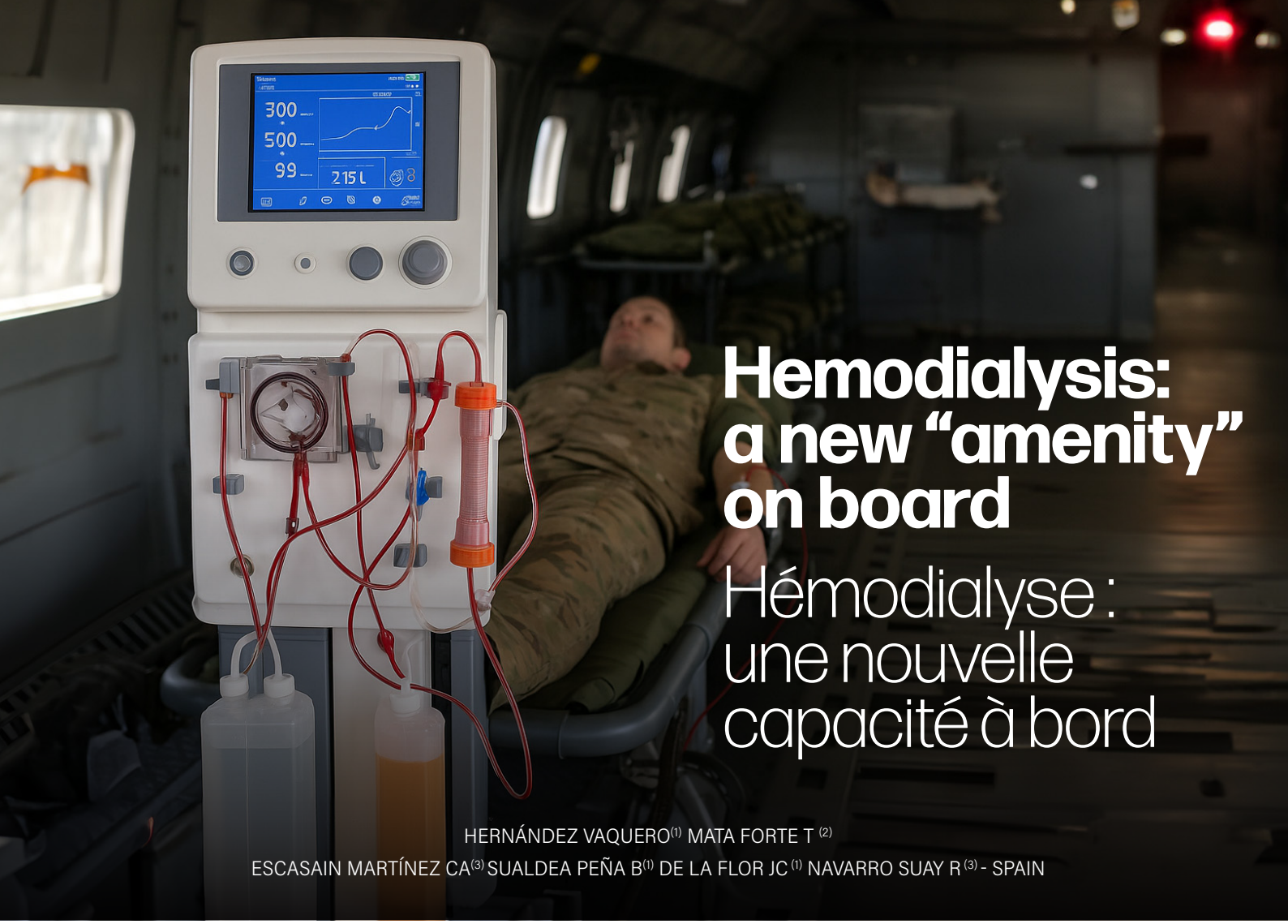

Hemodialysis: a new “amenity” on board

Hémodialyse : une nouvelle capacité à bord

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Summary

Acute kidney injury is a common condition among critically ill patients, and its incidence is likely to increase among casualties in armed conflicts. In some cases, treatment may require renal replacement therapy, posing challenges in military operations. This review examines renal replacement therapy in military operations, analyzing different therapeutic options, with a particular focus on strategic aeromedical evacuations. Although peritoneal dialysis and continuous renal replacement therapies may be viable options in other scenarios, home-based techniques could be useful for critically ill patients requiring renal replacement therapy, even during aeromedical evacuation.

Keywords: Dialysis; Military Medicine; Air Ambulances

Résumé

L'insuffisance rénale aiguë est une situation fréquente chez les patients en état critique, et son incidence est susceptible d'augmenter parmi les blessés des conflits armés. Dans certains cas, son traitement peut nécessiter une thérapie de remplacement rénal, posant ainsi des défis dans les opérations militaires. Cette revue examine la thérapie de remplacement rénal dans les opérations militaires, en analysant les différentes options thérapeutiques, avec un accent particulier sur les évacuations aéromédicales stratégiques. Bien que la dialyse péritonéale et les thérapies continues puissent être des options viables dans d'autres contextes, les techniques de dialyse à domicile pourraient être utiles pour les patients en état critique nécessitant une thérapie de remplacement rénal, y compris lors de l'évacuation aéromédicale.

Mots-Clés: Dialyse; Médecine militaire ; Ambulances aéroportées

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Introduction

The current global geopolitical scenario is at a turning point. (1) The conflicts in Ukraine and Gaza have renewed the need for training and the maintenance of operational units capable of responding to potential threats from symmetrical adversaries in highly restrictive environments, while also addressing potential needs arising from low-intensity conflicts. (2)

Spanish Military Health Services are the "set of organizations, activities, personnel, resources, and procedures whose primary objective is to provide medical support to military personnel, both in national territory and in operational environments." (3)

The inherent capabilities of medical units include deployment in areas with poor infrastructure or overwhelmed medical services due to exceptional circumstances, as well as the tactical, operational, or strategic evacuation of casualties or individuals affected by such events or military operations.

Medical support must be the best possible in each situation, ensuring "the most appropriate use of resources to meet operational needs". According to the different levels of treatment, medical facilities must attend to casualties. However, in all cases, it will be necessary to transfer them to higher levels of treatment, which in some instances will require carrying out strategic evacuations. (3)

Acute kidney injury (AKI) is a clinical syndrome with increasing incidence, particularly among critically ill patients, and is associated with higher mortality. (4)

The diagnosis of AKI is based on laboratory parameters such as serum creatinine levels and its variation over time. (5) Although its definition can also include urinary output, this may be the reason for the disparity in measuring the incidence of acute kidney failure in critical care units.

Historically, AKI in military settings has been associated with rhabdomyolysis, however, modern advancements allow for successful surgical interventions within the framework of damage control at Role 2 and Role 3 levels, increasing casualty survival, but requiring complex post-surgical care to ensure clinical success. This increase in complexity results to a higher incidence of AKI and associated complications, affecting the required care prior to casualty evacuation. (6)

Retrospective studies on AKI incidence in the Iraq and Afghanistan conflicts indicate that approximately one-third of combat casualties suffered from rhabdomyolysis, doubling their likelihood of developing AKI. Intensive care unit admissions also showed similar incidence rates, confirming AKI as an independent factor associated with mortality. (7,8)

Therapeutic strategies for AKI vary, from adjustments in the treatment to renal replacement therapy (RRT). Although there are recommendations for the initiation of RRT in severe AKI cases, there is no consensus on critical questions such as the optimal timing for initiation, the best modality, withdrawal timing, or its long-term prognostic impact. (9)

In asymmetric conflicts where airspace control is assured, the need for RRT before evacuation to a Role4 is unlikely. However, in larger-scale conflicts with prolonged evacuation times, RRT may become essential. (10) A retrospective study on U.S. Army intensive care unit patients in Iraq and Afghanistan (2002–2011) found that nearly 6% developed hyperkalemia, which could delay evacuation and jeopardize survival. (6)

Since 2023, the nephrology service at our hospital has been evaluating therapeutic options for AKI management in austere environments, operations, or disasters under military medical responsibility, including RRT application both in operational zones and during strategic evacuation.

This narrative review analyzes, from a logistical and operational perspective, different RRT options in strategic evacuation contexts.

Materials and methods

A narrative literature review was conducted on AKI and RRT in aeromedical environments. The search included scientific databases (UptoDate, PMC, and StatPearls) using the terms "acute kidney injury, conflict, crisis, war, aero evacuation, flight, trauma, dialysis." The search was restricted to case reports, case series, retrospective and prospective studies, systematic reviews, clinical guidelines, and narrative reviews, excluding those without full-text access.

The search on January 31, 2025, initially yielded no results due to the inclusion of "flight" and "aero evacuation." Removing these terms yielded seven results, while a broader search without requiring all terms returned 273 results from 2000 to 2025. Additional information was included from public administration and non-governmental organization guidelines. Nephrologists and military medical experts in aeromedicine reviewed the records, excluding those lacking relevant information or containing duplicate data. Ultimately, 15 articles related to AKI in military operations or RRT in military settings or disasters were selected. A targeted search on February 6, 2025, using "dialysis" and "hemodialysis" in Military Medicine, Armed Forces Medical Services Review, and Military Health Journal yielded 229 articles, of which seven were deemed relevant. Among them, one case report described the only documented instance of RRT administration during flight.

Discussion

AKI Incidence in War:

Historically, military AKI has been associated with rhabdomyolysis and crush syndrome. The first modern description was provided by Bywaters and Beal in 1941, following building collapses during the "Blitz". Although AKI was clinically described in earlier disasters, Bywaters correlated muscle destruction with myoglobinuria and suggested aggressive fluid therapy and urine alkalinization for prevention. (11)

During the Korean War, the U.S. Army estimated AKI incidence among severe casualties at 0.5%, with mortality linked to shock and multi-organ failure at 50–60%. The increased use of fluid therapy, shorter evacuation times, and early surgical interventions likely contributed to reduced mortality. (12,13)

Recent conflicts contributed additional data on AKI. A retrospective study of casualties from Iraq and Afghanistan (2002–2011) found that 31.1% had rhabdomyolysis, doubling their risk of AKI. Among ICU-admitted casualties, AKI incidence was 34.3%, typically developing within the first two days and proving to be an independent mortality risk factor. (14,15)

No open-source data were found, in this revision, on AKI incidence in military personnel in the Ukraine war. To date, the Spanish Armed Forces has not deployed any units with RRT capabilities abroad.

Renal Replacement Therapy in Operational Zones and Aero evacuation:

The availability of RRT in combat zones is not new. The U.S. Army established a dialysis unit at Wonju Military Hospital in Korea in the early 1950s. (15) Thereafter, in Vietnam, the "679th Medical Renal Detachment" provided hemodialysis in Saigon, while naval hospital ships carried dialysis capabilities too. (12,13)

The water treatment systems, dialysis fluids and machines, as well as the knowledge of the renal replacement techniques used in these conflicts, differ greatly from those available today.

In more recent conflicts, Role 3 units have occasionally deployed continuous renal replacement therapy (CRRT) monitors. (16) However, usage has been limited due to high evacuation capabilities to Role 4 facilities.

Only one documented case of in-flight RRT administration was found: a severely burn patient was evacuated from the Philippines to Texas with RRT maintained for 15 of 19.5 flight hours, achieving excellent fluid and electrolyte balance without adverse events. (17)

Indications and RRT Modalities in Conflicts and Aero evacuation:

Preventing AKI in combat casualties relies on early fluid therapy (18).

However, the fluid tolerance of combat casualties may be limited, and fluid overload should be avoided once the initial resuscitation goals have been achieved. High-intensity conflicts, with prolonged evacuation times, may may necessitate RRT for effective casualty management.

Classic RRT indications include severe metabolic acidosis, refractory electrolyte disturbances, severe AKI, and fluid overload unresponsive to diuretics. Rhabdomyolysis and crush syndrome are not RRT indications but can progress to a requiring dialysis scenario. (19)

As previously described, in a war environment, hyperkalemia and AKI may necessitate the initiation of RRT and could even delay the evacuation of the wounded. (6) Although there have been reports of exceptional cases of extracorporeal purification using improvised means, (20) it is always preferable to perform these therapies using dedicated medical devices or regulated purification techniques.

Peritoneal dialysis (PD) is a suitable technique for initiating RRT and can be considered an option for the acute treatment of renal failure, representing a priority choice in low-resource countries. However, the first weeks of treatment require large amounts of dialysis fluid, sometimes reaching up to 24 liters per day. This, combined with the increased risk of infection and the likely traumatic etiology of combat casualties, makes this technique less suitable for meeting the needs of a Role 2 or Role3. On the other hand, PD is the first-line treatment for children with AKI and may be considered an RRT option in communities affected by disasters with limited resources. (21,22)

From an aeromedical perspective, peritoneal dialysis does not appear to be the preferred technique when the patient requires aero evacuation. The insertion of a peritoneal catheter creates communication between the peritoneal cavity and the atmosphere. This could pose a risk due to the possible presence of air in the peritoneal cavity, which, according to Boyle-Mariotte's Law (23), would expand with altitude as atmospheric pressure decreases. This expansion of peritoneal gas could lead to increased intra-abdominal pressure.

Hemodialysis, whether prescribed as continuous or intermittent therapy, has been used as supportive treatment for war casualties or disaster victims over the past decades, including some casualties in recent conflicts in Iraq, Syria, and Afghanistan. (24,25) It is effective in managing fluid overload, clearing toxic metabolites, and controlling electrolytes. (26) CRRT allows for adequate extracorporeal purification while preserving the patient's hemodynamic stability, but it requires large volumes of dialysis and replacement fluids. Additionally, the balance systems that enable its operation may make its use suboptimal in operational zones and prevent its use during air transport

due to continuous exposure to turbulence and vibrations.

From a cost-effectiveness standpoint, continuous therapies, designed for uninterrupted use over several days, are not ideal for air transport of patients whose flights likely do not exceed a few hours.

Conventional hemodialysis machines, commonly used in nephrology units for chronic kidney disease patients, can perform intermittent or slow low-efficiency dialysis (SLED) therapies, but require ultrapure water and bicarbonate and acid concentrates to generate dialysis fluid. SLED therapies are an alternative to continuous therapies as they provide adequate purification while maintaining the patient's hemodynamic stability. But these therapies increases the logistical footprint. Ultrapure water can be easily obtained with a portable reverse osmosis unit if potable water is available, reducing the need for transporting and storing large amounts of fluids compared to continuous therapies. However, this also renders them unsuitable for aeromedical use.

Currently, commercially available home hemodialysis systems, though not specifically designed for this purpose, could facilitate "SLED-like" therapies, ensuring effective renal purification while maintaining hemodynamic stability in critically ill patients. Some home hemodialysis devices integrate a water purification and portable dialysis fluid generation system, further reducing the need for consumables and making them a potentially optimal option for renal support in operational zones. (27)

From an aeromedical perspective, these systems do not appear to have any clinical or technical contraindications for in-flight use. They function through mechanical and hydraulic systems that should not be affected by changes in atmospheric pressure. Logistically, they are lightweight, portable, have low power requirements, and their consumables demand minimal logistical support. As these devices are designed for home use and patient self-management, their simplicity allows operation by personnel with limited nephrology training, and session parameters can even be remotely programmed by a specialist.

However, aside from the case of a severely burned patient evacuated from the Philippines to the United States who received RRT with a home hemodialysis machine during the flight (17), no studies have evaluated the use of this technology in aeromedical settings.

This assessment could be valuable for planning future aeromedical missions.

Conclusion

AKI is a clinical syndrome present in over one-third of casualties treated in operational zones and is an independent risk factor associated with mortality. The current geopolitical situation suggests that, in high-intensity conflicts, the capacity for aeroevacuation may be delayed or reduced, while the incidence of AKI and electrolyte imbalances may increase. Treating these conditions and ensuring proper volume control in critically ill patients will be necessary before safely evacuating casualties.

Currently, RRT can be performed in any setting, with the ability to tailor prescriptions to both the patient's clinical condition and environmental constraints.

Continuous purification therapies are not suitable for aeromedical or naval environments due to weather conditions and navigability.

Home-based dialysis techniques can be easily deployed easily and applied even during strategic aero evacuations. However, their compatibility and performance in aeromedical environments have not been sufficiently studied.

There are no technical or clinical barriers to making RRT available in operational zones or during strategic evacuations, which could improve casualty survival rates and facilitate their medical management.

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Officer of the Military Health Corps since 2004. Holds a master's degree in emergency and Disaster Medicine from Miguel de Cervantes University and a postgraduate qualification in Wilderness Emergency Medicine from the University of Zaragoza. Medical specialist in nephrology, he has combined military service in the Spanish Armed Forces with civilian hospital practice. He has been assigned to units of the Spanish Army and the Military Emergency Unit, with several international deployments. Currently, he serves as Head of the Hemodialysis Unit at Hospital Central de la Defensa "Gómez Ulla", CSVE.