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Review Article

The Role of Hemodialysis in the Management of Acute Poisoning: Uses, Indications, and Clinical Outcomes

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ABSTRACT

Acute poisoning represents a significant medical emergency with the potential for severe morbidity and mortality. While supportive care, gastrointestinal decontamination, and specific antidotes form the cornerstone of management, extracorporeal removal therapies (ECRTs), particularly hemodialysis, play a critical role in accelerating toxin elimination for specific ingested substances. This paper provides a comprehensive overview of the utility of hemodialysis in acute poisoning, detailing its mechanisms of action, the crucial physical and chemical properties of toxins that dictate its efficacy, specific indications including common dialyzable intoxicants, and the observed clinical outcomes. Furthermore, limitations to its application are discussed. Hemodialysis offers a life-saving intervention by rapidly removing toxins, correcting metabolic derangements, and supporting vital organ function, thereby improving survival and expediting recovery in appropriately selected cases of severe acute poisoning.

INTRODUCTION

Acute poisoning is a global health concern, accounting for a substantial number of emergency department visits, hospital admissions, and fatalities annually [1, 2]. The clinical presentation can range from minor self-limiting symptoms to rapid onset of life-threatening organ dysfunction, neurological compromise, and cardiovascular collapse. Traditional management strategies focus

on stabilization of the patient, supportive care, prevention of further absorption (e.g., activated charcoal), and administration of specific antidotes where available [3]

However, for certain types of intoxications, these conventional approaches may be insufficient to prevent severe toxicity or death, especially when the ingested substance is highly destructive, rapidly absorbed, or overwhelms the body's

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natural clearance mechanisms. In such critical scenarios, extracorporeal removal therapies (ECRTs) emerge as a vital adjunctive treatment. Among the various ECRTs, hemodialysis stands out as the most widely available and effective modality for the direct removal of circulating toxins from the bloodstream [4]. This paper aims to elucidate the intricate role of hemodialysis in the management of acute poisoning, outlining its mechanisms, specific indications, and demonstrated clinical benefits.

2. Mechanism of Toxin Removal via Hemodialysis:

Hemodialysis operates on principles of diffusion and convection across a semi-permeable membrane. The patient's blood flows on one side of the dialyzer membrane, while a dialysate solution flows in the opposite direction on the other side.

Diffusion: This is the primary mechanism for toxin removal. Substances move from an area of higher concentration (patient's blood) to an area of lower concentration (dialysate) across the semi-permeable membrane, driven by a concentration gradient. Small-molecular-weight toxins readily diffuse across this membrane.

Convection (Ultrafiltration): This involves the bulk movement of water and solutes (including toxins) across the membrane due to a hydrostatic pressure gradient. As fluid is removed (ultrafiltration), dissolved solutes are "dragged" along with it (solvent drag). This mechanism contributes to overall toxin clearance, especially for larger molecules that might not diffuse as readily.

Beyond direct toxin removal, hemodialysis plays a crucial role in correcting the physiological derangements often associated with severe

poisoning. It effectively addresses fluid volume imbalances, restores electrolyte homeostasis (e.g., managing hyperkalemia), and corrects severe acid-base disturbances (e.g., metabolic acidosis) by facilitating the removal of acidic metabolites and the administration of bicarbonate via the dialysate [5]. By rapidly reducing the circulating toxin load and correcting physiological abnormalities, hemodialysis also indirectly supports the function of vital organs that may be under direct assault from the toxin, allowing them time to recover.

3. Indications for Hemodialysis in Acute Poisoning

The decision to initiate hemodialysis in acute poisoning is based on a combination of factors related to the physicochemical properties of the toxin, the clinical severity of the patient's condition, and the availability of alternative effective therapies.

3.1. Toxin Characteristics Favorable for Hemodialysis

For a toxin to be effectively cleared by hemodialysis, it generally needs to possess specific physicochemical properties that allow it to traverse the dialyzer membrane and be readily available in the circulatory system:

Low Molecular Weight: Toxins with a molecular weight less than approximately 500 Daltons are typically well-dialyzable. Larger molecules are less efficiently removed by standard hemodialysis.

Water-Soluble: Water-soluble compounds dissolve readily in the blood, making them accessible to the dialyzer. Lipophilic substances, conversely, tend to sequester in fatty tissues, reducing their availability for removal.

Low Protein Binding: Only the unbound fraction of a substance in the plasma is available for



filtration and diffusion across the dialysis membrane. Toxins with high protein binding (>80%) are largely unavailable for removal by hemodialysis.

Small Volume of Distribution (Vd): A small volume of distribution, typically less than 1 L/kg, indicates that the toxin primarily remains in the intravascular space rather than distributing extensively into peripheral tissues. Toxins with large Vd are "sequestered" in tissues and not efficiently removed from the blood during dialysis.

3.2. Common Poisonings Treated with Hemodialysis:

A mnemonic often used to remember common dialyzable toxins is "I STUMBLE":

Isoniazid: Particularly in cases of severe neurotoxicity (seizures) or metabolic acidosis.

Salicylates (Aspirin): Effective for severe salicylate poisoning, especially with neurological symptoms, persistent acidosis, or renal failure.

Theophylline: Indicated for severe toxicity, especially with arrhythmias or seizures.

Uremia: While not an acute poisoning, uremia represents an accumulation of endogenous toxins due to renal failure and is a primary indication for hemodialysis. Its inclusion in this mnemonic is due to the shared principle of toxin removal by dialysis.

Methanol: Crucial for preventing progression to severe metabolic acidosis, visual disturbances, and central nervous system depression caused by its toxic metabolites (formic acid).

Barbiturates: Especially long-acting barbiturates, when present in toxic concentrations causing

severe central nervous system depression and hypotension.

Lithium: Indicated for severe lithium toxicity, especially with altered mental status, seizures, or cardiac dysrhythmias, due to its small molecular weight and lack of protein binding.

Ethylene Glycol: Similar to methanol, hemodialysis is critical for removing ethylene glycol and its toxic metabolites (e.g., glycolic acid, oxalic acid), preventing severe metabolic acidosis, renal failure, and organ damage.

3.3. Clinical Indications:

Beyond the specific toxin, the patient's clinical status is paramount in deciding on hemodialysis:

Severe Metabolic Acidosis: Particularly if refractory to conventional bicarbonate therapy, as seen in methanol, ethylene glycol, or severe salicylate poisoning.

Life-threatening Electrolyte Disturbances: Such as severe hyperkalemia, which may directly result from or be exacerbated by the poisoning.

Acute Kidney Injury or Renal Failure: When the kidneys, the body's natural excretory organs, are compromised and unable to clear the toxin, dialysis becomes essential.

Deteriorating Clinical Status: Progressive central nervous system depression (coma), cardiovascular instability (hypotension, arrhythmias), or multi-organ failure despite optimal supportive care mandates consideration of hemodialysis.

High Serum Toxin Concentration: Even in asymptomatic patients, if the serum concentration of a highly toxic substance is dangerously high and likely to cause future toxicity.



4. Clinical Outcomes and Prognosis :

The judicious and timely application of hemodialysis in acute poisoning significantly impacts patient outcomes, often transforming potentially fatal intoxications into manageable conditions.

Improved Survival: Hemodialysis has been unequivocally shown to improve survival rates in life-threatening poisonings, particularly those involving methanol and ethylene glycol. Rapid removal of these parent alcohols and their toxic metabolites prevents irreversible organ damage and death [6, 7].

Rapid Clinical Improvement: Patients often exhibit swift clinical improvement following the initiation of hemodialysis. This can manifest as resolution of altered mental status, normalization of metabolic acidosis, stabilization of cardiac arrhythmias, and improvement in hemodynamic parameters.

Shorter Hospital Stays and Reduced ICU Care: By accelerating toxin clearance and promoting clinical recovery, hemodialysis can reduce the duration of hospitalization and the need for prolonged intensive care unit (ICU) admission, thereby optimizing resource utilization [8].

It is crucial to emphasize that the overall outcome is multifactorial and heavily dependent on several critical elements: the timing of hemodialysis initiation relative to ingestion, the specific type and dose of the ingested toxin, the patient's baseline health status, and the quality and comprehensiveness of concomitant supportive care provided. Early intervention, especially in severe cases, is often associated with more favorable outcomes.

5. Limitations :

Despite its efficacy in selected cases, hemodialysis is not universally effective for all types of acute poisonings. Its limitations stem primarily from the physicochemical properties of certain toxins:

High Protein Binding: Toxins extensively bound to plasma proteins (e.g., digoxin, tricyclic antidepressants, calcium channel blockers, phenytoin) are largely unavailable for removal by hemodialysis.

Large Volume of Distribution: Substances that distribute widely into body tissues and have a large volume of distribution (e.g., amitriptyline, benzodiazepines, opioids, chloroquine) are not effectively removed by hemodialysis as only a small fraction remains in the intravascular compartment [9].

High Lipophilicity: Highly lipid-soluble compounds tend to sequester in lipid-rich tissues, making them poor candidates for aqueous-based dialysis.

Rapid Tissue Distribution: Toxins that rapidly distribute from the blood into cells or tissues may have a transiently high blood concentration, but by the time dialysis can be initiated, much of the toxin has already moved out of the bloodstream.

CONCLUSION

Hemodialysis represents a cornerstone in the comprehensive management of severe acute poisonings involving specific dialyzable toxins. Its ability to rapidly remove toxins from the bloodstream, correct life-threatening fluid and electrolyte imbalances, and ameliorate severe acid-base disturbances is unparalleled among ECRTs. While effective for substances characterized by low molecular weight, water solubility, low protein binding, and a small volume of distribution, its utility is limited for toxins



lacking these ideal properties. Timely patient selection, accurate identification of the ingested toxin, and prompt initiation of hemodialysis in conjunction with meticulous supportive care are critical determinants for improving survival, accelerating clinical recovery, and optimizing outcomes in these challenging medical emergencies. Future research may focus on novel dialyzer technologies or combination therapies to broaden the applicability of extracorporeal removal for a wider range of toxic ingestions.

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