responses alone are unlikely to resolve it. Ciccarone (2019) described a "triple wave" in which prescription opioids, heroin, and illicit fentanyl successively drove overdose mortality, and emphasized the interaction of supply changes with demand shaped by social conditions. A broader public health framing makes the same point, calling for integrated approaches that combine prevention, treatment, and harm reduction (Blanco et al., 2020).

The analytical consequence is that the toxicological profile of a population changes quickly and unevenly. Synthetic opioids became involved in a rapidly increasing share of overdose deaths in the mid-2010s (Jones et al., 2018; Spencer et al., 2019), and national data show marked geographic variation in trends (Mattson, 2021). More recent work shows that polysubstance fentanyl deaths have spread across regions and demographic groups in patterns that differ by race and ethnicity (Friedman & Shover, 2023). A clinician or toxicologist who assumes yesterday's drug market will misjudge today's case, and local surveillance is therefore an interpretive input, not only a public health output.

8.2 Stigma, bias, and unequal care

Social context also shapes how professionals perceive and document patients. Volkow et al. (2021) argued that stigmatizing language around substance use disorders impedes help-seeking and treatment, and recommended person-first, medically accurate terminology. Evidence on implicit bias among healthcare professionals suggests that these attitudes are widespread and may influence communication and clinical decisions (FitzGerald & Hurst, 2017). In a toxicological case, a patient perceived as a "drug user" may be less likely to receive a full work-up for alternative diagnoses, and a patient perceived as socially secure may be less likely to be tested at all. The social characteristics of the patient thus affect which specimens exist, which tests are ordered, and how results are read.

Social determinants of health, including income, housing, education, and neighbourhood, influence access to care, exposure to hazards, and

outcomes, and healthcare organizations are increasingly expected to identify and respond to them (Magnan, 2017). Integrating such information into the toxicological chain is difficult, because social data are sensitive and may be used against patients in legal contexts. The ethical tension is genuine: the same contextual information that improves interpretation can, if misused, add to stigma or legal jeopardy. Governance arrangements should therefore specify who may access social information, for what purposes, and with what protections.

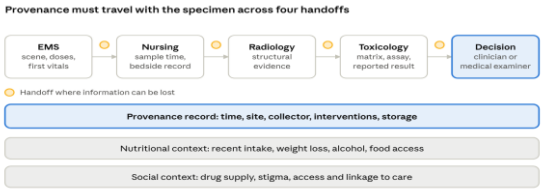
8.3 Linking systems and expanding the denominator

Surveillance and service innovations show how social context can be integrated constructively. Linked data systems combining EMS, hospital, and medical examiner records have improved characterization of overdose epidemiology (Slavova et al., 2017). Drug checking services, which analyse substances submitted by people who use drugs, can provide near-real-time information on the composition of the local supply, and a systematic review found evidence that such services can influence behaviour and engage populations that other services miss (Maghsoudi et al., 2022). Treatment pathways also matter: comparative effectiveness research on pathways for opioid use disorder indicates that outcomes differ substantially depending on whether patients receive medication-based treatment, behavioural care, or no treatment (Wakeman et al., 2020). Together, these developments suggest that the clinical decision following a toxicological result should include a plan for linkage to care, not only a diagnosis.

9. An Integrative Framework: Provenance, Context, and Interpretation

9.1 The pathway and where it leaks

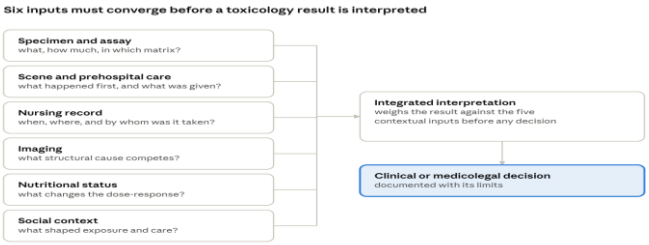
The preceding sections can be organized as a single pathway, shown in Figure 1. Information accumulates as the specimen moves from scene to laboratory to decision, but it can also be lost at each handoff. The central proposition of this review is that interpretive accuracy depends less on any single domain than on the preservation of provenance, meaning the who, when, where, and how of each observation and sample, across the entire chain. Diagnostic error research suggests that such failures are common and consequential in acute care (Newman-Toker et al., 2021), and interprofessional collaboration research indicates that structured communication can mitigate them (Reeves, 2018).



Specimen-to-decision pathway · 5 stages, 4 handoffs

Figure 1. The pathway from biological specimen to clinical decision, showing the five professional stages, the handoffs between them, and the nutritional and social context that surrounds the whole chain.

The framework proposes three principles. First, **provenance first**: every specimen carries a minimum dataset including collection time, site, collector, preceding interventions, and storage conditions. Second, **context in sequence**: contextual information is made available to interpreters in a defined order, so that analytical conclusions are reached and documented before potentially biasing narratives are introduced, as recommended by research on cognitive bias in expert judgment (Dror, 2020). Third, **context in full at the decision point**: the clinician or medical examiner who makes the final judgment receives the integrated picture, including prehospital, nursing, imaging, nutritional, and social data, ideally within a decision-support environment designed with the clinicians who will use it (Sutton et al., 2020).



Six inputs converging on one interpretation

Figure 2. How six sources of information converge on a single toxicological interpretation and the decision that follows it.

9.2 Domain responsibilities and failure modes

Table 2 summarizes, for each domain, what it contributes to interpretation, how it typically fails, and which mitigation the evidence supports. The table is intended as a practical checklist for multidisciplinary teams and for audit of case reviews.

Table 2. Contribution, typical failure modes, and mitigation by domain

Domain	Contribution to interpretation	Typical failure mode	Evidence-informed mitigation
Forensic toxicology	Identification and quantitation; choice of matrix	Postmortem redistribution; limited panels; ambiguous identification	Report matrix, site, and interval; use HRMS and direct biomarkers; state limits (Brockbals et al., 2018; Pasin et al., 2017)
Emergency medical services	Scene, first physiology, interventions	Lost scene details; unrecorded naloxone dosing; handoff gaps	Structured handoff and timestamped prehospital record (Cash, 2018; Reeves, 2018)

Domain	Contribution to interpretation	Typical failure mode	Evidence-informed mitigation
Nursing documentation	Specimen custody; continuous observations	Missing collection times; documentation burden; stigmatizing language	Embedded prompts; objective language; forensic nursing training (Moy et al., 2021; Valentine et al., 2020)
Radiology	Independent structural evidence	Uninformative requisitions; over-reading of nonspecific findings	Complete clinical information; explicit statement of limits (Castillo et al., 2021; Rutty et al., 2017)
Nutritional status	Modifier of pharmacokinetics and biochemistry	Unrecorded intake, fasting, or malnutrition	Brief nutritional history; consensus malnutrition criteria (Cederholm et al., 2019; Deng et al., 2017)
Social context	Exposure patterns, access to care, bias	Stigma; unequal testing; outdated assumptions about the drug supply	Local surveillance; person-first language; linkage to care (Friedman & Shover, 2023; Volkow et al., 2021)

10. Implications, Limitations, and Future Directions

10.1 Implications for practice and policy

For EMS services, the framework implies that timestamped records of drug administration and scene findings should be treated as part of the evidentiary chain and made available at the point of care. For nursing, it implies that collection time, site, and preceding interventions should be captured at the moment of labelling, with decision support designed to reduce rather than add to documentation burden (Moy et al., 2021; Sutton et al., 2020). For radiology and laboratory services, it implies that requisitions and reports should state their questions and limits explicitly. For forensic toxicology, it implies that reports should name the matrix, sampling site, and interval, and that uncertainty arising from novel compounds should be communicated in terms that non-specialists can use (Pasin et al., 2017; Peacock et al., 2019).

At the organizational level, case review should treat missing provenance data as a reportable quality deficiency in the same way as a missing consent form. At the policy level, linked surveillance and drug checking should feed local intelligence back to emergency departments and laboratories, shortening the time between the emergence of a new compound and its inclusion in routine testing (Maghsoudi et al., 2022; Slavova et al., 2017). Finally, professional education should address bias and stigma explicitly, since interpretive accuracy depends on how patients are perceived (FitzGerald & Hurst, 2017; Volkow et al., 2021).

10.2 Limitations

This review has several limitations. Its narrative design and purposive selection mean that it may over-represent literature that is visible and accessible and may not capture all relevant studies. Restriction to English-language sources from 2017 to 2024 excludes earlier foundational work and non-English evidence. Much of the epidemiological evidence is drawn from the United States, and the generalizability of findings to other health systems and drug markets is uncertain. The integrative framework is a conceptual synthesis and has not been empirically tested. Evidence on nutritional confounding in forensic cases is thinner than for other domains, and several claims in Section 7 rest on mechanistic reasoning and general pharmacological knowledge rather than direct forensic studies.

10.3 Future research

Four priorities emerge. First, prospective studies should quantify how often missing provenance data, such as collection time or prehospital drug doses, change the interpretation of toxicological results. Second, trials of embedded decision support for specimen documentation should evaluate both accuracy and nursing workload. Third, research should examine how nutritional status modifies dose–response relationships in real-world overdose and poisoning cohorts. Fourth, studies of equity should test whether patient characteristics predict the likelihood of testing, imaging, and documentation quality, with methods that allow the resulting disparities to be reduced.

11. Conclusion

A toxicology result becomes a clinical decision only after passing through the hands, records, images, bodies, and social circumstances that surround the specimen. The evidence reviewed here indicates that analytical sophistication, while essential, cannot compensate for lost provenance, incomplete prehospital and nursing records, uninformative imaging requests, unrecognized nutritional modifiers, or biased perceptions of the patient. An integrated framework that preserves provenance, sequences context to limit bias, and delivers the full picture to the decision-maker offers a pragmatic route to more accurate and more equitable interpretation. Implementing it requires cooperation among professions that rarely share a record, and the effort is justified by the consequences of error for patients, families, and the justice system.

References

1. Akhu-Zaheya, L., Al-Maaitah, R., & Bany Hani, S. (2018). Quality of nursing documentation: Paper-based health records versus electronic-based health records. *Journal of clinical nursing*, *27*(3-4), e578-e589.
2. Anderson, L. J., Flynn, A., & Pilgrim, J. L. (2017). A global epidemiological perspective on the toxicology of drug-facilitated sexual assault: A systematic review. *Journal of forensic and legal medicine*, *47*, 46-54.
3. Blanco, C., Wiley, T. R., Lloyd, J. J., Lopez, M. F., & Volkow, N. D. (2020). America's opioid crisis: the need for an integrated public health approach. *Translational psychiatry*, *10*(1), 167.
4. Brockbals, L., Staeheli, S. N., Gascho, D., Ebert, L. C., Kraemer, T., & Steuer, A. E. (2018). Time-dependent postmortem redistribution of opioids in blood and alternative matrices. *Journal of Analytical Toxicology*, *42*(6), 365-374.
5. Case, A., & Deaton, A. (2017). Mortality and morbidity in the 21st century. *Brookings papers on economic activity*, *2017*, 397.
6. Cash, R. E. (2018). Naloxone administration frequency during emergency medical service events—United States, 2012–2016. *MMWR. Morbidity and mortality weekly report*, *67*.
7. Castillo, C., Steffens, T., Sim, L., & Caffery, L. (2021). The effect of clinical information on radiology reporting: a systematic review. *Journal of medical radiation sciences*, *68*(1), 60-74.
8. Cederholm, T., Jensen, G. L., Correia, M. I. T. D., Gonzalez, M. C., Fukushima, R., Higashiguchi, T., ... & GLIM Core Leadership Committee, GLIM Working Group. (2019). GLIM criteria for the diagnosis of malnutrition–a consensus report from the global clinical nutrition community. *Journal of cachexia, sarcopenia and muscle*, *10*(1), 207-217.
9. Ciccarone, D. (2019). The triple wave epidemic: supply and demand drivers of the US opioid overdose crisis. *International Journal of Drug Policy*, *71*, 183-188.
10. Dasgupta, N., Beletsky, L., & Ciccarone, D. (2018). Opioid crisis: no easy fix to its social and economic determinants. *American journal of public health*, *108*(2), 182-186.
11. Deng, J., Zhu, X., Chen, Z., Fan, C. H., Kwan, H. S., Wong, C. H., ... & Lam, T. N. (2017). A review of food–drug interactions on oral drug absorption. *Drugs*, *77*(17), 1833-1855.
12. Dror, I. E. (2020). Cognitive and human factors in expert decision making: six fallacies and the eight sources of bias. *Analytical chemistry*, *92*(12), 7998-8004.
13. Faul, M., Lurie, P., Kinsman, J. M., Dailey, M. W., Crabaugh, C., & Sasser, S. M. (2017). Multiple naloxone administrations among emergency medical service providers is increasing. *Prehospital Emergency Care*, *21*(4), 411-419.
14. FitzGerald, C., & Hurst, S. (2017). Implicit bias in healthcare professionals: a systematic review. *BMC medical ethics*, *18*(1), 19.
15. Friedman, J., & Shover, C. L. (2023). Charting the fourth wave: Geographic, temporal, race/ethnicity and demographic trends in polysubstance fentanyl overdose deaths in the United States, 2010–2021. *Addiction*, *118*(12), 2477-2485.
16. Gundersen, C., & Ziliak, J. P. (2018). Food insecurity research in the United States: where we have been and where we need to go. *Applied Economic Perspectives and Policy*, *40*(1), 119-135.
17. Hedegaard, H., Miniño, A. M., Spencer, M. R., & Warner, M. (2021). Drug overdose deaths in the United States, 1999–2020.
18. Jones, C. M., Einstein, E. B., & Compton, W. M. (2018). Changes in synthetic opioid involvement in drug overdose deaths in the United States, 2010-2016. *Jama*, *319*(17), 1819-1821.
19. Krotulski, A. J., Papsun, D. M., Kacinko, S. L., & Logan, B. K. (2020). Isotonitazene quantitation and metabolite discovery in authentic forensic casework. *Journal of Analytical Toxicology*, *44*(6), 521-530.
20. Maghsoudi, N., Tanguay, J., Scarfone, K., Rammohan, I., Ziegler, C., Werb, D., & Scheim, A. I. (2022). Drug checking services for people who use drugs: a systematic review. *Addiction*, *117*(3), 532-544.
21. Magnan, S. (2017). Social determinants of health 101 for health care: five plus five. *NAM perspectives*.
22. Mattson, C. L. (2021). Trends and geographic patterns in drug and synthetic opioid overdose deaths—United States, 2013–2019. *MMWR. Morbidity and mortality weekly report*, *70*.
23. Mell, H. K., Mumma, S. N., Hiestand, B., Carr, B. G., Holland, T., & Stopyra, J. (2017). Emergency medical services response times in rural, suburban, and urban areas. *JAMA surgery*, *152*(10), 983-984.
24. Merz, F. (2018). United Nations Office on Drugs and Crime: World Drug Report 2017. 2017. *SIRIUS-Zeitschrift für Strategische Analysen*, *2*(1), 85-86.
25. Moy, A. J., Schwartz, J. M., Chen, R., Sadri, S., Lucas, E., Cato, K. D., & Rossetti, S. C.

(2021). Measurement of clinical documentation burden among physicians and nurses using electronic health records: a scoping review. *Journal of the American Medical Informatics Association*, *28*(5), 998-1008.

26. Newman-Toker, D. E., Wang, Z., Zhu, Y., Nassery, N., Tehrani, A. S. S., Schaffer, A. C., ... & Siegal, D. (2021). Rate of diagnostic errors and serious misdiagnosis-related harms for major vascular events, infections, and cancers: toward a national incidence estimate using the "Big Three". *Diagnosis*, *8*(1), 67-84.
27. Papsun, D. M., Krotulski, A. J., & Logan, B. K. (2022). Proliferation of novel synthetic opioids in postmortem investigations after core-structure scheduling for fentanyl-related substances. *The American Journal of Forensic Medicine and Pathology*, *43*(4), 315-327.
28. Pasin, D., Cawley, A., Bidny, S., & Fu, S. (2017). Current applications of high-resolution mass spectrometry for the analysis of new psychoactive substances: a critical review: D. Pasin et al. *Analytical and bioanalytical chemistry*, *409*(25), 5821-5836.
29. Peacock, A., Bruno, R., Gisev, N., Degenhardt, L., Hall, W., Sedefov, R., ... & Griffiths, P. (2019). New psychoactive substances: challenges for drug surveillance, control, and public health responses. *The Lancet*, *394*(10209), 1668-1684.
30. Reeves, S. (2018). Interprofessional collaboration to improve professional practice and healthcare outcomes. *Cochrane Database Syst Rev*, *8*, Cd000072.
31. Rutty, G. N., Morgan, B., Robinson, C., Raj, V., Pakkal, M., Amoroso, J., ... & Hew, R. (2017). Diagnostic accuracy of post-mortem CT with targeted coronary angiography versus autopsy for coroner-requested post-mortem investigations: a prospective, masked, comparison study. *The Lancet*, *390*(10090), 145-154.
32. Rzasa Lynn, R., & Galinkin, J. L. (2018). Naloxone dosage for opioid reversal: current evidence and clinical implications. *Therapeutic advances in drug safety*, *9*(1), 63-88.
33. Slavova, S., Costich, J. F., Bunn, T. L., Luu, H., Singleton, M., Hargrove, S. L., ... & Ingram, V. (2017). Heroin and fentanyl overdoses in Kentucky: Epidemiology and surveillance. *International Journal of Drug Policy*, *46*, 120-129.
34. Spencer, M. R., Warner, M., Bastian, B. A., Trinidad, J. P., & Hedegaard, H. (2019). Drug overdose deaths involving fentanyl, 2011–2016.
35. Sutton, R. T., Pincock, D., Baumgart, D. C., Sadowski, D. C., Fedorak, R. N., & Kroeker, K. I. (2020). An overview of clinical decision support systems: benefits, risks, and strategies for success. *NPJ digital medicine*, *3*(1), 17.
36. Tasew, H., Mariye, T., & Teklay, G. (2019). Nursing documentation practice and associated factors among nurses in public hospitals, Tigray, Ethiopia. *BMC research notes*, *12*(1), 612.
37. Torralva, R., & Janowsky, A. (2019). Noradrenergic mechanisms in fentanyl-mediated rapid death explain failure of naloxone in the opioid crisis. *The Journal of pharmacology and experimental therapeutics*, *371*(2), 453-475.
38. Ulwelling, W., & Smith, K. (2018). The PEth blood test in the security environment: what it is; why it is important; and interpretative guidelines. *Journal of forensic sciences*, *63*(6), 1634-1640.
39. Valentine, J. L., Sekula, L. K., & Lynch, V. (2020). Evolution of forensic nursing theory——Introduction of the constructed theory of forensic nursing care: A middle-range theory. *Journal of forensic nursing*, *16*(4), 188.
40. Volkow, N. D., Gordon, J. A., & Koob, G. F. (2021). Choosing appropriate language to reduce the stigma around mental illness and substance use disorders. *Neuropsychopharmacology*, *46*(13), 2230-2232.
41. Wakeman, S. E., Larochelle, M. R., Ameli, O., Chaisson, C. E., McPheeters, J. T., Crown, W. H., ... & Sanghavi, D. M. (2020). Comparative effectiveness of different treatment pathways for opioid use disorder. *JAMA network open*, *3*(2), e1920622.
42. Wille, S. M. R., Richeval, C., Nachon-Phanithavong, M., Gaulier, J. M., Di Fazio, V., Humbert, L., ... & Allorge, D. (2018). Prevalence of new psychoactive substances and prescription drugs in the Belgian driving under the influence of drugs population. *Drug testing and analysis*, *10*(3), 539-547.

Zimmermann, M., Zimmermann-Kogadeeva, M., Wegmann, R., & Goodman, A. L. (2019). Mapping human microbiome drug metabolism by gut bacteria and their genes. *Nature*, *570*(7762), 462-467