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Editorial

The invisible century of toxic exposures: why clinical toxicology must reinvent itself

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Editorial

We are living in what future historians will call the invisible century of toxic exposures—an era in which the most dangerous poisons are no longer the ones we can see, smell, or even detect with routine diagnostics. Instead, they emerge silently from synthetic chemistry labs, global supply chains, industrial waste streams, micro-environments, household products, online marketplaces, and, increasingly, from the hands of those who synthesize psychoactive compounds faster than regulators can name them. For clinicians, this means one thing: toxicology has fundamentally changed, but our diagnostic tools have not kept pace.

Modern emergency departments see fewer "classic poisonings" and far more poly-substance, poly-pathway, poly-mechanism cases. The patient with a presumed opioid overdose has perhaps co-ingested xylazine, fentanyl analogues, benzodiazepines, and synthetic cannabinoids. Agricultural workers exposed to pesticides may also exhibit biochemical fingerprints of heavy metals, industrial solvents, or microplastics. What once required a single antidote now demands a systems-level understanding of toxicokinetics, inflammation, metabolic stress, and genomic susceptibility. More troubling is that most exposures no longer have names; but only patterns.

The transition toward molecular and inflammatory biomarkers marks a turning point. High-sensitivity troponins have become essential in detecting drug-induced cardiotoxicity, outperforming traditional clinical markers in predicting injury severity and outcomes [1–3]. In parallel, biomarkers such as IL-6, IL-17, and calprotectin—traditionally associated with immunology and oncology—are emerging as promising early indicators of systemic toxicity, oxidative stress, and mitochondrial dysfunction. This is the beginning of precision toxicology: Where the question shifts from *"What did the patient take?"* to *"How is this toxicant interacting with this particular patient's biology?"*

Artificial Intelligence: The First Technology that Learns Toxicology Faster Than Humans

For the first time in medical history, AI systems can learn toxicological patterns faster than any curriculum, guideline or human expert. Machine-learning tools already outperform classical nomograms in predicting acetaminophen toxicity, organ failure risk and antidote requirements [4]. Deep-learning algorithms trained on chemical structures can anticipate toxicity profiles before a compound is even synthesized [5]. Large language models—though far from flawless—can rapidly synthesize toxic syndromes, suggest differential diagnoses, and flag hazardous interactions that clinicians may overlook. But this power comes with a warning: AI makes toxicology more accurate, but also more accountable. Algorithms require transparency, unbiased data, and clinical oversight—otherwise they risk reinforcing blind spots we cannot afford.

A Global Crisis in Toxicology Expertise

One of the most concerning realities is the widening gap between the complexity of exposure

and the available clinical expertise. Fewer clinicians train in clinical toxicology than ever before, while toxic exposures rise in diversity, potency, and frequency. In many countries, emergency physicians must make decisions without access to toxicologists, biomarkers, or diagnostics. Rapid antidote deployment remains uneven: atropine, fomepizole, high-dose insulin therapy, and lipid emulsions are not universally accessible. This discrepancy has created a silent global inequity: the outcome of a toxic exposure now depends more on geography than on dose.

What Must Change: A Blueprint for the Next Decade

To prevent toxicology from falling behind, we must radically modernize the discipline. I propose five immediate priorities:

1. Global biomarker standardization for cardiotoxicity, inflammation, and oxidative stress—enabling reproducible interpretation across institutions.
2. AI-supported diagnostic pipelines integrated into emergency medicine—not to replace clinicians, but to accelerate early decision-making.
3. Worldwide harmonization of toxicology education, including digitally shared curricula, simulation cases, and point-of-care decision tools.
4. Creation of international toxicology registries for early outbreak detection, substance monitoring, and real-time clinical pattern recognition.
5. Investment in portable biosensors and microfluidic assays—allowing poisoning to be diagnosed in minutes rather than hours.

Conclusion: A New Identity for a New Century

The age of obvious poisons is gone. Today's toxicants are faster, quieter, more complex and more interwoven with daily life than ever before. To protect patients, clinical toxicology must evolve—from a reactive specialty to a predictive, preventive and precision-driven discipline. This is not merely scientific evolution; it is a reinvention of the field's identity. If the twentieth century belonged to cardiology and oncology, the twenty-first will be shaped by exposure science—an arena where toxicology, AI, systems biology, and global health converge. Journals like Archives of Clinical Toxicology are not just publishing research; they are charting the intellectual roadmap for how humanity confronts invisible threats.

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