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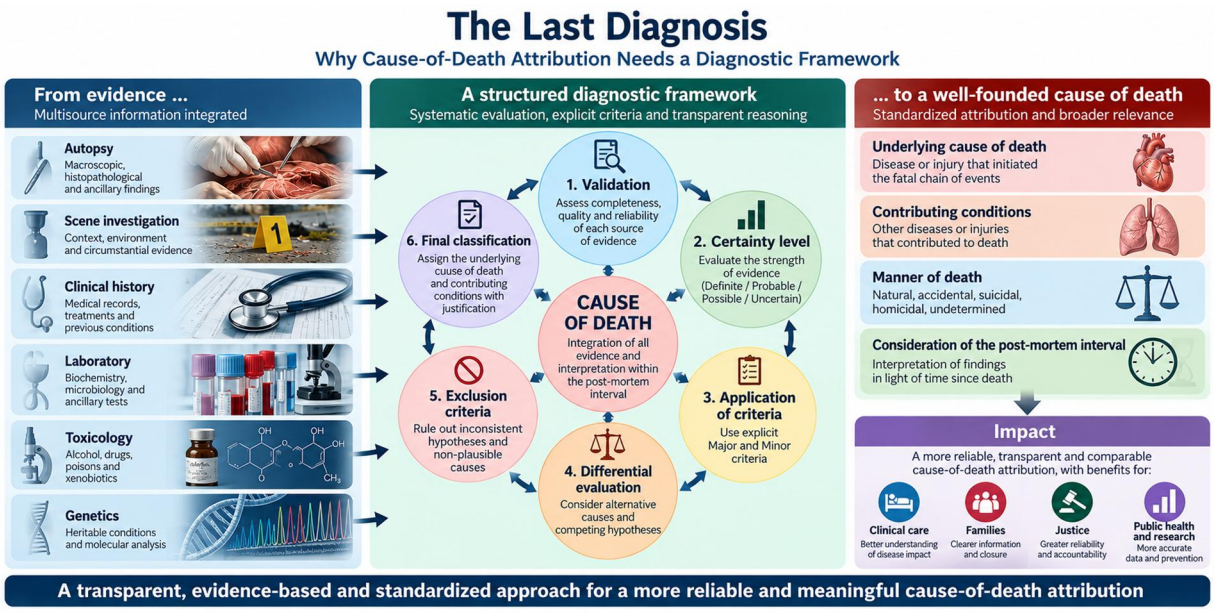
The last diagnosis: why cause-of-death attribution needs a diagnostic framework

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The cause of death is medicine's last diagnosis, but it is not supported by the same type of explicit diagnostic architecture that exists for many complex clinical conditions. International mortality systems standardize certification, coding and statistical comparability, yet they do not provide a general architecture for deciding whether a lesion, toxin, genotype, physiological event or circumstance was lethal in an individual case. This distinction matters for clinical genetics, family prevention, public-health surveillance, research reproducibility and legal proceedings. This Perspective argues for an upstream diagnostic layer between autopsy and International Classification of Diseases (ICD): a positive diagnostic architecture for cause-of-death attribution — one that defines how evidence is integrated into a causal diagnosis. Such a system would not replace ICD, death certificates or specialist guidelines. Rather, it would define diagnostic entities, entity-specific criteria where appropriate, exclusion criteria, minimum investigations, levels of certainty and standards for validation. The goal is not a literal "DSM of death", but an evidence-based architecture that makes causal attribution transparent, reproducible and empirically testable.

KEYWORDS
causal attribution, cause of death, death certification, diagnostic criteria, diagnostic framework, DSM, forensic pathology, postmortem diagnosis



GRAPHICAL ABSTRACT

The diagnosis medicine still leaves implicit

Medicine has progressively transformed diagnosis from implicit expert judgement into explicit, testable systems. Sepsis, acute respiratory distress syndrome, myocardial infarction, infective endocarditis and inherited cardiac disorders are no longer defined only by narrative expertise; they are supported by consensus definitions, operational criteria, measurements, exclusion rules and periodic revision (1–6). These architectures do not eliminate uncertainty, but they make it visible.

Cause-of-death attribution remains a major exception. Before a death can be certified, coded, counted or compared, someone must decide why that individual died. That judgement may integrate clinical history, scene investigation, autopsy findings, histology, toxicology, imaging, microbiology, molecular testing, biomarkers and family history. Yet most systems are better at standardizing what happens after a cause of death has been assigned than at standardizing the diagnostic reasoning that produces the attribution in the first place.

International systems rightly standardize mortality language, certification and coding (7–11). Autopsy and professional guidelines standardize examination, sampling and reporting (12–15). Disease-specific guidelines define many entities relevant to death investigation (5, 6, 16–18). These are essential achievements. But they do not constitute a general diagnostic architecture for transforming heterogeneous postmortem evidence into an individual cause-of-death diagnosis.

This missing layer is not semantic. The same autopsy finding may be recorded as causal, contributory, incidental or unexplained depending on context, available investigations and expert interpretation. Atherosclerosis may be lethal in one case and incidental in another. A genetic variant may be decisive, irrelevant or uninterpretable. A toxicological concentration may indicate poisoning, therapeutic use, postmortem redistribution or mixed causation. Cause-of-death attribution is therefore not a mere label; it is a diagnostic conclusion about causality. (Figure 1)

What exactly is missing?

Current systems already standardize investigation, reporting, certification, coding, and disease-specific diagnosis (5, 6, 8–13). Existing initiatives address important adjacent problems. ICD and mortality rules standardize statistical language; medical certificates standardize causal reporting; autopsy standards standardize examination and sampling; disease-specific guidelines standardize individual diagnoses. More recently, Principles of Evidence-based Reporting in FORensic Medicine-Pathology (PERFORM-P), the INFERENCE framework, Child Health and Mortality Prevention Surveillance Determination of Cause of Death (CHAMPS DeCoDe) and Post-Mortem Diagnostic Certainty Scale (PMDCS) have strengthened evidence-based reporting, causal reasoning, domain-specific diagnosis and diagnostic uncertainty (13, 14, 19, 20). Together these initiatives have substantially improved different components of death investigation.

What they do not standardize is the inferential transformation from heterogeneous evidence into an individual cause-of-death diagnosis. The missing component is not another laboratory test, another autopsy procedure or another disease-specific guideline.

The evidence already exists; what is missing is the grammar that allows it to become a diagnosis. A diagnostic grammar: a

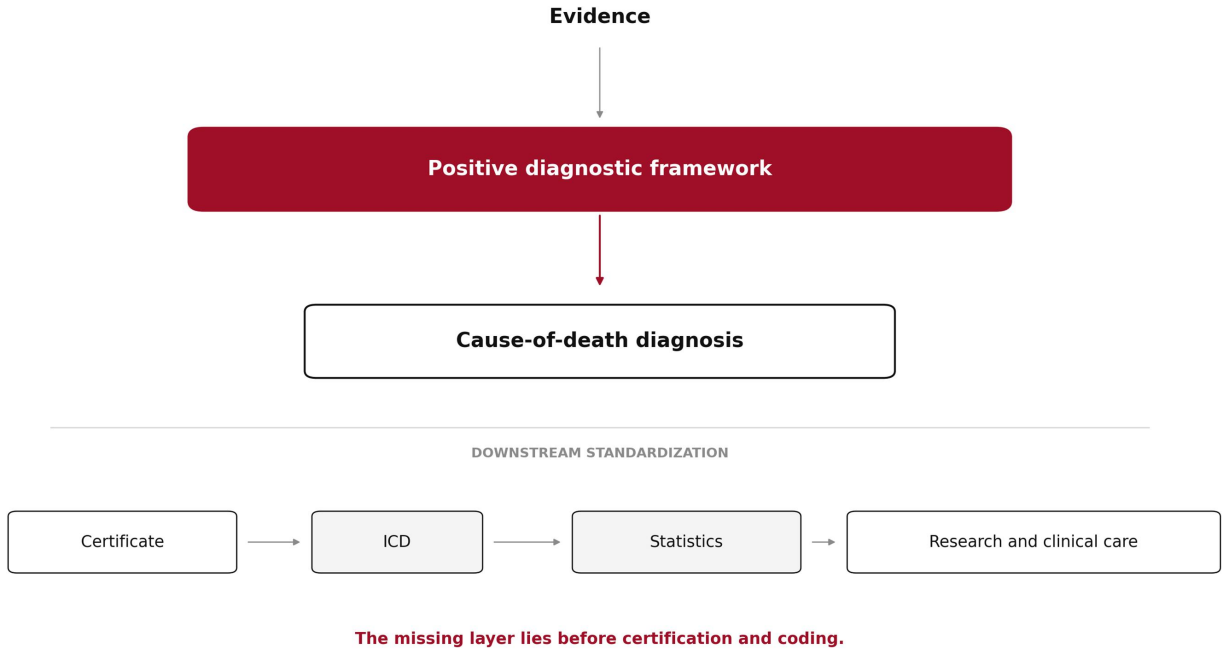


FIGURE 1
The missing diagnostic layer. Evidence is transformed into a cause-of-death diagnosis before certification, coding, statistics and clinical use; this upstream transformation remains less formalized than downstream ICD-based systems.

set of rules for transforming observations into causal statements, representing uncertainty, and adjudicating competing explanations. Without this diagnostic layer, the existing components remain essential but structurally disconnected. The proposed framework functions as the keystone that allows existing components — autopsy, toxicology, genetics, scene investigation — to operate as a coherent diagnostic system.

Historically, death investigation grew from two separate traditions: clinical pathology, focused on disease mechanisms, and forensic medicine, focused on legal evidence. Neither tradition developed a general diagnostic grammar for causal attribution, because each assumed that the relevant findings—disease or injury—would speak for themselves. In practice, they do not.

Why the last diagnosis matters

Cause-of-death attribution is the diagnosis that closes every clinical record. It determines whether relatives require genetic evaluation, supplies the denominator of mortality research, structures vital statistics and may influence legal responsibility. A death attributed to an inherited arrhythmia, an adverse drug reaction, pulmonary embolism or undiagnosed cancer generates profoundly different consequences for families, clinicians and health systems (7, 8, 21). In sudden cardiac death, postmortem findings can trigger cascade screening and prevention in surviving relatives (5, 6, 16).

Cause-of-death attribution is also a research variable. Global burden estimates, multiple-cause-of-death studies and civil registration systems depend on the quality of the original causal attribution before it is transformed into statistical codes (22, 23). If upstream attribution is inconsistent, downstream statistics may be precise but not diagnostically robust.

The legal implications are equally direct. In medicolegal settings, the difference between natural disease, intoxication, trauma, neglect and undetermined death can affect criminal proceedings, civil litigation and public accountability (21). A diagnosis of drowning, anaphylaxis, sepsis, ketoacidosis, opioid toxicity, myocarditis or sudden arrhythmic death may rest on probabilistic evidence rather than a single pathognomonic finding (24–29). The problem is not that expert judgement is unreliable by definition. The problem is that expert judgement remains difficult to audit when its criteria are implicit (Figure 2).

The paradox of modern medicine

Modern medicine has formalized diagnosis across many disciplines—including radiology, critical care, cardiology and infectious diseases—through explicit criteria, standardized thresholds and reproducible definitions (1–4, 30, 31). Death investigation has likewise become increasingly sophisticated. Yet it still lacks an equivalent general structure for translating heterogeneous evidence into a diagnosis of lethal causation.

Evidence-based medicine transformed clinical practice not by adding tests, but by building shared diagnostic structures. Death investigation has not yet undergone this same transformation. The paradox is striking: medicine applies explicit criteria to diagnose disease during life but still relies largely on implicit, locally variable reasoning to diagnose whether a disease, injury or exposure caused death.

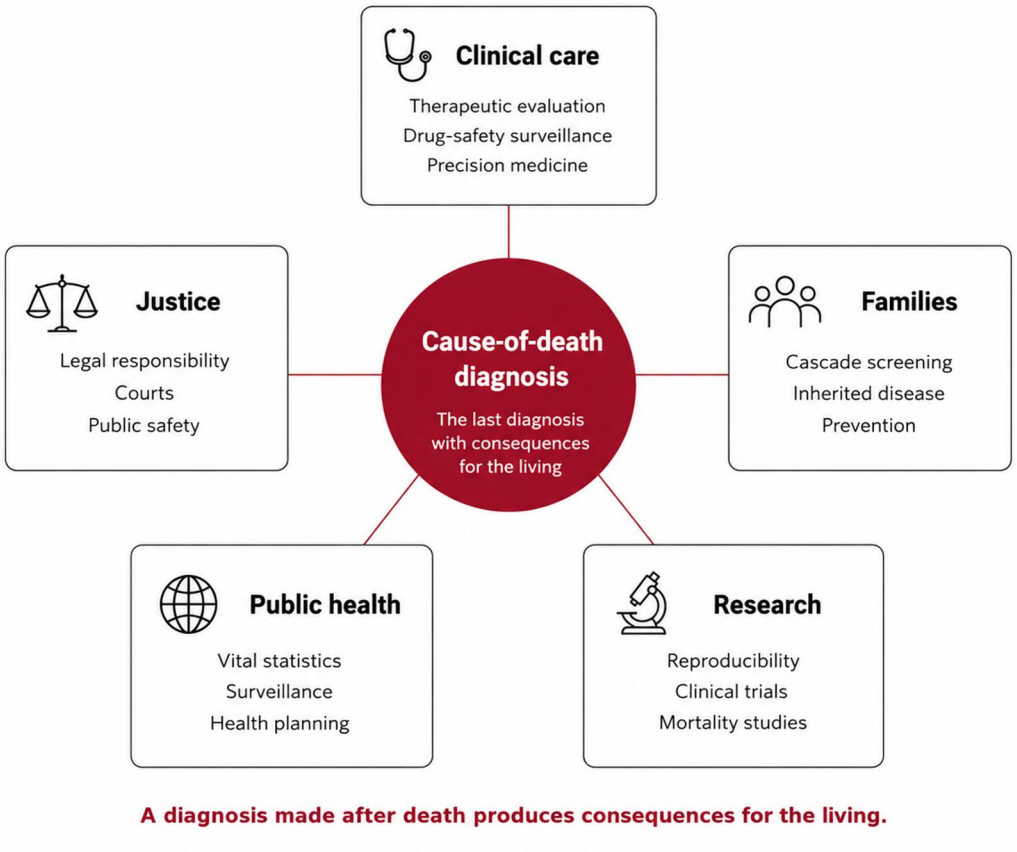


FIGURE 2
Why the last diagnosis matters. A cause-of-death diagnosis made after death can affect clinical care, families, research, public health and justice.

Current systems: what they standardize and what they do not

The current system is strong downstream. The medical certificate records the causal sequence and the underlying cause. ICD provides classification and coding rules (8). Digital Open Rule Integrated Cause-of-Death Selection (DORIS) and Iris automate code selection from certificate data (10, 11). The Dutch Forensic Death Coding system (FDC) improves forensic coding after diagnosis (32). All these systems standardize what happens after a cause of death has already been determined.

The missing layer is upstream. ICD does not specify how much myocarditis is sufficient to diagnose fatal myocarditis, which pulmonary emboli are lethal in a patient with competing disease, when drowning should be considered established rather than probable, or how opioid concentrations should be interpreted alongside tolerance and scene evidence.

ICD-11 has substantially expanded the semantic and representational capacity of the classification system, including mechanisms for capturing aetiology, temporality, diagnostic certainty, and other clinically relevant attributes (33). Nevertheless, its primary mortality function remains the standardized representation and statistical classification of causes of death. Cause-of-death attribution precedes coding and may itself involve diagnostic uncertainty (34). Thus, greater granularity and consistency in coding cannot by themselves establish the evidentiary criteria by which a particular finding is judged sufficient to have caused death in an individual case. The framework proposed here therefore addresses a complementary problem: not how an assigned cause should be encoded, but how heterogeneous postmortem evidence should be transformed into a sufficiently supported causal diagnosis before coding occurs.

Autopsy standards improve the quality of investigation but define process rather than universal diagnostic thresholds (12) (Table 1).

Evidence of a universal diagnostic gap

The diagnostic gap is visible across several domains of death investigation. First, many causes of death lack pathognomonic signs. Drowning, anaphylaxis, sepsis, diabetic ketoacidosis, pulmonary embolism, myocarditis, sudden arrhythmic death and some intoxications often require convergent evidence from history, circumstances, morphology, biomarkers and exclusion of alternatives (24, 25, 28, 29, 35–38).

Second, postmortem findings often have multiple meanings. Pulmonary oedema, visceral congestion, myocardial fibrosis, coronary atherosclerosis, aspiration, low drug concentrations, raised tryptase, vitreous chemistry abnormalities and genetic

variants may be causal, contributory, agonal, artefactual or incidental. Their interpretation depends on context and on the completeness of investigation (6, 25, 36, 39).

Third, diagnostic systems often handle uncertainty downstream rather than upstream. ICD coding can represent a certified cause, but it does not by itself determine whether the certified cause was diagnostically well supported (8, 9). Categories such as "probable", "possible", "unascertained" or "undetermined" are widely used, but their evidentiary thresholds are not always harmonized across diseases, institutions or jurisdictions.

Fourth, reproducibility is rarely measured. In clinical diagnosis, interobserver agreement, diagnostic accuracy, calibration and external validation are expected components of evidence generation (39–41). In cause-of-death attribution, comparable validation studies are still fragmented, despite important progress in minimally invasive autopsy, perinatal mortality classification, child mortality surveillance and disease-specific protocols (19, 20, 42, 43). Related challenges arise when diagnostic categories themselves are contested or when computational methods operate on pre-existing cause-of-death labels rather than on explicit criteria for causal attribution (44, 45). (Figure 3) (Table 2).

TABLE 1 The proposed layer fills the gap between investigation and certification/coding.

Layer	What it standardizes	Limitation
Autopsy standards (12)	Examination, sampling and reporting	Defines process, not diagnosis
Medical certificate (8, 9)	Causal sequence and underlying cause	Defines output, not input
ICD (8)	Statistical classification and coding	Defines language, not diagnosis
DORIS/Iris (10, 11)	Automated code selection	Defines automation, not diagnosis
PERFORM-P (13)	Evidence-based reporting	Defines how to document, not how to diagnose
INFERENCE (14)	Causal analysis procedure	Defines how to reason, not what to diagnose
CHAMPS DeCoDe (19)	Diagnostic standards for infant mortality	Domain-specific (infant mortality)
PMDCS (20)	Post-mortem uncertainty gradation	Defines uncertainty, not diagnosis
Dutch FDC (32)	Forensic cause-of-death coding	Defines coding, not diagnosis
Proposed approach	Entities, criteria, exclusions, certainty	Defines diagnostic grammar

Why a positive diagnostic framework is needed

The central claim is simple: the current system was designed to standardize the recording and coding of causes of death, not the positive diagnosis of lethal attribution. Many difficult causes of death are established predominantly through exclusion. A positive framework would specify what findings, in what combination, are sufficient to establish a cause. The missing object is not a new classification of death, but a diagnostic grammar for causal attribution: a method for converting evidence into a graded cause-of-death diagnosis.

A useful structure would separate three questions that reports often compress into one sentence. First, is the abnormality present and reliably measured? Second, is it biologically capable of causing

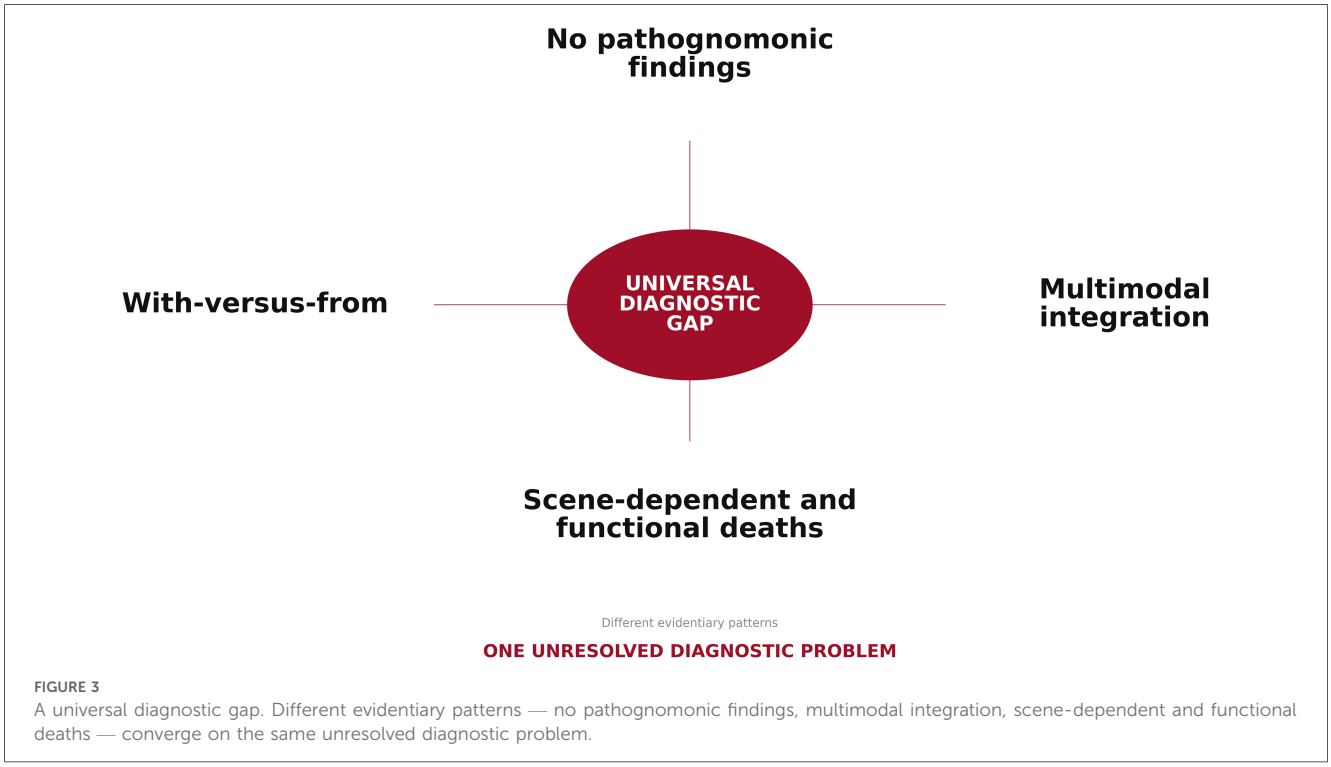


FIGURE 3
A universal diagnostic gap. Different evidentiary patterns — no pathognomonic findings, multimodal integration, scene-dependent and functional deaths — converge on the same unresolved diagnostic problem.

TABLE 2 Representative examples of the universal diagnostic gap.

Example	Why positive attribution is difficult
COVID-19 (18)	Infection may be incidental, contributory or underlying
Drowning (24)	No universally pathognomonic post-mortem finding
Hanging (38)	Suspension alone does not prove lethal compression
Opioids (26)	Concentration alone does not prove lethality
Myocarditis (28, 29)	Inflammation may be incidental or fatal
Pulmonary embolism (37)	Clot burden and comorbidity interact
Anaphylaxis (25)	Biomarkers are supportive but context-dependent
Hypoglycaemia (27)	Post-mortem biomarkers are matrix-dependent
Sepsis (35)	No validated criteria exist to ascertain death due to sepsis even when autopsy is performed

death in this person at this time? Third, is it the best explanation after reasonable alternatives have been excluded? A positive system would make the inference visible.

This matters especially when the same finding can play different causal roles. SARS-CoV-2 infection may be the initiating cause of fatal viral pneumonia, a trigger of thrombosis, a contributing stressor in a frail patient, or an incidental laboratory result. A pulmonary embolus may be the immediate lethal event, a complication of cancer, or an incidental non-occlusive finding. Opioids may be the primary cause, a contributor to aspiration, or part of a mixed intoxication. Without explicit categories, these distinctions are left to prose and local convention. Recent work by Grippo et al. has begun to address this gap algorithmically, but operates on certificate data after diagnosis, not on the diagnostic process itself (23).

It would also improve how uncertainty is communicated. "Consistent with drowning", "probable drowning", "death due to drowning" and "undetermined water-related death" are not equivalent statements. The PMDCS scale shows that explicit uncertainty language is feasible and increasingly necessary (20, 21).

Toward a positive diagnostic architecture

Any general diagnostic approach for cause-of-death attribution would need to answer three fundamental questions.

First, what lethal entity is being considered?
Second, what causal role did it play?
Third, how certain is that attribution?

Accordingly, this approach would comprise three complementary dimensions: diagnostic entity, causal role and diagnostic certainty.

The entity dimension identifies the candidate diagnosis. The causal-role dimension distinguishes underlying cause, immediate mechanism, contributory condition, competing alternative, incidental finding and undetermined role. Recent work by Grippo and colleagues demonstrates that multiple causes recorded on death certificates can be algorithmically assigned different causal roles; our proposal moves this logic upstream into the diagnostic process itself (23).

TABLE 3 Levels of diagnostic certainty in cause-of-death attribution.

Category	Definition
Established/Criteria met	All major criteria satisfied; main alternatives excluded
Probable	Most criteria satisfied, but a specific element is missing, unavailable or unassessable
Possible	Criteria compatible but one or more reasonable alternatives not excluded
Unascertained	Criteria insufficient for causal attribution, including when critical evidence is unavailable or unassessable; specify missing or non-evaluable data

The certainty dimension distinguishes established, probable, possible and unascertained diagnoses. PMDCS provides an important precedent for expressing post-mortem uncertainty, although it does not define diagnostic entities or causal roles (20) (Table 3).

A postmortem diagnostic framework must also distinguish negative evidence from unavailable or uninterpretable evidence. Failure to demonstrate a diagnostic feature does not necessarily establish its absence at the time of death, because the detectability and reliability of individual findings may depend on the postmortem interval and associated processes such as autolysis, decomposition and postmortem redistribution, as well as on preservation conditions, sampling, previous medical intervention, and the availability and quality of biological material. These effects are evidence-specific rather than uniform: the postmortem interval may substantially affect the interpretability of some diagnostic findings while leaving others comparatively preserved. Accordingly, criteria that cannot be reliably assessed should be recorded as unavailable or unassessable rather than negative. Such limitations should be incorporated into the level of diagnostic certainty rather than automatically count against the diagnosis. These limitations are not necessarily beyond empirical characterization. Prospective studies with standardized sampling at predefined postmortem intervals could quantify and model the time-dependent effects of postmortem change on the detectability, reliability and interpretability of individual diagnostic findings, allowing evidence-specific interpretability requirements to be progressively calibrated against postmortem interval.

ICD supplies vocabulary for statistical reporting. Autopsy protocols supply methods for observation. Disease guidelines define selected entities. What is missing is a grammar that specifies how observations become causal statements, how uncertainty is represented and how competing explanations are adjudicated.

Each diagnostic entity would be organized as a modular structure comprising entity-specific criteria, exclusion criteria, minimum investigations, evidence-specific interpretability requirements, causal-role definitions, certainty categories and validation metrics. Duke-ISCVID and Sepsis-3 illustrate that heterogeneous evidence can be integrated into explicit diagnostic systems (1, 4). Existing cardiac autopsy guidance and National

Association of Medical Examiners (NAME) standards already contain elements of this architecture (12, 15, 16). What remains missing is the diagnostic layer connecting evidence to causal attribution across conditions.

This approach is intended to structure scientific diagnostic reasoning. It is not intended to determine legal responsibility, criminal negligence or civil liability, which necessarily depend on additional legal and contextual considerations.

The proposed diagnostic architecture should remain applicable across the life course while allowing the evidentiary requirements of individual diagnostic entities to be adapted to age and developmental stage. This is particularly relevant in fetal, perinatal and paediatric deaths, where causes and mechanisms of death may differ substantially from those encountered later in life and causal assessment may require consideration of the mother–placenta–fetus system, including maternal and obstetric history, gestational age, fetal or neonatal findings, and examination of the placenta and umbilical cord (46, 47). Studies of stillbirth and perinatal mortality further illustrate that causal attribution may depend on integrating fetal findings with placental pathology, prenatal information and maternal clinical factors rather than interpreting postmortem findings in isolation (48, 49). More broadly, the exposome—the cumulative environmental exposures experienced across the life course—and associated gene–environment interactions may contribute to causal pathways across multiple organ systems and may therefore constitute relevant contextual evidence when supported by the circumstances and the diagnostic entity being evaluated (50). These considerations do not require an additional dimension within the proposed framework. Rather, they illustrate why entity-specific diagnostic criteria, exclusion criteria and minimum investigations may also need to be age-, developmental-stage- and population-specific.

The evidentiary requirements of individual diagnostic entities may also depend on the availability of appropriate specialist expertise and on relevant biological, environmental and social context. In neuropathological death investigation, for example, central nervous system examination is a distinct postmortem procedure for which specialist neuropathological expertise and multidisciplinary collaboration may be required, particularly in diagnostically difficult cases (51). Demographic, socioeconomic and geographic factors may likewise influence patterns of disease and mortality and may interact rather than operate independently, as illustrated by population-level evidence concerning race, ethnicity, socioeconomic status and place of residence (52).

Such factors should not be treated as diagnostic criteria in themselves. Rather, where relevant to a particular diagnostic entity, they form part of the contextual evidence against which postmortem findings are interpreted. Their inclusion therefore does not add a further dimension to the proposed architecture, but reinforces the need for entity-specific criteria, minimum investigations and levels of certainty that are sufficiently flexible to accommodate differences in biological context, exposure history and diagnostic resources.

A drowning module would specify scene documentation, recovery circumstances, external and internal findings, toxicology, trauma assessment and exclusion of post-mortem immersion — not because any single finding is pathognomonic, but because the diagnosis depends on the integration of all available evidence. Our proposal would not require every disease to follow the same evidentiary pattern; it would require every diagnostic entity to define its evidentiary pattern explicitly. (Figure 4) (Table 4).

Not a literal DSM of death

The phrase "DSM of death" is useful only as a provocation. A cause-of-death approach should not imitate psychiatric nosology uncritically, nor should it suggest that every death can be classified by checklist. Death investigation differs from clinical diagnosis in several ways: the patient cannot be re-examined, evidence may be degraded, legal requirements vary, and many attributions are causal rather than merely categorical.

The relevant analogy is narrower. Modern diagnostic systems make criteria explicit, separate positive evidence from exclusion, acknowledge uncertainty, and create a basis for revision. Cause-of-death attribution needs the same structure, adapted to postmortem evidence and causal reasoning.

Existing precedents—CHAMPS DeCoDe, PMDCS, PERFORM-P, INFERENCE, NAME standards, cardiovascular pathology guidelines—show that explicit attribution is possible (5, 6, 12–14, 16, 19, 20). But these remain domain-specific, population-specific or focused on certification or reporting. None provides a diagnostic grammar across adult and paediatric, natural and unnatural, clinical and forensic settings.

Artificial intelligence (AI) will not solve this alone

Clinical medicine developed laboratory medicine only after it had defined standardized diagnostic entities. Postmortem medicine cannot develop an equivalent laboratory discipline without the same foundation. Troponins, tryptase, vitreous glucose and molecular findings cannot become reliable causal criteria until reference ranges and decision thresholds are validated for post-mortem use.

AI can extract information, classify text and assist image interpretation (43). It may improve consistency in large datasets. But AI cannot solve the conceptual problem unless the target diagnosis is defined. A model trained on historical certifications may reproduce local practice, inconsistency and bias. A transparent diagnostic architecture would make AI safer and more useful by defining labels, required inputs and validation endpoints. The question is not whether AI can classify death certificates, but whether medicine can define the standards against which such classifications should be judged. The bottleneck is not computational. It is conceptual.

Once diagnostic entities, evidentiary requirements and minimum datasets are defined, multicentre digital infrastructures could provide an important basis for external validation and AI-assisted forensic research. Collaborative networks using

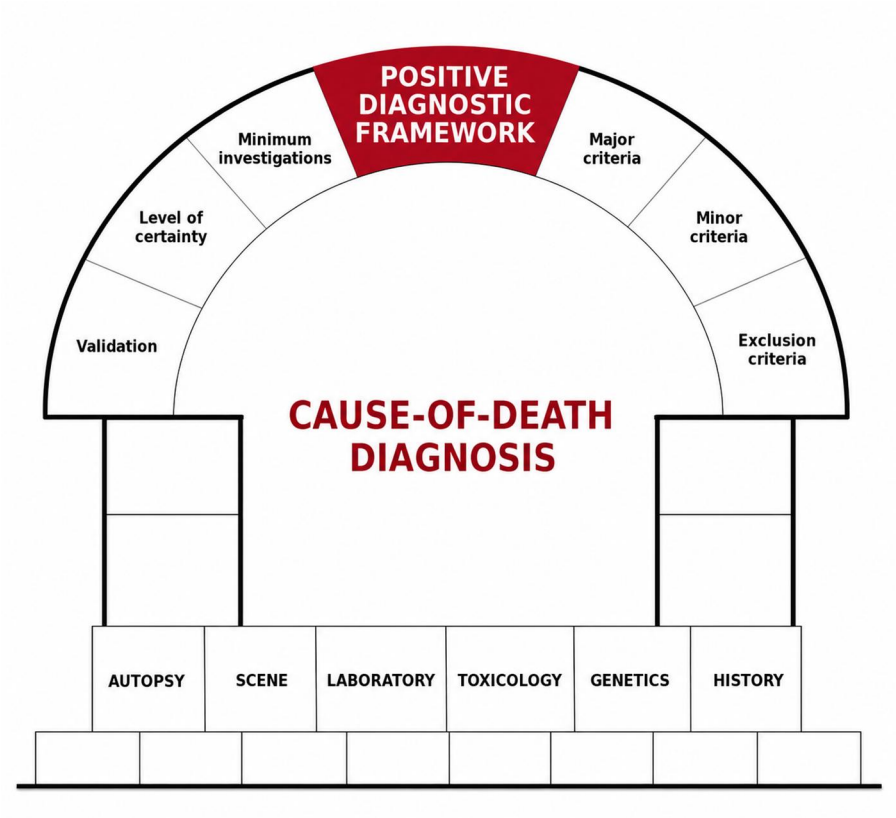


FIGURE 4
Architecture of a positive diagnostic framework for cause-of-death attribution. The evidence base (autopsy, scene, laboratory, toxicology, genetics, history) forms the foundation. Depending on the diagnostic entity, population and developmental stage, these broad evidence domains may encompass additional context-specific information (e.g., maternal, placental, umbilical-cord and fetal or neonatal findings where relevant). Criteria, exclusions, minimum investigations, levels of certainty and validation constitute the structural components. The framework integrates heterogeneous evidence into a transparent and reproducible diagnosis.

TABLE 4 Illustrative structure of a positive diagnostic module — drowning.

Module component	Example
Diagnostic entity	Drowning-related death
Diagnostic criteria	Body recovered from water; evidence compatible with vital immersion; no stronger alternative
Supportive criteria	Foam, overdistended lungs, watery airway fluid, compatible imaging
Required investigations	Scene reconstruction, full autopsy, toxicology, trauma assessment, cardiac assessment
Exclusion criteria	Post-mortem immersion, lethal trauma before immersion, primary cardiac/neurological event
Certainty levels	Established, probable, possible, unascertained
Validation metrics	Inter-rater reliability, agreement with reference panel, impact on ICD

standardized forensic repositories, interoperable platforms and shared benchmarking datasets may help overcome the limitations of small single-centre datasets and facilitate reproducible validation across institutions with different diagnostic resources (53). AI should nevertheless remain a decision-support tool for integrating heterogeneous evidence rather than an autonomous system for cause-of-death attribution.

A roadmap for the last diagnosis

The proposed framework cannot be implemented as a whole; like any enduring diagnostic architecture, it must be built incrementally. The roadmap below (Figure 5) illustrates how the architecture (Figure 4) can be progressively constructed.

A practical roadmap should proceed incrementally. First, an international working group should define shared principles: causal role, certainty, minimum investigation, exclusion and competing causes. Second, pilot entities should be selected from areas where diagnostic ambiguity is common and consequences are high: sudden cardiac death, pulmonary embolism, sepsis, anaphylaxis, drowning, metabolic death and intoxication. Third, each pilot entity should be translated into structured criteria and tested using retrospective cases, blinded expert panels, interobserver studies and prospective registries. Fourth, certified causes should be linked to diagnostic certainty, allowing mortality statistics to preserve uncertainty

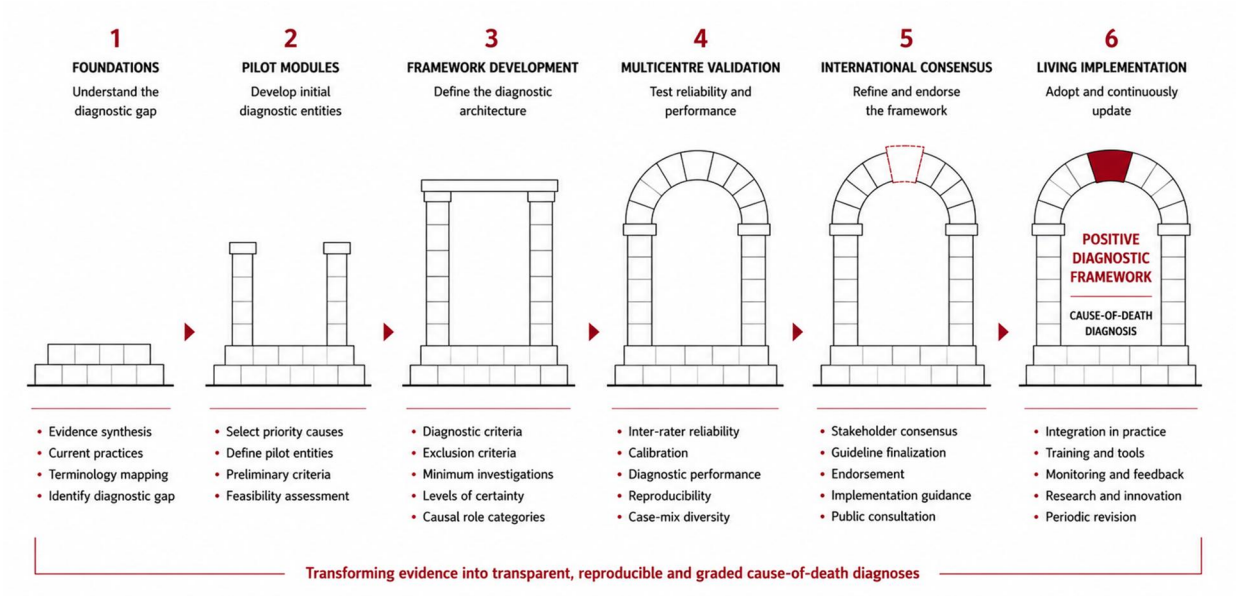


FIGURE 5
Roadmap toward a positive cause-of-death framework. Implementation should begin with consensus principles, proceed through modular pilot entities and validation, and ultimately connect diagnostic certainty to certification, coding and mortality research.

rather than flattening it. Fifth, the system should be periodically revised as evidence, biomarkers, imaging, genomics and epidemiology evolve.

Prospective registries could also support strategic foresight by identifying emerging or changing mortality patterns and by enabling scenario-based assessment of whether existing diagnostic criteria remain adequate as epidemiological, environmental and technological conditions evolve.

Implementation would require collaboration among forensic pathologists, clinical pathologists, epidemiologists, intensivists, geneticists, toxicologists, statisticians, certifiers, public-health agencies and legal stakeholders. Some deaths will remain unexplained despite optimal investigation. A good diagnostic grammar should protect that conclusion rather than obscure it (Figure 5).

Conclusion

Cause-of-death attribution is one of the most consequential diagnoses in medicine, yet it remains less formally structured than many diagnoses made during life. Existing systems for autopsy, certification, ICD coding and disease-specific diagnosis are indispensable, but they do not fully solve the upstream problem of causal attribution.

A positive diagnostic architecture would make the last diagnosis explicit. It would define what counts as evidence, how competing causes are excluded, how certainty is expressed and how diagnostic entities are validated. Its purpose would not be to eliminate expert judgement, but to make that judgement transparent, reproducible and open to scientific improvement.

Medicine has built diagnostic systems for the living. The last diagnosis deserves the same.

Author contributions

MN: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. EA: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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The author MN declared that they were an editorial board member of Frontiers, at the time of submission.

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