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Review Article

Hemoadsorption in Poisoning and Intoxication

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Abstract

This narrative review provides a detailed and comprehensive examination of hemoadsorption therapy and its role in treating severe poisoning. First, the global problem of suicidal and nonsuicidal self-injury is described, with regional differences in the types of poisons used noted. Lower- and middle-income countries are disproportionately affected by pesticides compared to high-income countries. Organophosphates often constitute the majority of pesticide poisoning in many of these countries. Next, we review the history of hemoadsorption therapy from its early origins to its current evolution. The key physical and chemical principles underlying extracorporeal therapy and its effectiveness are described. A review of the literature examining the evidence for the efficacy of hemoadsorption therapy in poisoning is presented. Current evidence-based guidelines are summarized, including toxin types, clinical indications, and the extracorporeal therapies recommended. Emerging evidence regarding the use of hemoadsorption therapy for severe organophosphate and calcium channel blocker poisoning is also considered. A care pathway for considering hemoadsorption in poisonings where formal guidelines are lacking is proposed. Both the hemoadsorption strategies used and the potential adverse effects of this therapy are discussed. For this narrative review, the PubMed/Medline was searched from inception to April 30, 2025, using the terms ("hemoperfusion" OR "hemadsorption") AND ("poisoning"). Clinical trials, randomized controlled trials, and meta-analyses were included, along with additional relevant studies identified through a manual review of references. The role of modern resin bead hemoadsorption therapy for severe poisoning is expanding to include removal of commonly encountered poisons that are protein-bound and have a large volume of distribution. Using a multicycle approach, hemoadsorption therapy has shown improved outcomes for both calcium channel blockers and organophosphate poisoning.

Introduction

In 2012, the World Health Organization (WHO) estimated over 800,000 deaths due to suicide and identified poisoning as a significant public health concern.[1,2] Data from the United States National Poison Data System reported just over three million poison encounters logged during 2013.[3] A concerning finding was a 4.7% increase in human exposure, resulting in serious outcomes, including death.

Specifically, self-poisoning with pesticides has received attention over the past two to three decades. Three-quarters of suicides occur in low- and middle-income countries (LMIC), and it is estimated that 30% of these are related to pesticide ingestion.[1]

There is significant variation in pesticide-associated suicide across the globe.[4] Estimates on the African continent reflect that approximately 22% of suicides are pesticide-related. However, this figure is based on data from only four countries and may underestimate the problem. More recent data from South Africa (a single center serving a population of 1.8 million people) reported a five-fold increase in admissions to the intensive care unit (ICU) among patients presenting with cholinergic symptoms from suspected organophosphate and carbamate poisoning between 2012 and 2017.[5]

High-income countries, including the USA and Japan, report relatively few suicide cases related to pesticide use, with no cases reported in Canada between 1995 and 1998.[6]

Estimates from six countries in Central America suggest that pesticides account for approximately 30% of suicides in this region.[7] Brazil, the largest country in South America, reported an estimated 7% of suicides associated with pesticide ingestion.[4]

Recent estimates of suicide from pesticide use in Southeast Asia are around 11%.[6] Suicide by ingestion of a poison or hanging is a leading cause of death in India among patients 15 to 40 years of age, with pesticide ingestion responsible for 63% of poisoning.[8] Organophosphates have been estimated to account for at least 40% of pesticides.[9]

In the Western Pacific region, including China, the Philippines, Fiji, and Malaysia, 48% of suicides are associated with pesticide

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Table 1. Extracorporeal elimination principles and physicochemical characteristics of toxins

Characteristics	Adsorption	Diffusion	Convection
Molecular weight removed	Up to 60,000 Da	<500 Da	>500–40,000 Da
Protein binding	High or low	Low (<80%)	Low (<80%)
Ideal volume of distribution	<1 L/kg	<1 L/kg	<1 L/kg

use.[6] This is despite a reduction in suicide rates in many of these regions, specifically in China, where pesticide use was previously estimated at 60%.[6]

Data from the Eastern Mediterranean countries of Egypt, Iran, and Pakistan estimate a 7% pesticide-related suicide rate in this region.[6] This may underestimate the problem, as another study from Pakistan reported pesticides in 31% of suicides and attempted suicides.[10]

Low- to middle-income countries in the European region report fewer than 1% of suicides related to pesticides each year, and approximately one-third of countries in this region reported no pesticide-related suicides.[6]

Overall, there is a substantial burden of intentional poisoning involving pesticides globally, disproportionately affecting low- to middle-income countries.

For non-pesticide overdoses and poisoning, the Extracorporeal Treatment in Poisoning Workgroup (EXTRIP) has systematically reviewed over 20 commonly implicated drugs and toxins and has issued updated recommendations regarding extracorporeal therapy, including hemoadsorption therapy.[11,12]

Blood purification technology and its evolution

Blood purification as an extracorporeal strategy traces its roots to early dialyzer development. Initial milestones date to ancient Egypt (~1,500 BC) with leech-derived anticoagulants.[13] Advances in atomic theory, molecular understanding, and osmotic pressure have informed modern extracorporeal therapies.[13,14] The discovery of diffusion and nitrocellulose enabled early dialyzer modeling.[13,15] In 1914, Abel *et al*.[16] demonstrated in dogs that salicylates could be removed using a hirudin-anticoagulated dialyzer, exceeding renal clearance. By 1946, dialysis had been applied clinically, including in salicylate overdoses.[17]

In the 1950s, barbiturate overdose was common in the USA (~15,000 hospitalizations annually).[18] Hemoperfusion using lactate-loaded anion-exchange resin for barbiturate overdose was described in 1958.[18] In 1965, Dunea *et al*.[19] introduced charcoal hemoperfusion commonly referred to as the "Yatzidis charcoal artificial kidney", which demonstrated adsorption of endogenous and exogenous substances, including salicylates, while noting adverse effects, such as nausea, hypotension, and thrombocytopenia.[20] Early limitations included uncoated charcoal caking, difficult blood return, and incomplete toxin removal.

Over the following two decades, hemoperfusion with coated and uncoated charcoal was widely applied despite challenges related to variable toxin properties, limited pharmacokinetic understanding, and uncontrolled data.[21] In 1976, Amberlite XAD-4 resin hemoperfusion for lipid-bound drugs (glutethimide and barbiturates) in eight patients demonstrated substantial drug removal and clinical response, marking the first clinical use of styrene divinylbenzene copolymers.[22] During the 1970s and 1980s, coated charcoal and resin hemoperfusion were applied in poisoning, autoimmune disease, vasculitis, and liver failure.[23]

By the 1990s, adverse effects had been better defined. A retrospective study involving approximately 800 patients treated with modern coated charcoal hemoadsorption for intoxications from organophosphates, carbamates, organochlorides, herbicides, insecticides, and drugs reported hypotension in 22% (4.6% requiring vasoactive agents), systemic bleeding in 3% (15 deaths, 1.87%), and thrombocytopenia in 31%.[24] Other parameters, including white cell count, hemoglobin, albumin, calcium, and phosphate, declined statistically, but these were unlikely to be clinically significant. Overall mortality exceeded 44%.

Skepticism regarding hemoadsorption during the 1980s and 1990s has shifted over the past decade as blood purification technologies have evolved.[25] Recognition of sepsis as a dysregulated host response, coupled with evidence from animal models of soluble mediator blockade, pointed to the immune response as a therapeutic target.[26–28] This led to the conceptualization of blood purification strategies for the nonspecific modulation of inflammatory mediators.[29,30]

The materials used in blood purification have evolved considerably. Early systems employed uncoated activated carbon, which was associated with particle deposition in organs and platelet aggregation in vitro, as well as poor selectivity and low elimination efficiency.[31,32] Encapsulation improved surface smoothness and biocompatibility but reduced adsorptive capacity.[31]

Polymeric materials, such as Amberlite IR-20 ion-exchange resin, have been used for lipid-soluble drugs, although they may affect platelet counts and electrolyte balance.[22,31] Modern sorbents are synthetic porous polymers of styrene or acrylic acid arranged as beads to maximize surface area and adsorption capacity.[23,25,31] These materials are designed for blood compatibility, mechanical strength, and thermal stability to withstand sterilization.[31,32]

Current concepts in extracorporeal drug removal

A poison may be either an exogenous substance or a substance normally present in the body, whereas poisoning refers to exogenous exposure (irrespective of intent) to either, which may cause toxicity.[33] It appears intuitive that with increasing toxicity, more rapid removal will lead to improved clinical outcomes; however, our understanding of toxin or drug clearance is related to the blood compartment and does not directly reflect total body clearance or target organ clearance. Further complicating issues are the variety of toxins with different pharmacokinetic properties and the lack of knowledge regarding the dose of poison ingested.

The possibility of extracorporeal removal of a toxin or poison, and the technique used, depends on the characteristics of the toxin.[33–35] The important physical characteristics are molecular weight, protein binding, volume of distribution, solubility, and endogenous clearance. Three important techniques can be considered for toxin removal, each based on differing principles: hemodialysis, hemofiltration, and hemoadsorption. Optimizing poison removal involves matching the substance's physical characteristics with the appropriate elimination technique (Table 1).

Molecular weight

The movement of a toxin or poison depends on the size of the molecule relative to the pore size of the membrane. This applies to the dialysis process using a low-flux membrane. In general, smaller molecules (lower molecular weights) pass through the membrane more easily than larger molecules. Small molecules are typically defined as those smaller than 500 Daltons. Middle molecules, defined as having a molecular weight from 500 to 40,000 Daltons, are better suited to hemofiltration for elimination.[36] Synthetic polymers (resins) can have different pore sizes, from a few hundred Daltons to 60,000 Daltons, allowing for different hemoadsorption cartridge selections to target specific molecular sizes of interest.[37]

Protein binding

The important concentration for protein-bound toxins or drugs is the free or unbound concentration gradient across the pores. Given the large molecular weight of albumin (the predominant human protein), the drug–protein complex cannot pass through the standard filter or cartridge pore.[35] With increasing drug concentrations, saturation of albumin binding occurs. Above this threshold drug or toxin concentration, the proportion of free drug or toxin increases, which makes removal possible. Finally, another factor that may play a role is the binding constant of the drug or toxin to albumin. If this is low, rapid dissociation can occur, and removal is possible.[33]

Volume of distribution, solubility, and clearance

All appropriately selected extracorporeal therapies may clear toxins or drugs from the intravascular compartment. Many drugs and toxins distribute into the extravascular compartment and therefore have a larger volume of distribution.[38] Highly lipid-soluble drugs with low plasma protein binding will have a large volume of distribution. Removal from the tissue compartment will be limited and only occurs if there is rapid redistribution into the intravascular compartment during extracorporeal therapy, if therapy is continuous. This is usually not the case due to saturation of current filters and cartridges. Therapies are commonly applied intermittently with an appropriate time interval for redistribution between consecutive therapies.[33] Time from ingestion may also affect the clearance by extracorporeal therapy, as well as the duration of therapy. Extracorporeal clearance is likely to be clinically useful if it can increase and supplement endogenous clearance by 30% (untested rule of thumb) or if endogenous clearance is low (<4 mL/kg/min).[35]

Evidence of the use of hemoadsorption for poisoning

Current evidence

The EXTRIP workgroup has established extensive evidence-based guidelines for the use of extracorporeal therapy in poisoning.[39] Table 2 outlines the role of hemoadsorption among other extracorporeal therapies for poisoning.[39–52] The recommendation to use hemoadsorption therapy and the order of preference among extracorporeal therapies is provided in Table 2, and this varies between toxins.

Evolving evidence

Current recommendations advise against extracorporeal therapy for calcium channel blocker (CCB) poisoning.[53,54] Amlodipine and several other CCBs, including diltiazem, nifedipine, and verapamil, were considered nondialyzable. A previous report by Roberts *et al*.[55] specifically reviewed a case of diltiazem overdose treated with a single three-hour cycle of hemoadsorption. They found no clinical improvement during or immediately after hemoadsorption using a coated charcoal filter. Charcoal is effective for certain endogenous substances, such as urate and creatinine, but it is nonspecific and, when coated, may limit its effectiveness.[31,56] Diltiazem and amlodipine are significantly protein-bound, lipophilic, and have a large volume of distribution (>1 L/kg). A single application of hemoadsorption with charcoal is therefore unlikely to remove significant amounts of these drugs, as they are likely to have been distributed outside the intravascular compartment into tissue (time dependent), limiting drug clearance beyond the vascular space.[34]

A different strategy utilizing modern resin hemoadsorption cartridges may provide a solution for lipophilic drugs. Polymer adsorbent resins are nonpolar (neutral) and can adsorb lipophilic substances. These neutral microporous adsorbent resins rely on a three-dimensional molecular sieve formed by micropores (<2 nm) and mesopores (2−50 nm) within the resin beads.[56] Adsorption occurs by van der Waals forces, and these resins have a high adsorptive capacity for medium- and large-molecular-weight substances with high lipid solubility and protein binding.[31] Figure 1 illustrates the mechanism of removal using modern resin bead hemoadsorptive technology.

An ex vivo extracorporeal model demonstrated almost 90% removal of amlodipine from the blood compartment within two hours using this technology.[57] A case report using the Jafron HA 230 cartridge (resin bead) demonstrated reversal of shock in less than one elimination half-life of amlodipine, with concurrent retention of substantial amounts of amlodipine in the filter.[58] In this case report, two six-hour cycles were applied 18 hours apart.

There were likely two important differences between the unsuccessful attempt by Roberts *et al*.[55] to use hemoadsorption for a calcium channel blocker overdose and the case report described above. First, charcoal binding is relatively poor, whereas resins are well suited for highly lipophilic and protein-bound substances with superior adsorbent properties. Second, a multicycle approach with an intercycle interval may be prudent, allowing time for the transfer of solutes or toxins from tissue back into the blood. This strategy may be useful because saturation prevents continuous hemoadsorption, thereby inadvertently limiting heparin exposure to six-hour cycles per 24-hour period. Figure 2 describes the proposed approach to successful blood and tissue clearance of drugs and toxins.

Another recent case report using a modern polymer bead-based hemoadsorption system with hemodialysis demonstrated successful clinical use in a case of an amlodipine overdose. Although pharmacokinetic data or surrogate measures of drug removal were not available, the patient recovered fully from multiorgan failure, including acute kidney injury, following the addition of hemoadsorption to standard care.[59]

A retrospective observational study conducted in a single-center ICU over three years compared hemoadsorption therapy with standard care in 24 patients with CCB poisoning and shock. Thirteen patients received hemoadsorption therapy in addition to standard care, and 11 received standard care according to established guidelines.[53] A detailed analysis of changes in hemodynamics, vasopressor doses, other interventions used, and lactate was performed. Baseline details, including demographics, hemodynamic data, lactate levels, and SAPS II scores, were compared between groups. Despite greater initial severity in the hemoadsorption group, with lower blood pressure, higher lactate levels, and more organ dysfunction, this group demonstrated greater improve-

Table 2. EXTRIP recommendations for extracorporeal therapy, emphasizing hemoadsorption therapy[39–52]

Drug/toxin	Recommendation	Type of therapy	Indications
Acetaminophen	Yes	IHD/IHA/CRRT	Severe poisoning: [APAP] > 1,000 µmol/L, NAC not given. Other conditions apply.
Barbiturates	Yes	IHD/IHA/CRRT	Severe long-acting barbiturate poisoning
Atenolol	Yes	IHD	Severe poisoning with renal impairment
Sotalol	Yes	IHD	Severe poisoning with renal impairment
CCB	No	–	–
Carbamazepine	Yes	IHD/IHA/CRRT	Life-threatening dysrhythmias or refractory seizures
Digoxin	No	–	–
Ethylene glycol	Yes	IHD/CRRT	Osmolar gap ≥20, anion gap ≥22, seizures, coma, and AKI II/III
Gabapentinoids	Yes	IHD	Severe poisoning with renal impairment
Lithium	Yes	IHD/CRRT	Coma, seizures, dysrhythmias, renal dysfunction with [Li] >4 mEq/L or >5 mEq/L
Metformin	Yes	IHD/CRRT	Lactate >15 mmol/L, pH <7.1, or less severe poisoning with shock, decreased consciousness, or liver or renal dysfunction
Methanol	Yes	IHD/CRRT	Severe poisoning: coma, seizures, visual loss, pH <7.15; anion gap and other factors may be considered
Phenytoin	Yes	IHD/IHA	Severe poisoning with coma or severe ataxia
Salicylates	Yes	IHD/IHA/CRRT	Severe poisoning: pH ≤7.2, hypoxemia, altered mental status, [salicylate] >5.8 mmol/L with renal dysfunction or >6.5 mmol/L with normal GFR
Thallium	Yes	IHD/IHA/CRRT	Severe poisoning with [thallium] >4.9 µmol/L
Theophylline	Yes	IHD/IHA/CRRT	Severe poisoning: seizures, dysrhythmias, shock, or [theophylline] > 555 µmol/L in acute exposure (half this in chronic exposure). Consider extremes of age.
Valproic acid	Yes	IHD/IHA/CRRT	Severe poisoning: mechanical ventilation, shock, cerebral edema, high NH3, pH <7.1, or [valproate] >6,250 µmol/L (roughly 10× therapeutic upper limit)

Therapies are listed in the suggested order of preference. AKI, acute kidney injury; APAP, acetaminophen; CCB, calcium channel blocker (amlodipine, diltiazem, or verapamil); CRRT, continuous renal replacement therapy; IHA, intermittent hemoadsorption; IHD, intermittent hemodialysis; NAC, N-acetylcysteine.

ment in mean arterial pressure during the first 48 hours, a faster peak-to-trough lactate reduction (14 vs. 4 hours), a trend toward shorter high-dose insulin euglycemic therapy (HIET) duration (1 vs. 3 days), and only one death (7.7%).[60] This compares favorably with two other observational studies describing the safety of HIET therapy among 7 and 46 patients, respectively, with no control groups.[61,62] The mortality rates in these studies were 14% and 20%, respectively. Finally, the safety of modern hemoadsorption therapy with respect to platelet counts, bleeding, and transfusion requirements appears well supported.[63]

The use of modern resin hemoadsorption may contribute to improved hemodynamic stability, faster resolution of shock, and possibly improved outcomes. The beneficial effects could theoretically be attributed to the faster clearance of CCBs from both the vascular and tissue compartments through the multicycle approach described in Figure 2.[63] Given that the recommendation for HIET therapy in CCB overdose is based on animal studies, case series, and two noncomparative retrospective studies evaluating safety, further consideration of hemoadsorption use is warranted, particularly in light of the results of a detailed comparative case-control study that does not currently exist for HIET therapy.

The burden of pesticide self-poisoning has been well documented, and organophosphates represent a major toxin in this group, with Southeast Asia, China, Africa, and South America bearing the brunt of this problem.[64] With millions of lives lost over the past few decades, apart from antimuscarinic therapy, there has been surprisingly little progress in the management of this condition, and the potential role of hemoadsorption has received limited attention in the literature. This may be due to the burden of this disease being disproportionately higher in LMIC and the evidence stemming from a limited number of regions.

In 2022, a systematic review and meta-analysis (SRMA) was published, identifying 11 OPP studies, all conducted in China.[65] Randomized controlled trials comparing standard care with hemoperfusion and hemofiltration plus standard care were searched for in the following databases: WanFang, Chinese Biomedical Literature, China National Knowledge Infrastructure, Medline, and Cochrane. Eleven studies included 811 patients admitted with acute severe organophosphate poisoning. Eligibility patients were required to have an appropriate history of exposure and cholinesterase activity of less than 30%.

The control group received standard care consisting of the usual decontamination, antimuscarinic therapy, cholinesterase reactivators, and supportive care, including mechanical ventilation. The intervention group received standard care plus hemoperfusion and hemofiltration. The methodological quality of the studies was deemed poor because 5 of the 11 studies did not report randomization, none described concealment, and only one study reported blinding.

Overall mortality was reported in 10 studies (699 patients), and the intervention was associated with reduced mortality (odds ratio 0.38, 95% CI 0.25−0.57). Four studies demonstrated a significant reduction in atropine requirements in the intervention group, while

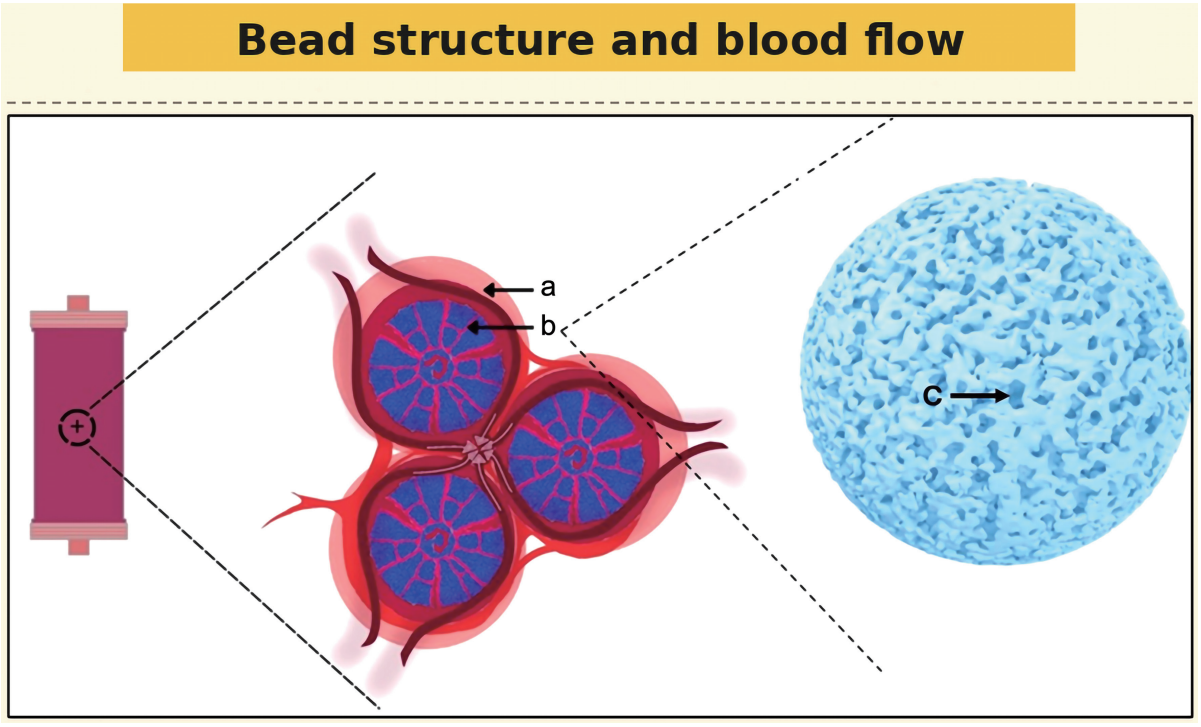

Fig. 1. An enlarged view of the bead structure and blood flow within a modern resin polymer cartridge. (a) Interparticle blood flow: blood flow between the beads within the cartridge. (b) Interphase blood flow on the external surface of the beads. There is an external transfer of the solute by diffusion to the outer surface of the sorbent. (c) Intraphase blood flow: blood flow through the porous structure of the bead. There is an internal mass transfer of the solute by convection through the pore into the inner surface, where adsorption occurs.[31]

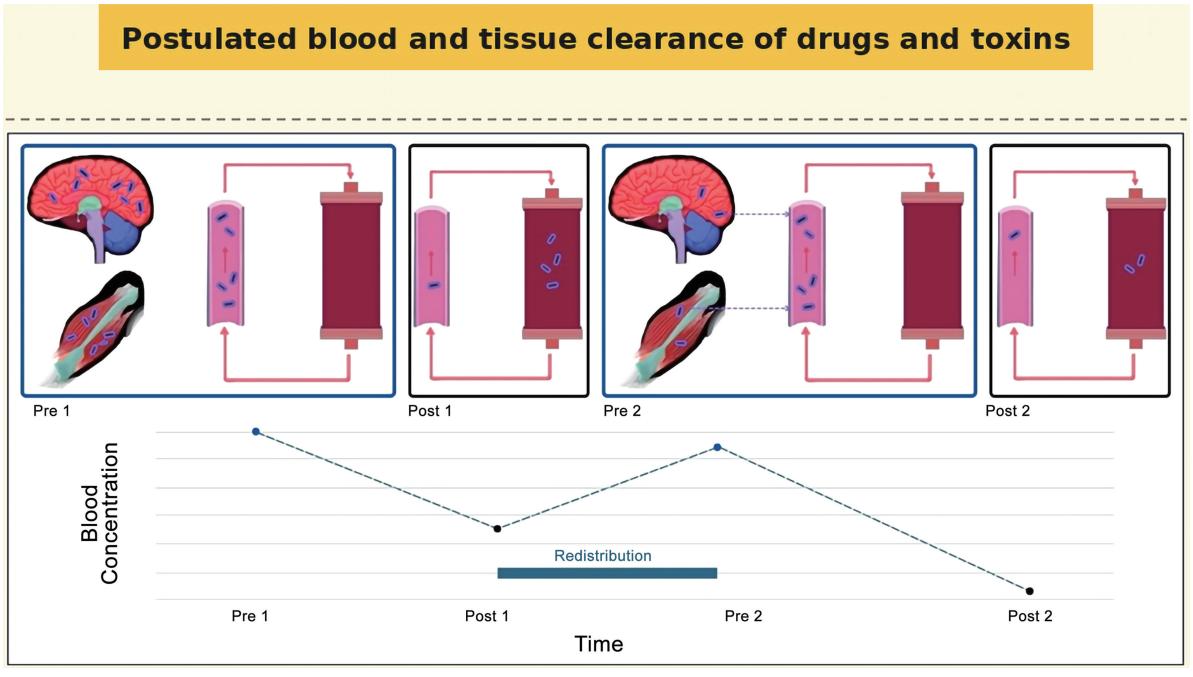

Fig. 2. Postulated blood and tissue clearance of drugs and toxins. Pre 1 (pre-hemoadsorption therapy cycle 1) describes significant toxin concentration in tissue and blood, causing symptoms. Post 1 (post-hemoadsorption cycle 1) demonstrates a reduction in blood toxin concentration due to adsorption onto the hemoadsorption cartridge. Pre 2 (pre-hemoadsorption therapy cycle 2) indicates the movement of toxin from tissue to blood along a concentration gradient developed by the first cycle of hemoadsorption therapy. Post 2 (post-hemoadsorption cycle 2) illustrates a second cycle of toxin clearance, reducing the poison burden. The graphic describes the changes in blood and tissue concentrations during the cycles of hemoadsorption therapy.

Table 3. Published studies on hemoadsorption for organophosphate poisoning (PubMed)[24,68–76]

Reference	Nonrandomized study design	n (HA vs. SC)	Cartridge	Outcomes (HA vs. SC)
Dong *et al.*[68]	Prospective observational	34 vs. 34	HA230	Mortality 3% vs. 17%; LOS days 11 vs. 18; MV days 2.3 vs. 7.4; Atropine mg 119 vs. 485
Bo *et al.*[69]	Unavailable	20 (HA 3 cycles) vs. 16 (HA 1 cycle)	HA230	IMS 5% vs. 25%; Atropine mg 251 vs. 622
Hu *et al.*[70]	Not stated	28 (HA + CHF) vs. 28 (HA + SLEDD)	HA230	Mortality 7% vs. 4.5%
Liang *et al.*[71]	Not stated	31 vs. 30	HA330	Mortality 19% vs. 16%; LOS days 7.5 vs. 16.1; MV days 3.8 vs. 6.8
Peng *et al.*[72]	Not stated	67 vs. 41	Charcoal	ICU LOS days 4 vs. 6; MV days 5 vs. 8; Atropine mg 568 vs. 1,228; Mortality 7.5% vs. 34%
Martinez Cheucos *et al.*[73]	Observational	10 (no control)	Charcoal	Fat biopsy clearance 0.1%; Mortality 20%
Kang *et al.*[74]	Retrospective	40 vs. 28	Charcoal	Mortality 20% vs. 18%
Gil *et al.*[24]	Retrospective	67 (no control)	Charcoal	Excess mortality 44%; Complications: thrombocytopenia 31.1%, hemorrhage 3%, hypocalcemia 69.1%
Altintop *et al.*[75]	Retrospective	17 vs. 7	Charcoal	No comparisons. Severity associated with mortality
Guo *et al.*[76]	Retrospective	49 vs. 49	Unknown	Mortality 6% vs. 29%

"No control" in column 3 refers to the absence of an SC group. CHF, continuous hemofiltration; HA, hemoadsorption; HA230, resin cartridge (Jafron Biomedical Co. Ltd.); ICU, intensive care unit; IMS, intermediate syndrome; LOS, length of stay; MV, mechanical ventilation; n, number; SC, standard care; SLEDD, sustained low-efficiency daily dialysis.

five studies showed a significant reduction in the duration of mechanical ventilation. Finally, 10 studies (745 patients) reported a shorter cholinesterase restoration time in the intervention group.

More recently, a randomized controlled trial comparing hemoadsorption therapy (with 500 mL/h of hemofiltration) with standard care was published.[66] This study was completed after publication of the previous meta-analysis and reported both randomization and concealment methods. It was conducted outside China (South Africa) at a single center. Forty patients with severe organophosphate poisoning (cholinesterase levels <200 IU/L, reflecting approximately 5% cholinesterase activity) requiring invasive mechanical ventilation were recruited. The Jafron HA 230 cartridge was used in series with a continuous renal replacement circuit (Primaflex). Two cycles of hemoadsorption, six hours in duration, separated by a 12–18-hour interval, were performed. The primary outcome was a significant reduction in the proportion of patients in the hemoadsorption arm requiring a prolonged ICU stay. The duration and total dose of atropine were significantly lower, as was the duration of mechanical ventilation, in the hemoadsorption group compared with the standard care group. A detailed cost analysis demonstrated substantial financial savings. A reduction in ICU length of stay from a median of 17 (standard care) to 10 days (hemoadsorption) provided evidence of a significant but less immediately apparent advantage—namely, improved ICU bed turnover and increased bed availability. The estimated savings per patient in ICU was just over 7,000 euros. The proportion of patients developing severe complications, including death, cardiac arrest, organ dysfunction, status epilepticus, reintubation, and tracheostomy, was also significantly lower in the hemoadsorption group.

A recent observational study from a single center reported substantial benefits for 75 patients. Forty-one patients receiving hemoadsorption therapy were compared with 34 receiving standard care. The hemoadsorption group had greater disease severity, as demonstrated by a significantly higher severity-of-illness score (SAPS II), higher predicted mortality, and lower Glasgow Coma Scale (GCS) scores. Despite these differences, hemoadsorption was shown to have a protective effect, with the standard care group experiencing significantly more severe complications, including death, cardiac arrest, cerebral herniation, septic shock, acute kidney injury, reintubation, and tracheostomy.[67]

Finally, we found 10 non-randomized published studies evaluating hemoadsorption therapy for organophosphate poisoning indexed under PubMed. Table 3 summarizes the main outcomes of these studies.[24,68–76]

Overall results from observational data, the randomized controlled trial meta-analysis, and the most recent randomized controlled trial all show benefits with the use of hemoadsorption therapy for acute severe organophosphate poisoning. These include benefits in terms of duration of antidote therapy, decreased need for organ support (mechanical ventilation), shorter hospital stays, fewer severe complications, and lower mortality. Hemoadsorption safety data from the South African randomized trial showed no significant effects on platelet count, bleeding, or transfusion requirements.

Although less well-known, clinical experience (nonrandomized and without control groups) with the use of hemoadsorption for other toxins, including paraquat, mushroom, and snake venom, also exists.[56,77–79]

A case report involving a snake bite of the fifth finger of the left hand in a 62-year-old patient reported on the use of hemoadsorption with a polystyrene resin (Cytosorb®).[79] The snake was identified as belonging to the *Montivipera xanthina* species. There was a delay in acquiring antivenom, and no response was observed after initial debridement, fasciotomy, antibiotics, tetanus prophylaxis, and other supportive care. Hemoadsorption was subsequently initiated, and a clinical response was noted, both in terms of systemic and local perfusion.

A retrospective study evaluating 58 patients (children and adolescents) with the use of styrene divinyl benzene resin (hemoad-

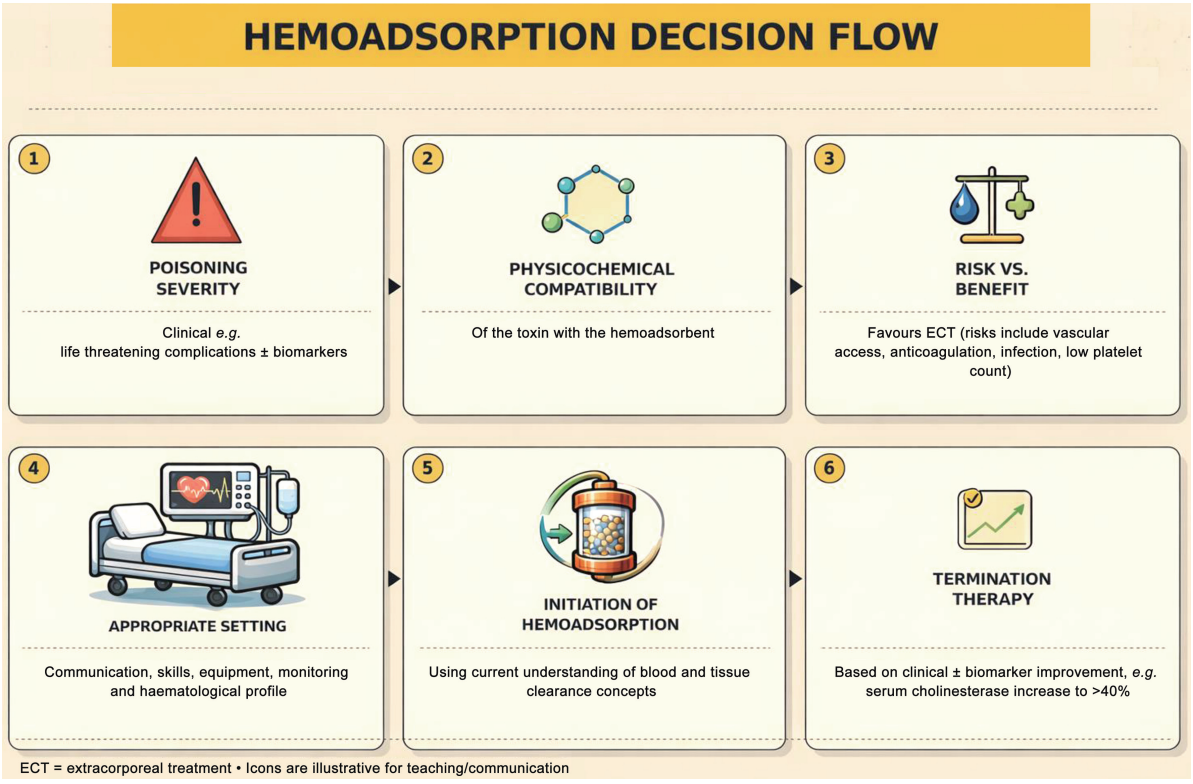

Fig. 3. Suggested care pathway for hemoadsorption when formal guidelines are lacking. ECT, extracorporeal therapy.

sorption) in 26 cases demonstrated that survival depended on the amount of mushroom ingested and early admission and initiation of extracorporeal blood purification therapy.[80]

A recent case report demonstrated the effectiveness of a modern resin cartridge (HA 230) in removing significant amounts of enalapril (ACE inhibitor). In this case, the patient ingested an unknown quantity of enalapril and three antiretroviral drugs, presented in shock with a lactate of 10 mmol/L, and required large doses of vasoactive agents. Within five hours of completing a six-hour cycle of hemoadsorption, there was a shock reversal with the patient weaned of all vasoactive drugs, and lactate decreased to 1.5 mmol/L. There was an almost 10-fold reduction in detected enalapril concentrations and reductions in the three antiretroviral drugs in the blood samples after adsorption compared to those obtained immediately before. Significant removal of enalapril and all three antiretroviral drugs by Extracorporeal Blood Purification (ECBP) was demonstrated.[81]

The role of hemoadsorption using modern resin cartridges for various toxins is growing. Despite an increasing number of reports, well-conducted comparative studies are limited, and this situation is unlikely to change given the variety of toxins and the difficulty of accumulating large enough cohorts to conduct randomized trials. A proposed care pathway for the use of hemoadsorption when clinical data are limited or absent is described below.

Suggested care pathway for hemoadsorption in poisonings where formal guidelines are lacking

We suggest considering the risks associated with severe poisoning, as summarized in the suggested care pathway shown in Figure 3. These include life-threatening complications, infectious complications in the ICU or hospital, organ dysfunction, anticipated prolonged duration of organ support, prolonged ICU stay, and mortality. If present, these factors should prompt consideration of the physicochemical properties of known or suspected toxins. Compatible hemoadsorption characteristics may facilitate elimination, and an assessment of extracorporeal therapy risks can then be weighed against the risks of poisoning and delayed toxin removal. Extracorporeal therapy risks include those associated with vascular access, anticoagulation, infection, biocompatibility, and platelet consumption. In the appropriate clinical setting, with adequate communication, expertise, equipment, and monitoring, and with a suitable hematological profile, hemoadsorption therapy can be performed based on our current understanding of blood and tissue clearance. Initial therapy, based on current cartridge saturation, often allows 6−12 hours of hemoadsorption per cycle; manufacturer information guides this step. Subsequent treatment sessions may be performed daily for two to three days, with frequent assessment of clinical recovery or surrogate biomarker changes suggesting tissue clearance. The termination of therapy can be based on clinical recovery and, if available, concordant biomarker improvement. For example, rising serum cholinesterase levels in organophosphate poisoning suggest tissue clearance, provided that exposure and ongoing absorption have been addressed.

Limitations

Most of the studies described here have important limitations. Only one randomized trial adhered to the CONSORT reporting guidelines. The other clinical trials did not report randomization, concealment, or blinding. Selection bias is not only a problem in

nonrandomized studies but also arises when concealment is absent. Although blinding may be difficult to achieve in this clinical setting, its absence raises the possibility of detection bias.

The wide range of toxins ingested may result in clinical heterogeneity, and even within the organophosphate class, there are many compounds with variable characteristics. Several types of hemoadsorption cartridges are available for clinical use. These can be used for varying durations and at different frequencies, resulting in treatment heterogeneity.

Observational studies are prone to biases and confounding, with no control over cointerventions. Outcome follow-up may be inconsistent, and missing data may influence these outcomes. Reporting bias may exaggerate findings, as positive results are more likely to be published.

Limited sample sizes were a universal feature of all the studies described in this review. This is a problem inherent in toxicology and impacts the precision of the results. Random outliers may influence results in either direction. Another common feature was that these studies were single-center, limiting generalizability.

Although data from several countries demonstrated consistent benefit of hemoadsorption therapy, this conclusion must be tempered by the limitations discussed.

Conclusions

The role of hemoadsorption therapy for severe poisoning has a long history, with recent advances in modern resin bead technology and an expanding body of evidence extending the potential utility of this therapy to commonly encountered poisons that are protein-bound and have a large volume of distribution. Using a multicycle approach, hemoadsorption therapy has shown improved outcomes for both CCBs and organophosphate poisoning.

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The conceptual content and decision logic of Figure 3 were developed by SO, who also created the initial flow diagram in PowerPoint. ChatGPT was used only as a visual formatting tool to assist in converting the author-created diagram into a horizontal flow diagram according to author-specified layout and color instructions. No scientific content, clinical decision logic, or interpretation was generated by ChatGPT. All authors reviewed and verified the final figure and take full responsibility for its content.

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Conflict of interest

The authors have no conflict of interest related to this publication.

Author contributions

Study concept and design (SO), acquisition of data (SO, JMB), analysis and interpretation of data (SO), drafting of the manuscript (SO), critical revision of the manuscript for important intellectual content (SO, JMB), administrative, technical, or material support (SO), and study supervision (SO). Both authors have made significant contributions to this study and have approved the final manuscript.

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