BANTAO Journal 2026; 24(1): 1-4

BJ
BANTAO Journal

Editorial

Climate-Related Nephropathies: Emerging Pathways, Global Burden and Future Directions

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Abstract

Rising global temperatures and more frequent extreme heat events are increasingly threatening kidney health. Ambient heat has been consistently associated with different kidney diseases, but most evidence concerns acute kidney injury during hot weather. In dialysis p-atients, extreme heat has been associated with more hospital admissions and deaths, and hurricanes, floods and wildfires have already interrupted dialysis services.

We use "climate-related nephropathy" as a broad label covering a broad spectrum of kidney manifestations. Experimental data link recurrent dehydration, polyol-fructokinase pathway, vasopressin and hyperuricaemia, but cause of chronic kidney disease of unknown aetiology in agricultural communities is not yet fully understood. The most exposed workers in hot regions, especially in lower socio-demographic regions, are underrepresented in routine data, and evidence is mainly limited to observational study on rest, shade and hydration programmes which seems to be associated with improved kidney outcomes. Early detection and kidney-protective therapy may prevent or delay kidney failure, though their environmental value has not been measured.

Indeed, dialysis is itself resource intensive. The 2025 KDIGO Controversies Conference reviewed these de–mands and carbon-footprint studies have quantified emissions for both renal replacement modalities. Haemodialysis uses large volumes of water and elec-tricity, whereas peritoneal dialysis generates plastic waste and depends on regular deliveries.

Nephrology must integrate workplace prevention, heat-health and dialysis continuity planning, and sustainab-le practice to make long-term viable use the scarce resources we have in our planet.

The kidney as a climate-sensitive organ

Ambient heat has been consistently associated with kidney morbidity in epidemiological studies, while global temperatures and the frequency of extreme heat events continue to rise [1,2]. Although plausible physiological mechanisms link heat stress to kidney injury, the renal consequences of heat and of other atmospheric exposures have attracted attention only recently. Acute morbidity during hot weather accounts for most of the epidemiological evidence. The effect of years of repeated exposure on the incidence and progression of chronic kidney disease (CKD) has been examined far less [2], and preventive measures have been tested in a handful of studies, few of them in people with established kidney disease or in workers who face heat every working day.

Climate-related nephropathy is used here as a broad label, under which fall acute kidney injury (AKI) during heatwaves and the chronic tubulointerstitial disease described among agricultural workers in hot regions, together with the renal complications of vector-borne and water-borne infections, whose transmission may shift with temperature and rainfall, and the indirect effects of drought and food insecurity on people who already have kidney disease [2-4].

Emerging pathways

Rodents subjected to recurrent heat-induced dehydration develop proximal tubular injury, renal inflammation and fibrosis In these models the polyol pathway is activated in the kidney and endogenous fructose is metabolised through fructokinase, which is one of the proposed routes of injury [5]. Vasopressin, hyperuricaemia and urate crystalluria have been implicated as well [6], but how much each contributes to chronic injury in people is unknown. Clinical or subclinical rhabdomyolysis

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during heavy physical work may add a further mechanism of acute tubular injury.

Among working-age agricultural and other manual workers in Central America, Sri Lanka and parts of India, there were selected CKD cases with predominant tubulointerstitial injury, with little or no proteinuria and without traditional causes sufficient to explain it [6]. Regional terminology includes Mesoamerican nephropathy, CKD of non-traditional or unknown aetiology, and chronic interstitial nephritis in agricultural communities. Heat and physical workload are among the leading candidates, while agrochemical exposure, metals and other environmental contaminants, infections and genetic susceptibility have also been proposed. Here, although several factors may interact, no single cause has been established [6]. Case definitions remain heterogeneous and are likely to evolve as surveillance and aetiological understanding improve.

Leptospirosis, dengue, malaria and hantavirus infection can all affect the kidney, and climate change can alter their geographic suitability and transmission patterns [4]. The size of these effects differs among pathogens and ecological settings. Flooding can increase contact with contaminated water and with water-borne infections that involve the kidney. Observational studies, pooled in a recent meta-analysis, have associated long-term exposure to ambient fine particulate matter with incident CKD [7]. However, the heterogeneity among studies is high and causality remains uncertain. Nowadays, wildfire smoke contributes as an episodic source of particulate exposure that is growing in importance.

Global burden

Large population-based studies have associated high ambient temperatures with increased AKI and kidney-related health-care utilization [8,9]. These data come mostly from high-income settings with reliable administrative records, and heat-exposed occupational populations in tropical and subtropical regions, where manual labour is common and nephrology services are scarce and underrepresented. The natural history of heat nephropathy adds a further difficulty, since the disease may present as kidney failure years after the relevant exposure.

Many of the populations most vulnerable to the heat-related kidney burden of a warming climate have contributed relatively little to cumulative greenhouse-gas emissions, and they may also have limited access to adequate shade, rest and hydration at work. Agricultural workers in hot regions who develop progressive tubulointerstitial disease often have few therapeutic options, and in many health systems kidney replacement therapy is hard to obtain. The burden of CKD is already concentrated in settings with a lower Socio-demographic Index [10], and heat-related kidney injury in a warming climate appears to be reinforcing that pattern.

For patients on dialysis the risk takes another form. Extreme heat has been associated with more hospital admissions and more deaths in this population [11-13], with a harder volume management in hot weather, and a storm or flood that cuts transport, electricity or water that can be fatal to someone who needs treatment three times a week. Hurricanes, floods and wildfires have already interrupted dialysis services, and what was learned from those episodes has been put into practice unevenly.

The dialysis paradox

Few treatments in medicine consume as much as dialysis, i.e. in-centre haemodialysis session uses large volumes of water and electricity, disposable circuits and dialysers, and a return journey for the patient, while peritoneal dialysis replaces most of that with regular deliveries of fluid bags and the plastic waste they leave behind. The 2025 KDIGO Controversies Conference on green dialysis reviewed these demands in detail [14]. Carbon-footprint studies have put numbers on the greenhouse-gas emissions of both modalities [15,16], while haemodialysis also draws heavily on water [14].

Some of this can be reasonably cut within existing practice: reverse-osmosis reject water can be reclaimed for non-clinical uses, and dialysate flow can be lowered where the clinical situation allows [14]. Home treatment spares the patient's journey to the unit, though part of the saving is taken back by consumables, deliveries and electricity at home, and certainly, the sum works out differs from one setting to another. Transplantation and conservative kidney management, for the patients who are suitable and who want them, use resources differently over the years, and any comparison between modalities depends on the health system and on how its electricity is generated. Further upstream, early detection and guideline-directed kidney-protective therapy may delay or avert kidney failure reducing the need for replacement therapy, bur the environmental value of that has not been measured.

Future directions

Prospective studies of heat exposure and renal injury have to reach the populations at greatest risk and linking kidney function data from occupational health programmes, primary care and community screening to the meteorological and occupational exposure data offers one way to do so. Cross-shift urinary markers of tubular stress and injury offer a way of detecting acute kidney stress during heat-exposed work [17]. How transient biomarker elevations relate to later CKD is

still unclear, and that link is what their use as end–points for workplace prevention programmes would depend on.

Intervention evidence comes mainly from observa–tional and quasi-experimental studies, in which water, rest and shade programmes have been associated with improved kidney outcomes [18]. In a large Nicaraguan cohort of 1044 sugarcane workers that contributed to 1938 person-harvests, an incident kidney injury, clini–cally diagnosed AKI and inflammatory markers decli–ned among burned cane cutters as the rest, shade, hydration and hygiene programme was progressively strengthened, although the study was not randomised [19]. Controlled evaluation of a comparable program–mme would give an estimate of effect size that an observational design cannot.

In people with established kidney disease, heat-health planning rests on individualised advice on hydration and on medication review, temporary adjustment of diuretics, renin-angiotensin system inhibitors and other kidney-protective medications during heatwaves but there is little evidence to guide it [2]. Dialysis services also require continuity plans for disruption of electri–city, water supplies and transport during extreme events with regular rehearsal and update as part of di–saster preparedness.

The relative contributions of heat, dehydration, uric acid, fructose metabolism and toxic co-exposures to chronic tubulointerstitial injury remain uncertain. Allopurinol attenuates injury in experimental heat stress nephropathy [20], and the fructokinase depen–dence of dehydration-induced injury in mice [5] points in the same direction. At present, no human clinical trial data currently supports pharmacological prevention. Susceptibility factors that modify individual risk in exposed populations are another target for genetic studies.

Climate-related kidney risk extends beyond clinical practice through occupational conditions, water secu–rity, urban environments and energy systems [21,22]. International nephrology initiatives have increasingly called for advocacy, climate-resilient kidney care and environmentally sustainable practice. In addition, much of what would protect heat-exposed workers lies in la–bour regulation and workplace practice. The adap–tation of kidney services to extreme weather falls to health-system emergency planning, and the environ–mental footprint of dialysis is set by procurement, wa–ter and energy policy as much as by clinical choices.

Conclusions

Ambient heat has been consistently linked to AKI in settings with reliable records, but how far repeated exposure contributes to chronic tubulointerstitial di–sease is still unresolved. The people most exposed, outdoor workers in hot regions, are the ones routine data see least, and often the ones with limited access to shade, rest and water during the working day. Patients on dialysis are exposed in a different way, to the heat itself and to anything that interrupts thrice-weekly treatment. Nephrology needs to plan for a hotter and less stable climate, from workplace prevention to heat-health and continuity planning for people with estab–lished kidney disease, and at the same time reduce what its own treatments, dialysis above all, cost the environment. Early detection opens the way to guideline-directed kidney-protective therapy, which delays kidney failure in eligible patients and hence, the need for replacement therapy, while the environmental value of that has still to be measured.

Conflict of interest statement. None declared.

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