ICU
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Greener ICU

Treating Catecholamine Refractory Hypotension in Septic Shock

Increase mean arterial pressure
in catecholamine refractory septic shock[1,3]

Reduce Norepinephrine Infusion
while maintaining mean arterial pressure[1,2]

Increase Chances of Survival
for patients with less severe septic shock (<15 µm/min NE)[5] and patients at risk of AKI (increased serum creatinine x1.5)[4]

Empressin 40 I.U./2 ml concentrate for solution for infusion. Active substance: Argipressin. **Composition:** One ampoule with 2 ml solution for injection contains argipressin, standardised to 40 I.U. (equates 133 microgram). 1 ml concentrate for solution for infusion contains argipressin acetate corresponding to 20 I.U. argipressin (equating 66.5 microgram). **List of excipients:** Sodium chloride, glacial acid for pH adjustment, water for injections. **Therapeutic indication:** Empressin is indicated for the treatment of catecholamine refractory hypotension following septic shock in patients older than 18 years. A catecholamine refractory hypotension is present if the mean arterial blood pressure cannot be stabilised to target despite adequate volume substitution and application of catecholamines. **Contraindications:** Hypersensitivity to the active substance or to any of the excipients. **Undesirable effects: Metabolism and nutrition disorders:** Uncommon: hyponatremia Unknown: Water intoxication, diabetes insipidus after discontinuation. **Nervous system disorders:** Uncommon: tremor, vertigo, headache. **Cardiac disorders:** Common: arrhythmia, angina pectoris, myocardial ischaemia. Uncommon: reduced cardiac output, life threatening arrhythmia, cardiac arrest. **Vascular disorders:** Common: peripheral vasoconstriction, necrosis, perioral paleness. **Respiratory, thoracic and mediastinal disorders:** Uncommon: bronchial constriction. **Gastrointestinal disorders:** Common: abdominal cramps, intestinal ischaemia Uncommon: nausea, vomiting, flatulence, gut necrosis. **Skin and subcutaneous tissue disorders:** Common: skin necrosis, digital ischaemia (may require surgical intervention in single patients). Uncommon: sweating, urticaria. **General disorders and administration site conditions:** Rare: anaphylaxis (cardiac arrest and / or shock) has been observed shortly after injection of argipressin. **Investigations:** Uncommon: in two clinical trials some patients with vasodilatory shock showed increased bilirubin and transaminase plasma levels and decreased thrombocyte counts during therapy with argipressin. **Warning:** less than 23 mg sodium per ml. **Prescription only**. **Marketing authorisation holder:** OrphaDevel Handels und Vertriebs GmbH, Wintergasse 85/1B; 3002 Purkersdorf; Austria. **Date of revision of the text:** 02/2022

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References: **1.** Evans L, Rhodes A, Alhazzani W et al.: Surviving sepsis campaign: international guidelines for management of sepsis and septic shock 2021. Intensive Care Med (2021) 47:11811247 **2.** Russell JA: Benchtobedside review: Vasopressin in the management of septic shock. Crit Care. 2011; 15(226):119 **3.** Dünser M.W.: Arginine vasopressin in advanced vasodilatory shock: a prospective, randomized, controlled study; Circulation.2003 May 13;107(18):23139.17. **4.** Gordon A.C. et al.: The effects of vasopressin on acute kidney injury in septic shock. Intensive Care Med 2010; 36:8391. **5.** Russel JA: Vasopressin versus Norepinephrine Infusion in Patients with Septic Shock. N Engl J Med 2008; 358:87787

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ICU_Management

Greener ICU

Intensive care units are essential in providing life-saving care to critically ill patients. However, ICUs can have an environmental impact. Approximately 5% of worldwide anthropogenic greenhouse gases result from healthcare activities.

ICUs use significant energy to power equipment, ventilators, monitoring systems, and other life-support devices. They also consume substantial amounts of water while providing patient care, cleaning, and sanitation. ICUs also generate significant medical waste. All these lead to environmental pollution and water contamination.

It is important to mitigate the environmental impact of ICUs. This can be achieved through energy-efficient technologies, sustainable building practices, waste reduction and recycling, and optimal water management. ICUs must increase their focus on sustainable practices to minimise the environmental footprint of medical equipment and supplies. Implementing energy-saving measures to reduce energy consumption, utilising renewable energy sources, implementing efficient waste reduction strategies, improving inventory management, setting up recycling programmes, promoting water-efficient practices, minimising the use of hazardous chemicals and choosing safer alternatives, implementing proper chemical storage, handling, and disposal protocols, educating staff about the importance of responsible chemical management, incorporating sustainable design principles when constructing or renovating ICU facilities, engaging with sustainability organisations, healthcare networks, and regulatory bodies to exchange best practices, and tracking and monitoring energy consumption, water usage, waste generation, and other environmental metrics are essential. By implementing these measures, ICUs can contribute to a greener, more environmentally friendly healthcare system.

In this issue, our contributors discuss strategies on how critical care can reduce its environmental impact, aspects related to research, education and clinical practice and the importance of implementing environmentally sustainable strategies in critical care.

As always, if you would like to get in touch, please email JLVincent@icu-management.org.

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GREENER ICU

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OTHER FEATURE ARTICLES

Rapibloc®
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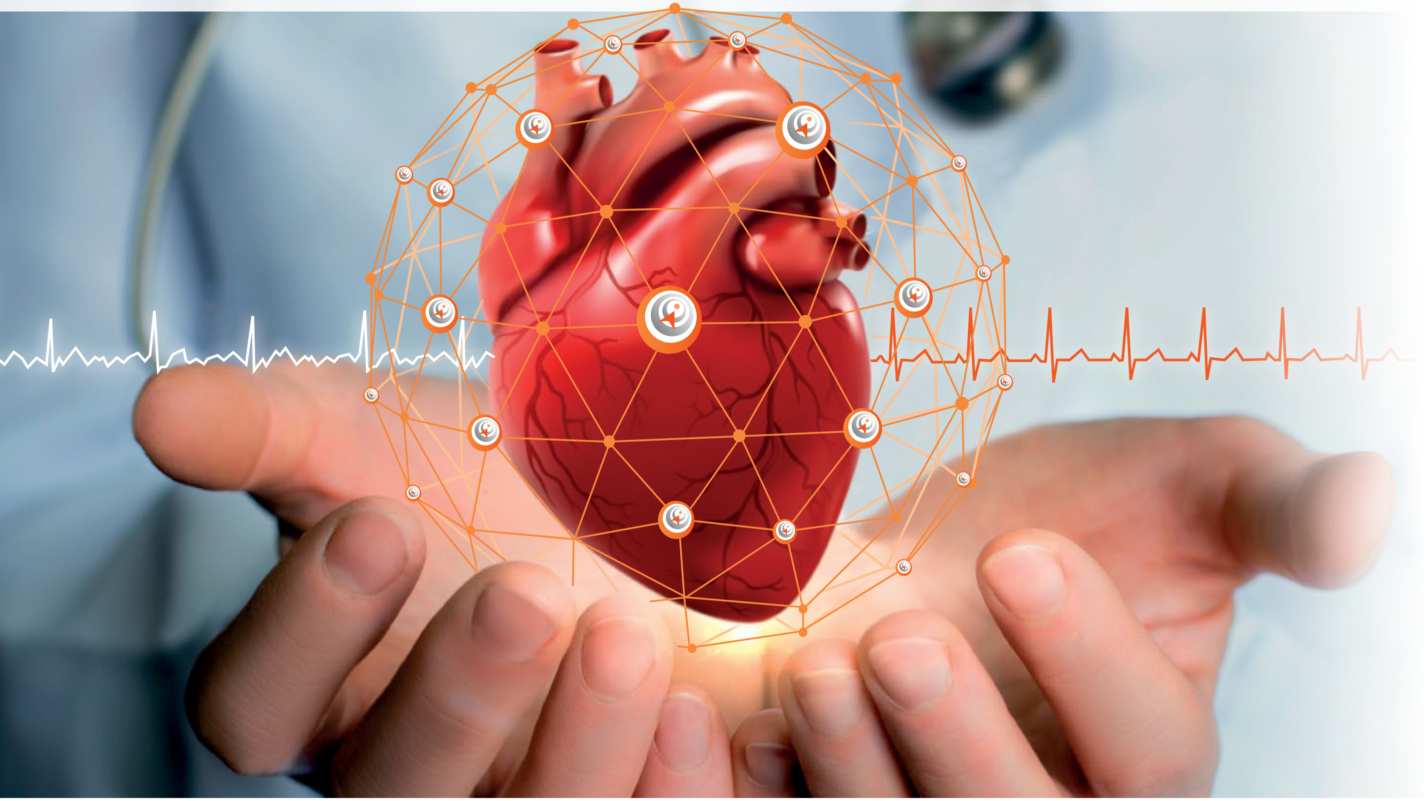
Rapid Rate Control with Myocardial Protection.[1]



Rapid control of ventricular rate in patients with SVTs and AF[1]

First-line for patients with cardiac dysfunction[2]

- **Limited effect** on blood pressure and inotropy[3]
- **Favourable safety profile for patients with renal and hepatic comorbidities** due to inactive metabolites and hydrolysis by plasma esterases[1,4]
- **Compatible with pulmonary disorder patients** due to highest cardioselectivity (β1/β2-selectivity = 255:1) among β1-blockers[5]
- **Limited rebound and tolerance effect** due to lack of pharmacochaperoning activity[6]

Rapibloc® 300 mg: Rapibloc® 300 mg powder for solution for infusion. **Composition:** A vial of 50 mL contains 300 mg landiolol hydrochloride which is equivalent to 280 mg landiolol. After reconstitution each mL contains 6 mg landiolol hydrochloride (6 mg/mL). Excipients with known effect: Mannitol E421, sodium hydroxide (for pH adjustment).
Therapeutic Indication: Landiolol hydrochloride is indicated for supraventricular tachycardia and for the rapid control of ventricular rate in patients with atrial fibrillation or atrial flutter in perioperative, postoperative, or other circumstances where short-term control of the ventricular rate with a short acting agent is desirable. Landiolol hydrochloride is also indicated for non-compensatory sinus tachycardia where, in the physician's judgment the rapid heart rate requires specific intervention. Landiolol is not intended for use in chronic settings. **Contraindications:** Hypersensitivity to the active substance or to any of the excipients, severe bradycardia (less than 50 beats per minute), sick sinus syndrome, severe atrioventricular (AV) nodal conductance disorders (without pacemaker): 2nd or 3rd degree AV block, cardiogenic shock, severe hypotension, decompensated heart failure when considered not related to the arrhythmia, pulmonary hypertension, non-treated phaeochromocytoma, acute asthmatic attack, severe, uncorrectable metabolic acidosis. For further information on warnings and precautions for use, interaction with other medicinal products and other forms of interaction, fertility, pregnancy, lactation, effects on ability to drive and use machines, unsiderable effects, and habituation effects, please refer to the published SmPC **Prescription only/available only from pharmacy. Date of revision of the text:** 09/2021.
Marketing authorization holder: Amomed Pharma GmbH, Leopold-Ungar-Platz 2, 1190 Vienna, Austria

1 Summary of Rapibloc® Product Characteristics, current version. – **2** Hindriks G., et al. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association of Cardio-Thoracic Surgery (EACTS). European Heart Journal (2020) 00, 1-126. – **3** Shibata et al. Direct Effects of Esmolol and Landiolol on Cardiac Function, Coronary Vasoactivity, and Ventricular Electrophysiology in Guinea-Pig Hearts. J Pharmacol Sci 118, 255 – 265 (2012). – **4** Yokoyama H. (2016) Stabilization in Off-Pump Coronary Artety Bypass. Springer Tokyo Heidelberg New York Dordrecht London © Springer Japan. – **5** European Heart Journal Supplements (2018) 20 (Supplement A), A1-A24. – **6** Nasrollahi-Shirazi S et al. Comparison of the b-adrenergic receptor antagonists landiolol and esmolol: receptor selectivity, partial agonism, and pharmacochaperoning actions. J Pharmacol Exp Ther 2016; 359:73–81

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The Green Intensive Care: From Environmental Hotspot to Action

Together we must reduce the impact of the healthcare sector and shift towards a circular economy. This paper describes the shift of three ICU environmental hotspots: gloves, gowns, and CRRT bags.

Introduction

The healthcare sector is one of the most carbon-intensive sectors, contributing to 4.4% of global net greenhouse gas emissions and toxic air pollutants (Karliner et al. 2022). Around 71% of emissions are primarily derived from the production, transport, and disposal of medical products such as pharmaceuticals, medical devices, personal protective equipment (PPE), hospital equipment, and instruments. The Netherlands is above the global average, with 7% of its national footprint associated with the healthcare sector (Gupta Strategists 2022). Hospital care results per year in 3.8 kilotons of extracted materials, 17.6 kilotons of CO_2 emissions and 4803 kilotons of waste (Steenmeijer et al. 2022). Zooming in on the waste, this consists of 15% hazardous materials (e.g. blood and infected materials) and 85% general hospital waste, of which 55% is plastics (WHO 2018). In the last decade, there was a tendency to increase efficiency and prevention of iatrogenic infection. Therefore, there was a shift to single-use products, especially in the operating room and the intensive unit (ICU). In these departments, most of the (plastic) waste is generated (Hunfeld et al. 2022).

Given the current climate crisis, we must start working towards more holistic approaches to reduce the impact of the healthcare sector and shift towards a circular economy (Hinrichs-Krapels et al. 2022). We discuss three relevant approaches. First, a circular economy contains three core principles: (1) design out waste and pollution, (2) keep products and materials in use for as long as possible, and (3) regenerate natural systems (Ellen MacArthur Foundation 2020). While simple in theory, there are many complexities and trade-offs when shifting towards circular practices. Second, the 7 Pillars of the Circular Economy framework (materials, energy, water, biodiversity, human society and culture, health and well-being, and generating value) can be used as a holistic lens to map or to describe sustainability issues and to identify environmental hotspots (Kirchherr et al. 2017). Third, based on these environmental issues and hotspots, the 10R strategies can be used as a starting point for circular interventions by healthcare staff (Reike et al. 2018). The 10Rs represent Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover. Refuse (meaning not buying/using the product in the first place) is the strategy with the highest impact in the hierarchy of circular interventions, while Recover (generating energy from incineration of waste) represents the strategy with the lowest impact.

In the transition from a linear to a circular system, knowledge about the environmental impact of products and actions is needed in order to determine environmental hotspots and to use the 10R strategies. This knowledge can be obtained through so-called Life Cycle Assessments (LCA) or a Material Flow Analysis (MFA). LCAs involve the analysis of the environmental impact of natural resource extraction, manufacturing, packaging, transport, use/reuse, and recycling/waste disposal of certain products or processes (McGain et al. 2020). LCAs related to intensive care medicine have been performed for reusable central venous catheter insertion kits and septic ICU patients in the United States and Australia (McGain et al. 2020; McGain et al. 2018). An LCA of all the activities occurring within the entire ICU would be a considerable undertaking, though not impossible. Another method is the Material Flow Analysis (MFA). An MFA provides a quantitative understanding of all the goods and waste flows that enter and leave the system. It can be used to manage resources and waste flows (Brunner and Rechberger 2004; Allesch and Brunner 2015). We are the first ICU that applied an MFA to identify environmental hotspots in the hospital context at the department level. We have recently published the results of this MFA (Hunfeld et al. 2022). This MFA provides the necessary information for intensive care in its desired transition from a linear to a circular system, with detailed insights into materials mass, carbon footprint, agricultural land occupation and water usage related to the products that are used in the intensive care unit.

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From the MFA, we identified multiple environmental hotspots. This paper will describe how the intensive care of Erasmus MC improved its sustainability by changing three environmental hotspots: gloves, gowns and CRRT bags and their packaging.

From Hotspots to Three Cases

To approach the transition towards a circular hospital from a holistic view, we set up a multidisciplinary consortium comprising partners from an academic hospital (Erasmus MC), a technical university (TU Delft) and a university of social sciences (Erasmus University Rotterdam). Within the circular economy, co-creation and collaboration are key and ideally, co-creation and collaboration involve the whole value chain (**Figure 1**). Our consortium is built around the hospital value chain and serves an extensive network (from materials producers to waste processors). The relevance of this value chain is described previously (Hinrichs-Krapels et al. 2022) and concludes that if we want to move towards more radical and long-term shifts in designing interventions towards transitions, a quadruple-helix approach will be necessary. This will involve cross-disciplinary and cross-sectoral research and implementation across (1) industry, (2) government, (3) academia, and (4) the public. Together with master students from Industrial Design Engineering and Behavioural Economics, we examined how to improve three environmental hotspots. We will describe these cases in more depth below. The case description will follow the following items: environmental hotspot analysis, R approach (**Figure 2**), redesign, behavioural change (if applicable) and supply chain implications.

The final phase of a case consists of implementation of the redesigned product in the ICU. In our setting, this is guided by the green team of the ICU. This green team is vital to harnessing employee expertise, motivating, and finding new and better ways to transition (Trent et al. 2023). Our ICU green team is a diverse team, representing the ICU medical profession by nurses, doctors, and pharmacists, together with expertise from infection prevention, logistics and procurement, and project management leadership.

Gloves

Hotspot analysis

The largest number of individual units procured for the ICU are nitrile gloves, with an average of around 108 gloves being used daily per patient treated in the ICU. Their aggregated weight also makes up more than 12% of the total weight of disposable medical material used. From the impact assessment, nitrile was highlighted as the material with the highest impact intensity in terms of carbon footprint (9.3 kg CO_2-eq/kg nitrile) and water usage (0.5 m^3 water/kg nitrile) (Circular Intensive Care Unit Erasmus MC, Report Metabolic 2021). Given the high environmental impact of gloves, we aimed to redesign their use.

R-approach

Refuse and Reduce will result in the largest impact. This requires a change in the behaviour of the medical staff. In our ICU, it is currently common to wear gloves for all procedures. We recently started a new campaign, together with the infection prevention department, showing medical staff when gloves are needed. For example, in a non-isolation patient's room: only wear gloves when dealing with excreta (e.g., bodily waste including faeces, urine, and mucus), medication (administration of chemotherapy), and blood. To refuse and reduce the use of gloves, we combined this campaign with a newly designed glove box. Rethink is the other R-strategy related to the gloves. Both the packaging (short-term solution) and the material (nitrile, long-term solution) require a more sustainable redesign.

Redesign

This research and design project addressed the problem from three different perspectives: user-centred, product-centred, and supply-centred (vd Berg et al. 2022). The users of the gloves were observed during their work to identify the problems that occur. The product was analysed by trying to take out the gloves one by one from the cardboard dispenser. Due to poor design and packaging, the gloves are difficult to dispense one by one. By analysing the waste, it became clear that around 6% of the gloves end up in the waste unused. The project resulted in a redesign of the current glove dispenser with a focus on five aspects: 1) dispensing one glove at a time, 2) dispensing gloves at the cuff, according to infection prevention rules, 3) vertical position of the box, which is more ergonomic to the user, 4) the use of colours

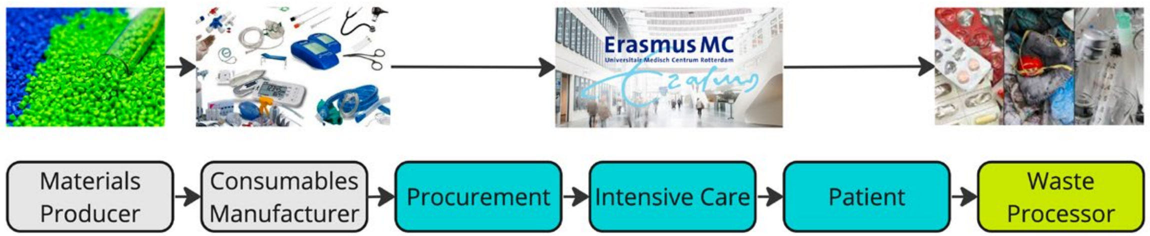

Figure 1. Current linear value chain of medical consumables in the hospital care sector

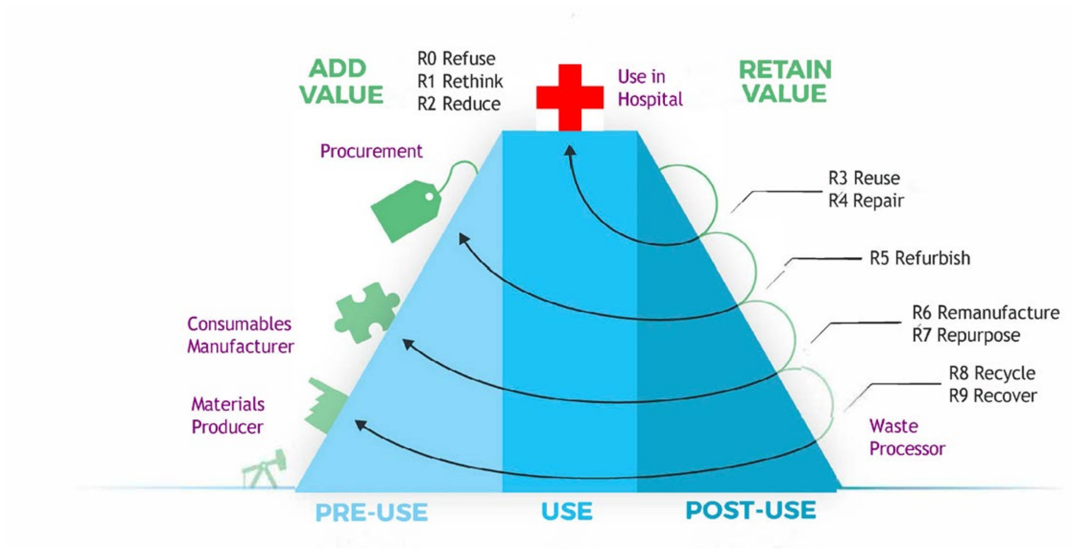

Figure 2. The 10R Circular Economy strategies depicted along the value chain (purple) for medical consumables

on the dispenser for different sizes, so nurses will see at a glance which size gloves the box contains, and 5) a small V-shaped opening which makes the undesirable behaviour of placing gloves back almost impossible. The final glove box design can provide benefits for multiple stakeholders within the healthcare system and also outside the ICU.

Supply chain implications
The case highlighted two important interfaces with the supply chain: First of all, in line with the above analysis, a redesign and manufacturing of a new type of dispenser and a better approach to how the dispensers are filled (stacked instead of bunched up). At the same time, another interface with the supply chain is to ask the market to design and manufacture (at scale) different types of gloves consisting of material with less environmental impact (e.g. a different type of nitrile [Hunfeld et al. 2022]).

Gowns
Hotspot analysis
Our MFA showed that 16 single-use gowns per ICU patient per day are used. Of all personal protective equipment, gowns were the largest contributor to CO_2 emissions during the first six months of the COVID-19 pandemic (Rizan et al. 2021), which means that a reduction in gown usage is an important step towards a circular hospital.

R-approach
We aimed to Reduce gown usage in two distinctive ways: a transition from wearing gowns to wearing aprons when working with non-isolation patients and - when working with these non-isolation patients - to only wear aprons when dealing with excreta and blood. To achieve this goal, behavioural change in ICU personnel was needed.

Redesign
The case of gowns did not need a redesign. There are aprons and washable gowns available on the market.

Behavioural change
To facilitate behavioural change, we combined a policy change and informational campaign with nudging. To examine the effect of two different nudges on gown usage amongst ICU personnel, we ran a field experiment at Erasmus MC (consisting of 4 ICU Units: A, B, C and D). Specifically, we tested the effect of a visual prime and social norm nudge on apron usage. Upon the introduction of the policy change, for 1.5 weeks, we counted how many aprons were used during the day shift in non-isolation rooms across the ICU (i.e., baseline measurement). Next, we introduced a visual prompt sticker and prime (i.e., banner) in Units A and B and a social norm sticker in Units C and D. The social norm sticker stated that 81% of ICU personnel from a comparable hospital preferred to act sustainably and only wear an apron when needed. To examine the effectiveness of our interventions, for a period of 1.5 weeks, we counted how many aprons were used. To examine the effect of each nudge independently, we distinguished between Units A and B and Units C and D. We found an 8 percent point decrease in apron usage between the pre-intervention measurement and the post-intervention measurement in the visual prime condition. Unexpectedly, the social norms stickers led to a 6 percent point increase in apron usage. Neither differences were statistically significant. We will continue our search for ways to encourage more sustainable behaviour amongst ICU employees. We have conducted a series of interviews with ICU personnel to involve the employees themselves in this behavioural transition. Another step forward would be to move from Reduce to Reuse by moving from single-use aprons to washable aprons.

Supply chain implications
This case shows multiple implications for the supply chain. One implication is a switch from single-use gowns to less polluting washable gowns (Vozoola et al. 2018). For Erasmus MC, this requires a tender because of the academic hospital status. This takes time, so Erasmus MC decided to switch to aprons in the meantime. These aprons fulfil the infection prevention rules regarding non-isolation patients. However, gowns are needed for isolation patients. At the moment, we don't have information about the environmental impact of aprons compared to washable gowns. This information is needed before we can set out a future policy: switching to washable gowns for all patients or the use of washable gowns for isolation patients only?

CRRT bags and their packaging

Hotspot analysis

One of the low-hanging fruit cases are the continuous renal replacement therapy (CRRT) bags with their packaging. On average, the ICU of Erasmus MC uses 30,000 5-litre bags (Fresenius Medical, 's-Hertogenbosch, the Netherlands) per year. This adds up to 3,600 kg of plastic waste. Since this is a clean waste stream that can be separated easily from other waste streams, we asked the waste processor if it was possible to create a separate logistics recycle stream for the CRRT packaging and the bags. The waste processor analysed the type of plastic, and both the bag and the packaging appeared to be a pure polypropylene polymer suitable for high-quality recycling. The connectors at the bottom of the bag have to be removed because they consist of a different type of plastic, unsuitable for this type of recycling.

R-approach

For this hotspot, the Recycling of empty CRRT bags (without connectors) and their packaging is a fitting strategy.

Redesign

In this case, there was no need to redesign the product itself. However, a special cutting tool was designed to split the connectors from the bag. Also, a box was made to store empty bags and packaging. This box is attached to the CRRT trolley that is parked outside the patient's room containing new CRRT bags. The ICU nurses are asked to put the CRRT bag packaging in this box as well as the empty bags after having removed the connectors.

Supply chain implications

This case also highlighted two interfaces with the supply chain. First of all, a reverse, closed-loop supply chain needs to be developed to recycle the packaging. Second, collaboration with the supplier needs to be initiated to redesign the CRRT bag in such a way that the connectors can be easily cut off/torn off to enable recycling of the CRRT bag itself. It also stresses the importance of the use of pure plastics that can be recycled for both packaging and the product itself. This should be taken into account during tenders.

Summary: Lessons for the Future

Our three cases show that the transition towards circular intensive care requires a total value chain approach. Collaboration and co-creation with academic partners and industrial partners (manufacturers, suppliers, waste processors) and users (e.g. medical staff) is essential in the change towards more sustainable products, protocols and processes. From our experience, a case usually starts within our multidisciplinary green team (Bein and McGain 2023). After the green team has defined a new case, we collect data about how many products are used on an annual basis and we ask infection prevention specialists (part of our green team) for advice regarding the case and the planned intervention. With this information, a case is then redesigned within our consortium and tested in the ICU. The final step involves the implementation of the newly designed case. This step requires a sharp focus on behaviour and communication within the ICU. Again, it is the green team that advises on the implementation and communication. With this strategy, we were able to implement many sustainable cases already. The involvement of procurement is key and in case of public procurement, alignment with the tendering calendar is an important factor to take into account. Finally, make sure that you can show data on the environmental and financial impact of a case. This helps medical staff change their behaviour.

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Conflict of interest

None. ■

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Moving Environmental Sustainability from the Fringe to the Centre Ground in Critical Care

Critical care must move to a way of working that recognises climate change is a medical emergency, necessitating us all to put sustainability at the forefront of our actions as a multidisciplinary team working together in the best interests of our patients, our environment and our resources.

Planetary Health and Public Health

People's health depends on the health of the planet. The ever-escalating climate crisis negatively impacts public health, from the direct impact of extreme weather events, including heatwaves, wildfires, droughts, hurricanes, rising sea levels and flooding (Romanello et al. 2022) to the indirect impacts of climate-change-instigated migration and conflict. The United Nations (UN) recognises the urgent need to resolve human-induced climate change in their Framework Convention on Climate Change (UNFCCC), Intergovernmental Panel on Climate Change (IPCC), and annual Conference of the Parties (COP) (UN Climate Change 2023). The COP26 Health Programme included five priority initiatives for improving the climate crisis: 1) building climate resilient health systems; 2) developing low carbon sustainable health systems; 3) adaption research for health; 4) inclusion of health priorities in Nationally Determined Contributions; and 5) raising the voice of health professionals as advocates for stronger ambition on climate change (WHO Climate Change and Health 2021).

We are in a critical decade, with the IPCC (2023) highlighting that despite challenges thus far, it is not too late to restrict global warming to 1.5°C by 2030 through "rapid and deep emissions reductions across all sectors of the global economy" (Stiell 2023). Otherwise, the human health issues resulting from the climate crisis will worsen, leading to both an environmental catastrophe and a global public health medical emergency (Howard et al. 2023). However, climate change is not the only interlinked planetary and public health concern. To avoid 'carbon tunnel vision', a holistic approach to environmental sustainability should also address ecosystem issues related to water, land, atmosphere, biosphere and resource availability (Deivanayagam and Osborne 2023; Fang et al. 2022). Furthermore, social justice issues can be both a cause and an effect of ecological problems with interrelated public health implications (**Figure 1**). It is also unethical how people in low-income countries often experience the worst impacts of climate change, and yet they contribute minimally to planetary damage (Chapman and Ahmed 2021).

Environmental Sustainability and Intensive Care

Intensive care clinicians and managers must become more aware of the intrinsically linked planetary and public health problems in **Figure 1** to understand better how they can actively participate in both mitigation by reducing healthcare's environmental footprint (ANZICS 2022) and adaptation by adjusting to current and future ecological issues (Bein et al. 2020), as outlined in **Table 1**.

The 'People, Planet and Profit' model recognises the interconnectivity of financial, social and ecological systems, with sustainable resourcing of one element impacting and being co-dependent on the others (Elkington 2002; Oung 2022). The true success of all sectors, including healthcare, requires this triple-bottom-line philosophy. Still, clinicians and healthcare managers have not yet widely normalised addressing environmental sustainability, despite healthcare causing 4.4% of the total greenhouse gas emissions globally (Karliner et al. 2019) and intensive care generating a significantly high environmental footprint (McGain et al. 2018; McGain et al. 2020). We must urgently move environmental sustainability from the fringe to the centre ground in intensive care. This means a new way of thinking to prioritise sustainability in all aspects of clinical care, including purchasing and using drugs and equipment, using energy efficiently (with renewable sources where possible) and dealing with waste. Healthcare should not be resting on its laurels, believing it already does enough good on behalf of others; in relation to environmental sustainability, we need less tokenism and more implementation. What was viewed previously as "hippy green" activism should now rapidly transition into mainstream realism.

Placing sustainability into the centre ground in how we work, think, and approach healthcare cannot be restricted solely to interested individuals; instead, it needs to involve the entire

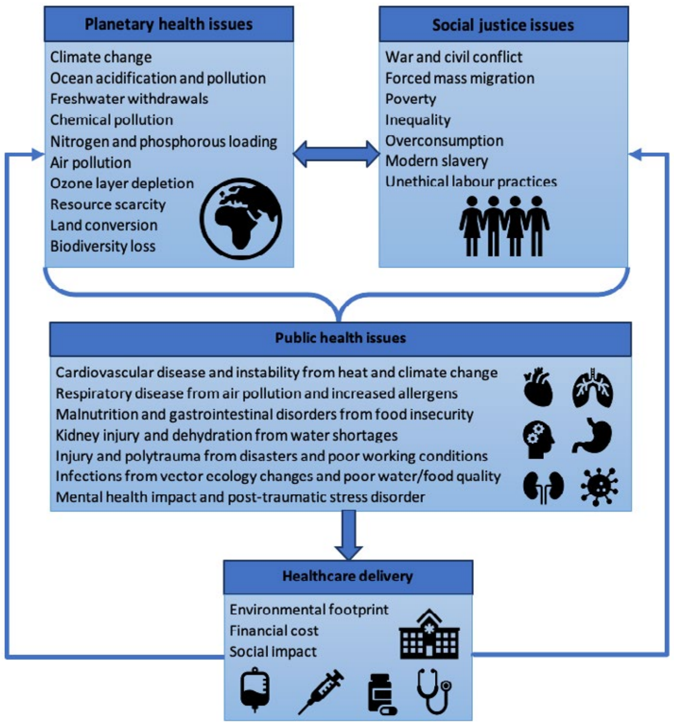

Figure 1. Planetary health, social justice, public health and healthcare delivery interconnectivity

multidisciplinary team. Managers and non-clinical facing staff are at least as necessary, if not more important, than nurses, pharmacists, allied health professionals, assistant roles and doctors. It is incorrect to view sustainability as more expensive than continuing as we are – far from it. If done well, sustainable healthcare can deliver better patient care, save resources and money, add social value, and generate less waste (Mortimer et al. 2018).

Operationalising Intensive Care Sustainability

What does putting sustainability into the centre ground mean, though? Operationalising sustainability by changing platitudes into actions requires leadership and teamwork between directorate management, estates, waste, pharmacy, procurement and all roles working in an intensive care unit (Trent et al. 2023). A multi-disciplinary intensive care sustainability team can be set up and linked with other directorates and an overarching hospital sustainability team. Before absolving individual responsibility by assuming sustainability teams cover everything, it is essential to remember that responsibility is simultaneously individual and collective and that agreed intensive care sustainability actions should be coordinated to be most effective (Stamps et al. 2020). For example, the critical care unit at the University Hospital of Wales has a carbon footprint of approximately 1% of the Health Board's total carbon footprint. This hospital's intensive care unit can and has made efficiencies, including turning computers off overnight, using light-emitting diode bulbs, and not fully charging unnecessary electrical equipment at all times. Without coordination with other directorates and wide rollout across a hospital site, the efficiencies made in intensive care will be very small but still important as part of a whole system approach.

Another example of operationalising healthcare sustainability is the 'gloves off' campaign initiated by nurses in Great Ormond Street Hospital, London who demonstrated that decreasing unnecessary non-sterile glove use saves money and reduces waste (Greener NHS 2020; NHS England 2018). The critical care team in the University Hospital of Wales spends in excess of £100,000 on non-sterile gloves. Reducing inappropriate gloves use by 20% could save £20,000 without impacting patient care and decreasing the critical care unit's environmental footprint. Rolling out a 'gloves off' campaign in intensive care units across a region, network or country would significantly improve environmental sustainability and achieve significant financial savings without impacting patient care. To do so requires education for glove users, coordination within teams, good role models and clear leadership.

Zentensivism is a concept used to delineate a different way of practising intensive care; with less intervention and more compassion (Ahrens 2021; Siuba et al. 2020). Fewer tests do not mean less care. Tests should be considered in terms of 'is this test justified' and 'will the result of this test change my management' or will watching and waiting provide better holistic patient and family-centred care? Zentensivism was not initially connected to sustainability, but there is a clear link between sustainability and fewer tests, better recognition of when further interventional care will not improve the patient's outcome and earlier initiation of end-of-life care as the most appropriate course of action. Patients in intensive care have a proportionately high mortality rate (Detsky et al. 2017). If those most at risk of dying can be identified more clearly and earlier, we can deliver better, more sustainable care. This principle also applies to whether intensive care should play a role at the outset of critical illness; nearly all of us will be critically ill before we die, but that does not mean nearly all of us should receive critical care as the best care option. Medicine and wider society need to engage better about what is possible and, in a broader sense, what is most appropriate and sustainable at the end of life.

Tools and Resources for Sustainable Intensive Care

There are resources now available to clinicians, managers, researchers and educators which explicitly relate to environmental sustainability. The following is a list of intensive care-specific resources to help guide planning, implementing and evaluating environmental sustainability initiatives for intensive care units:

- A Beginner's Guide to Sustainability in the ICU (ANZICS 2022).
- Critical Care Susnet – sustainability network hosted by the Centre for Sustainable Healthcare and endorsed by the Intensive Care Society and British Association of Critical Care Nurses (CSH Networks 2023).
- My Green ICU collection for the European Society of Intensive Care Medicine's Intensive Care Medicine journal (Bein and McGain 2023).

Those wanting to improve the environmental sustainability of their local unit should also consider indirectly relevant resources which fit the ethos of stewardship, 'less is more', the Goldilocks Principle (not too much, not too little and just the right amount of intervention) and complication prevention. For instance, the ICU Liberation bundle (Society of Critical Care Medicine 2020), ventilator-associated pneumonia bundle (Mastrogianni et al. 2023), antimicrobial stewardship (Murphy et al. 2022) and fluid stewardship (Hawkins et al. 2020) all promote a speedier

Mitigation	
Decreasing the environmental impact of intensive care services	Reduce the demand for intensive care through health promotion and preventative measures to reduce admissions into intensive care and facilitate early discharge out of intensive care
	Use lean delivery, 'Zentensivism' (less is more) and Goldilocks principle (not too much or too little but just right) to minimise waste and ensure care is patient-centred and clinically appropriate
	Use environmentally friendly products and processes where possible in the intensive care unit
	Follow a circular economy approach in intensive care where possible: refuse, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover energy
	Consider which intensive care unit equipment and supplies have a high environmental footprint and liaise with industry and researchers to find alternative sustainable solutions
	Embed environmental sustainability into quality improvement initiatives using SusQI methodology
	Integrate environmental sustainability into undergraduate and post-graduate education for all disciplines, along with education for healthcare assistants, technicians and support roles
	Provide leadership for environmental sustainability at intensive care departmental and executive hospital levels through strategic guidance and resources to enable the intensive care unit to reach environmental targets that are specific, measurable, achievable and meaningful to staff
Adaption	
Intensive care unit preparation for current and future planetary health issues	Emergency planning for extreme environmental events – consider how the hospital and intensive care unit would manage sudden and sustained disruption to the availability of: · Electricity, gas and water · Medicines, equipment, other healthcare supplies, food and water · Transport of patients, family and staff · Waste disposal
	Emergency planning for environmentally caused illness, infections and trauma – consider how the intensive care unit would manage a sudden and sustained increased demand for: · Bed capacity and required staffing for a large rise in the number of critically ill patients · Isolation rooms and personal protective equipment for infectious diseases · Equipment for more patients, including ventilators, renal replacement therapy machines, intravenous pumps, medicines, oxygen, fluids and nutrition · Psychosocial support for patients, family and staff members
	Future-proof planning for resource scarcity – consider which intensive care equipment and supplies depend on consumables, rare metals and fossil fuels and liaise with industry and researchers to find alternative sustainable solutions.

Table 1. Environmental issues: adaption and mitigation for intensive care units

recovery for the critically ill with fewer complications and less resource use, thereby lowering the environmental footprint of an intensive care unit stay. Initiatives to reduce inappropriate intensive care unit admissions and enhance timely discharge can also be developed using a sustainability lens.

There are a variety of environmental sustainability resources, organisations and events that are relevant to all healthcare areas, including intensive care, such as:

- SusQI Framework – model to embed sustainability within quality improvement to address environmental sustainability, reduce financial cost and add social value while improving healthcare quality with free resources and templates.
- Centre for Sustainable Healthcare – engages healthcare professionals, service users and the wider community to understand better the interconnectivity between health and the environment and work towards reducing healthcare's resource footprint.
- Health Care Without Harm – an international organisation with regional sections for América Latina (Spanish and Portuguese versions), Asia, Europe and US-Canada and publications and resources translated into multiple languages.
- Centre for Sustainable Health Systems – supports research, education, communities of practice, strategic initiatives and events related to promoting sustainable healthcare.
- Nordic Centre for Sustainable Healthcare – brings together stakeholders, organisations and projects to provide a network and platform for promoting ecologically sustainable healthcare.
- Healthcare Ocean – provides advocacy, education and collaboration to reduce the unintentional oceanic damage caused by the procurement and delivery of healthcare.
- WHO Health-care waste – World Health Organization guidance on ensuring safe and sustainable healthcare waste management.

Conclusion

Intensive care units use proportionately excess amounts of energy, consumables, medicines and staff in our care processes, and we generate large amounts of waste. We must recognise how intensive care's environmental footprint contributes to poor planetary health. It is time for environmental sustainability to become an urgent central focus in delivering intensive care services to minimise the damage caused to our environment whilst also providing the best and most appropriate care for the critically ill.

Conflict of interest

There are no conflicts of interest for Dr Jack Parry-Jones. Dr Heather Baid has received grants related to healthcare environmental sustainability from the University of Brighton Rising Stars award, and the British Association of Critical Care Nurses and Research England. ■

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Green ICU-4Ps: It Is Not An Option To Not Accomplish It

The critically ill patient should be framed within sustainable medicine. It is crucial to mitigate the causes so that we do not have to adapt to the undesirable effects of the unsustainability of our clinical practice. We propose a simultaneous approach to sustainability in people, products, processes, and our planet.

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Introduction and Justification

GREEN ICU (GREater ENvironmental sustainability in Intensive Care Units) is a multidisciplinary initiative that aims to develop evidence-based guidelines to reduce the environmental footprint of intensive care practice. Nowadays, we need a sustainable approach to our critical patient care that reduces the environmental impact of an ICU.

According to the Brundtlandt Report (1987), sustainable development is development that meets the requirements of the present generation without jeopardising the needs of future generations. Being aware of the scarcity of energy, resources and ecological footprint that measures the impact of our health activity is necessary to initiate any sustainability strategy.

Thirty-six years after Brundtlandt's definition, the danger is not only for future generations but also for current generations. Air pollution is the fifth most frequent cause of mortality worldwide: 4.2 million deaths/year (Schraufnagel et al. 2019). The main pollutants are sulphur dioxide, nitrogen oxide and volatile organic compounds.

A variety of strategies are included in sustainable medicine to lessen our effect on the environment: reducing our greenhouse gas emissions, water pollution, ecotoxicity, and social and economic impact. To prevent worse things from happening, just like with our patients, the main thing is to do no harm, including to our planet (Fang 2022).

The reality is that there is a problem of lack of sustainability in our health services, hospitals, and ICUs. Healthcare accounts for 5% of the world's GHGs. If healthcare were a nation, it would be the fifth largest GHG nation (Lenzen 2020).

It has been quantified that 30% of our clinical care is low value which would pollute without any health benefit (Barratt 2022). We, the professionals who care for each of our critical patients, are the guarantors of solving this. Therein lies another problem: our lack of regular updates on what we need to know to be part of the solution.

The impact on the environment is analysed through:

A. Medical care. Expenditure, energy use of facilities and type of care.
B. Life cycle analysis (LCA) or cradle-to-grave analysis. Analyses the environmental impact of natural resource extraction, manufacturing, packaging, transport, use/reuse and recycling/disposal of product or process waste (McGain 2018).
C. Material flow analysis (MFA). Quantifies material and waste flows entering and exiting the system defined in a given space (patient admitted to ICU) and time (day), with identification of environmental hot spots in ICU that require urgent efforts with opportunities for sustainable innovation.
D. The carbon footprint, which represents the total volume of greenhouse gases (GHG: CO_2, methane, nitrous oxide, others) produced by our activity, measured in CO_2 emissions. As an indicator of this footprint, we use CO_2 emissions or Carbon Dioxide Equivalent (CO_2e). Its calculation helps an organisation to know its impact on the climate.
E. Identifying the impact of the way we dispose of our waste.

In the following section, we present studies with different approaches that aim to objectify the environmental impact of our professional activity with data on the previously listed points.

A. Medical Care

Healthcare and the associated expenditure vary greatly from country to country. In the U.S., it is more than 17% of GDP. A higher carbon footprint can be inferred from higher spending on healthcare. In the U.S., healthcare accounts for 10% GHG of the national total (Matthew 2020). In Australia and European countries, it is 7% (Malik 2018). The hospital and pharmaceutical sectors have the largest combined footprint (60%). This carbon footprint in the hospital sector was observed in a study in the U.K., which attributed 20% to buildings (electricity and gas) and 80% to clinical care (Tennison 2021).

Regarding hospitals as well as buildings, they consume 40% of the planet's materials, 30% of its energy and generate 20% of the solid waste stream. The ICUs of our hospitals, as structurally individual departments, can receive regular information on their energy expenditure with the aim of reducing energy and water use and initiating strategies with technicians and administrators.

Regarding healthcare, expenditure, and GHGs, they do not imply better outcomes and life expectancy (Bein 2023). It has also been studied how much of the GHG emitted would be avoidable. It was assessed that 10% of medical care is harmful, and 30% is low-value care (Barratt 2022). Reducing iatrogenesis and increasing adherence to "do not do" recommendations reduces burdens on the patient, expenditure, and the environment (Bein 2023).

Indeed, the deterioration of health caused by the unsustainability of the system perpetuates itself. Healthcare services themselves deal with a greater number of pathologies related to climate change, which leads to greater production of GHGs due to this new workload (Salas 2019; Sherman 2021).

B. Life Cycle Analysis

In healthcare and in our ICUs, a wide variety and quantity of materials enter, are used, and disposed of, each with its own life cycle (LCA) and environmental impact. Between 2005 and 2020, the use of disposable materials has more than doubled, and the use of PPE during the COVID-19 pandemic has exacerbated this (Statista 2022).

ReCiPe is a method that assesses LCA developed in 2008 through cooperation between Radboud University Nijmegen, Leiden University and PRé Sustainability. It aims to transform our huge inventory of various life cycles into a limited number of indicators. ReCiPe 2016 is an improvement of ReCiPe 2008 (and its predecessors CML 2000 and Eco-indicator 99). This method is updated (by Radboud University) to incorporate new data and research.

The scoring of these indicators expresses the relative severity in an environmental impact category. In ReCiPe they divide the indicators into 18 mid-point indicators and three end-point indicators. Each item is also evaluated according to its temporality, management expectations or technological progress. The ReCiPe framework includes advantages such as the use of global impact mechanisms, consensus modelling and long-term thinking based on the precautionary principle.

C. Material Flow Analysis

ICUs are a major contributor to CO_2 emissions (Hunfeld 2022). They conducted a material mass flow analysis (MFA) in a university ICU in Rotterdam in 2019. The MFA was measured by analysing inputs and outputs of the ICU throughout the year in kilograms, average number of products used x number of patients/day and mass in kg of materials used per patient/day. The study was followed by an environmental footprint analysis. The secondary objectives of this study were to obtain data on mass, carbon footprint, water use and to determine the environmental hotspots in an ICU. The study, during which 2,839 patients were admitted in 2019, with an average stay of 4.6 days, showed an MFA of 247,000 kg during their ICU stay. Of this MFA, 50,000 kg was incinerated as hospital hazardous waste. The environmental impact per patient resulted in 17 kg of mass, 12 kg CO_2e, 300 L of water use and 4 m^2 of agricultural land occupation per day.

Five critical points were identified in this study: non-sterile gloves, isolation gowns, bed protectors, surgical masks and syringes (including packaging).

With this material flow analysis, it is clear that carbon net zero does not equate to zero environmental impact. Every day, pharmaceuticals and consumables that cause ecological damage and GHG emissions are used and wasted (Grand View Research 2021). Therefore, it is important to stress that there are processes with advantages over others (recycling compared to manufacturing), but they all have a negative effect. Furthermore, the best way to reduce the damage to the planet is to reduce consumption.

D. Carbon Footprint

In our daily lives, we should reach carbon neutrality, which is achieved when the same amount of carbon dioxide (CO_2) is emitted into the atmosphere as is removed from it in different ways, which is called a zero carbon footprint. The current carbon footprint is mainly derived from human use. The first cause is fossil fuel combustion, and the second cause is deforestation. In addition, we generate a carbon footprint when we use products and when we dispose of them. Also, we far exceed our GHG generation in relation to the earth's capacity to buffer it.

We release pollutants into the air, either directly from the source or secondary to the interaction between different compounds in the atmosphere (ozone of nitrogen oxides in the presence of sunlight). Our biological stores of carbon are the oceans and forests. The Amazon rainforest stores up to 200 billion tonnes of carbon. However, 20% of its area has been deforested in the last 60 years, and it is still increasing exponentially. The causes of this are agriculture (soy: the main component of propofol, palm), oil, droughts, and fires caused by climate change (D'Amato et al. 2017).

To help us understand ourselves and initiate decarbonisation and ecological transition, we can use ScopeCO_2 (at sanidadporelclima.es; free online tool), which calculates our carbon emissions, also from hospitals. In this tool, GHGs are calculated from the activity data entered by the user for the year of calculation. It distinguishes between emissions generated in sources owned and controlled by the healthcare institution, associated with electricity consumption purchased from the energy producer, and others, for example, generated by staff travel or patient transfer services.

In this tool, emission factors of the type of kg of CO_2 per kWh of electricity consumed are applied, following the international GHG Protocol methodology and with data from the Spanish Climate Change Office (Ministry for Ecological Transition and the Demographic Challenge) and the National Commission for Markets and Competition for electricity.

The carbon footprint of the health sector is equivalent to 4% of global net emissions (McGain et al. 2020). In Spain, the ecological footprint is 2.6 times higher than the sustainable footprint. But improvement is possible. The U.K. NHS has achieved a reduction in its carbon footprint of 580 kt CO_2e by 2021 (NHS 2020).

To help reduce this impact, fifty countries - Spain among them - committed at COP26 to developing climate-resilient, low-carbon health systems (COP26 Health Programme). Of these, forty-five committed to transforming their health systems to make them more sustainable and reduce their emissions. Fourteen countries even set 2050 as the target date for GHG=Zero.

The platform that brings together health actors committed to tackling the climate emergency is Health#ForTheClimate. Its aim is to help reduce the sector's carbon footprint and achieve carbon neutrality by 2050. This initiative is part of Community#ForTheClimate, a multidisciplinary platform with the aim of implementing the Paris Agreement and which has the support of ECODES, the company MSD and the collaboration of the social responsibility healthcare network.

E. Waste Disposal

Identifying the impact of the way we dispose of our waste. The scale of the problem is enormous. The NHS generated 624,000 tonnes of waste between April/19 and March/2020. Although ICU waste has not been systematically quantified, approximately 50% could be recyclable (McGain 2009). At the NHS level (Silva et al. 2021), 47% of waste was incinerated, 16% was recycled, 7% went to landfill, and the remainder underwent alternative treatments. Since the COVID-19 pandemic, medical waste has increased by up to 350% in some countries, mainly from plastic personal protective equipment (PPE).

Incineration does not completely destroy the waste and leads to further contamination of air, water and soil (Fang 2022). Studies have shown higher rates of cancer and perinatal defects in communities around waste incinerators (Thompson 2008).

Wastewater treatment plants are not designed to remove pharmaceuticals. Products are discharged into water (they have even been detected in drinking water) or used as agricultural fertiliser. According to the Swedish Chemical Agency, the environmental impact on water of these discharges depends on three factors of the products or pharmaceuticals: persistence (ability to resist degradation), bioaccumulation (in the fatty tissue of aquatic animals) and toxicity (potential harm). The impact of these factors on everyday drugs such as propofol (Mankes 2012; Favetta 2002), opioids, antibiotics (Gothwal 2015), lido and bupivacaine, sugammadex and paracetamol has been studied with disappointing findings. In that study, hazardous materials such as cadmium, chromium, dioxins, polycyclic aromatic hydrocarbons, BTEX compounds, sulphur dioxide, nitrogen oxide, etc., which are thrown away, have been found to cause, through ingestion, inhalation or topical absorption: respiratory, cardiovascular, gastrointestinal, renal and nervous system diseases. Plastic, despite its recycling, remains plastic, only decreasing its size or deteriorating its quality. Only paper has less impact, but its recycling is also associated with air and water pollution.

Special attention should be paid to the fact that 90% of oral medicines (mainly antibiotics and antidepressants prescribed on an outpatient basis) are excreted in wastewater as active substances (original dosage form or metabolites) via the faeces and urine of patients. As for the disposal of antibiotics, since wastewater is rich in nutrients and bacteria, this type of waste can lead to the development of antibiotic-resistant strains. This causes more than 33,000 deaths and the loss of more than 874,000 disability-adjusted life years/year in Europe (Cassini 2019). This will worsen with antibiotic resistance genes already detected in environmental samples.

In addition, detergents of hospital laundries also contribute to environmental damage (Fang 2022). These products have surfactants (which damage fish gills and increase vulnerability to toxins), phosphate (already banned), EDTA (which increases the bioavailability of heavy materials) or bleaching agents (hydrogen peroxide is biocidal).

The last step for any product may be landfilling, even after recycling it or treated in waste plants or incinerated. Landfills have been associated with public health risks. Methane, CO_2, nitrogenous products, heavy metals, and bioaerosols (fungi, enterobacteria, endotoxins) can, through their contamination of soil, water and air, cause rhinitis, asthmatic flare-ups, and infections (Health Protection Agency 2011).

What is crucial is prevention, prioritising the least (Royal College of Anaesthetics 2022) and best first use. The impact of disposing of used items is impossible to be harmless nowadays. This is the reason for the COP26 Health Programme. In addition, in Latin America, the Health Care Without Harm Programme works to transform the global health sector to be ecologically sustainable and promote environmental health and justice, highlighting in 2022 the initiative "Hospitals that heal the planet".

In Madrid, the Santa Cristina Hospital achieved full quality and environmental certification for all its processes in March 2022 with the development of a Management System based on the ISO 14001:2015 standard, minimising its impact on the environment and collaborating in the sustainability of its surroundings based on energy efficiency, water consumption and proper waste segregation. Its objectives include implementing legal recommendations and requirements, pollution prevention, sustainable use of resources, energy efficiency programmes, environmental commitment with its suppliers and promoting training for continuous environmental improvement.

The Hospital Universitario del Henares was inaugurated in 2008, with a polyvalent ICU which, following the COVID-19 pandemic, has sixteen structural beds. Its construction provided it with natural light, and it was defined as a paperless hospital. During the COVID-19 pandemic, we were overwhelmed by the large amount of waste from patient care. In the aftermath, we felt it was the ideal time to optimise our clinical practice for more sustainable critical patient care. Nevertheless, at the moment, all ICUs have in common several intrinsic aspects in their activity that make it difficult to achieve a GREEN ICU:

- Increased number of diagnostic and therapeutic procedures, especially in high-tech ICUs, which may even generate more GHGs without necessarily improving mortality, prognosis or patient comfort.

PRODUCTS	PROCESSES	PEOPLE	PLANET
• Use fewer products	• Achieve more with less	• Healthcare professionals	• Reduce
• Use better products	• Early detection	• Patient	• Reuse
• Better use of products	• Better healthcare	• Family and society	• Recycle

Table 1. ICU-4P's and their approaches

- Increased average life expectancy and comorbidity of our patients.
- Continuous activity of staff, resource use, and energy demands.

Knowing each other is essential to find solutions. We have already come a long way. The Drawdown Report (drawdown.org) is an international initiative launched by climate change scientists. It considers the hundred most practical options that, if implemented, may halt climate change in just one generation. There have been proposals for solutions focused on critical patient care for more than a decade (Chapman 2011) and even studies on it (Baid 2020). However, we need to have at hand a sustainability kit for our ICUs along the lines of those already developed by the Australian and New Zealand Intensive Care Society (ANZICS 2022). They are a guide for intensivists who want practical measures to reduce the carbon footprint of our ICUs. We present our approach where medical and environmental ethics walk hand in hand (MacNeill 2021).

Goals

The characteristics of our objectives are that they must be agreed upon, assumed by all, focused on the long term, with a real impact, and with a local and global scope with the aim of moving from a linear to a circular system and integrated into our work and personal identity.

- **Primary objective:** to train professionals who work in critical patient care and develop strategies to reduce the environmental impact of a sixteen-bed polyvalent ICU.
- **Secondary objectives:** focused on the 4Ps to cure and care for our planet, people must act on themselves, on the products and processes of critical patient care.
  - Products
  - Processes
  - People
  - Planet

Management: Research, Training, and Clinical Practice for a Sustainable ICU

The approach to the analysis of our situation must be holistic and integral, with the participation of the whole team and the evaluation of processes and results. This great complexity is an enormous opportunity to work together on different variables without having to use differentiated strategies that may conflict.

For an ICU to be sustainable, it needs measures to prevent its carbon footprint, resource use and waste management. It also needs to apply broader and broader concepts. Moving from the best available evidence-based medicine, having added patient-based medicine and now it is also time for planet-based medicine. A planet-based medicine that needs the 10 Rs: reject, rethink, reduce, reuse, repair, refurbish, remanufacture, reuse, recycle and recover.

A sustainable ICU is a concept of a non-linear but cyclical development. It is based on a dynamic equilibrium that allows self-regulation and feedback. According to the principle of subsidiarity, problems should be solved as close as possible to their source. This is where we are on the front line in our ICUs.

We need to know, through subsequent research and training, what to measure and how to solve each step of our clinical practice in a GREEN ICU. Following the secondary objectives set out above, we are going to order our suggestions for sustainability without implying this as an order of priorities.

Products

Use fewer products

- Less use of raw materials in their manufacture (**Table 2**) (Fang 2022).

Metals	Plastics
Stainless steel (cannulas, needles, and laryngoscope blades) contaminates through coke (fuel with high carbon content). It emits naphthalene, ammonium, and sulphur compounds. In addition, stainless steel contains 10-20% chromium, which impairs photosynthesis and is associated with respiratory diseases, neurological damage, and tumours (Ukhurebor 2021).	Ethylene and propylene are extracted by fracking, which produces wastewater containing salts, organic matter, and radioactive materials. According to the U.S. Environmental Protection Agency, there is an increased need for hospitalisation for cancer, neurotoxicity, liver damage, kidney damage, and foetal development.
Titanium releases radionuclides, contaminates groundwater and has toxicity from the chlorine used for cleaning.	Processing fossil fuels to produce plastic resins releases carcinogens and nerve agents.
Cobalt used in surgical implants and batteries is 60% mined in the Republic of Congo, with no respect for even human rights in its extraction (Amnesty International 2016).	Most of the environmental impact of plastics happens after use. Both in the form of macro and microplastics.

Table 2. Reasons for using less raw materials

- Reduced use of single-use equipment. Gloves are the largest single-use product. Latex gloves contribute to deforestation because they require rubber. On the other hand, nitrile gloves are made from a petroleum-derived copolymer of acrylonitrile and butadiene. Highlight the GOSHs Gloves Off Campaign of the Great Ormond Street Hospital for children (NHS) with its mission to encourage health professionals to reduce the unnecessary use of non-sterile gloves.
- Fewer products, less local carbon emission from the energy in their manufacture.
- Reduced need for transport, reduced GHG emissions. NHS-related road transport is responsible for 3.5% of all journeys in England. It accounts for 7,285 tonnes of nitric oxide/year and 330 tonnes of particulate matter, mostly less than MW 2.5 (NHS 2020). Air pollution leads to 40,000 deaths per year in the U.K. so NHS-related transport could be responsible for 1,400 of those deaths (Royal College of Physicians 2016).
- Lower MDR rate, reduced need for isolations and rationalisation of the use of drugs, gowns, and gloves.

Use better products

- Purchase more energy-efficient technology and products.
- Ensure suppliers manufacture products and drugs (e.g., propofol) ethically and sustainably.
- Evaluate with manufacturers to remove redundant parts

from devices already packaged as a set for use.
- Longer-lasting batteries, less polluting in their manufacture and disposal.
- Local products with a smaller ecological footprint in their transport due to the distance and means of transport.
- Use of bronchodilator inhalers, etc. with a lower carbon footprint.
- Use of drugs in more concentrated formulations.
- Purchase reusable versus single-use equipment. There are NIV face interface LCAs, breathing circuits, dressing boxes, bed linen.
- Plastic-free packaging.

Better use of products
- Adapt stocks to consumption of both medication and materials to avoid expiry.
- Better treatment of equipment that is used and can be repaired in situ by a biomedical engineer in a short period of time.
- Avoid using medicines, monitoring, and vascular accesses with little value in the healing process of that disease.
- Protocol cleaning of filters to improve air quality.
- Use perfusions that come from other places of care other than the ICU.
- Manufacture products with alternative substances to plastic.

Processes

Achieving more with less
- Digitalisation and use of intelligent technologies.
- Streamlining our processes: individualised protocols for each hospital and patient.
- Informed consent for admission and other techniques, data protection document without needing to sign them on paper. Transmission from the patient's unit or family information room with an electronic document holder via Wi-Fi to a SELENE form (our computer programme).
- Request for blood products with the double check on the form or consult the SELENE blood bank to avoid the use of paper.
- Individualisation of the need for consumables and diagnostic tests, both analytical and radiological tests.
- Individualised monitoring needs. Night mode of screens to save energy.
- 'Choose wisely' initiative: consider useful measures daily, rethink therapeutic objectives and in accordance with the patient's wishes (Auriemma 2019). Recommendations NOT TO DO in both adults and paediatrics (SEMICYUC 2019-Hernandez 2023).

Early detection
- Early detection of patients at risk, fewer ICU admissions due to optimisation of management on the ward or earlier admissions in ICU resulting in shorter stays due to less pre-ICU deterioration, and fewer readmissions due to post-ICU surveillance. The above, thanks to HEWS-type programmes (Abella 2023), would lead to lower resource consumption and waste generation.
- Early detection of MMR would lead to avoiding outbreaks with the consequent lower consumption of resources and generation of waste derived from the necessary isolations.
- Early detection of professional burnout with an adequate professional ratio to help continuous process improvement.

Better health care
- Training in our generated environmental effects and strategies to minimise them.
- Doing our healthcare right the first time: diagnosis, choice of antibiotics, surgery, avoiding malnutrition, etc. (Fang 2022). This would avoid complications, increased length of stay, waste, and costs.
- Digitalisation with access to data from other healthcare centres.
- Optimising monitoring and transmission of all possible data to the P.C. in the unit or via Wi-Fi of isolated patients in the ICU. These would avoid the use of gowns, gloves, etc., by avoiding the need to enter.
- Accurately predict the drugs amounts and which drugs we are going to use in our actions.
- Preventing the acquisition of new disease processes other than those that have led to their admission (**Table 3**).
- Improve information transmission (I.T.) to avoid duplication, errors or readmissions at the time of I.T. on transfer to the ward.
- Better menus adapted to disease and type of patient to avoid food wastage.
- Fewer changes in home treatment patterns and quicker reconciliation.

Persons

Health professionals
- Approach by healthcare professionals (Bein 2021) legal regulations and policies with a three-pronged strategy: ecological, social, and financial.

Less infections with UTI campaigns, pneumonia, bacteraemia zero to avoid use of more resources (in their microbiological diagnosis, treatment, and ICU stays)	Individualise daily sedation and NMB, fewer days of MV, less critical patient weakness
DDS to avoid VAP	Start early rehabilitation, to avoid deconditioning or appearance of sore ulcers
Discontinue/de-escalate antibiotics to avoid MMR or possibility of *C. difficile* (same with omeprazole)	Dilute in fewer mL I.V.s to avoid both cost and water overload
Controlled indication of certain devices that could be elective, e.g., bladder catheter	Prevention of nephrotoxicity with optimal nephrotoxic titration with levels of nephrotoxic drugs

Table 3. Preventing the acquisition of new disease processes

- Creation of "Green teams" with bottom-up initiatives (Bein 2023). Lead for coordinated work, being a collaborative and interprofessional work.
- Reducing therapeutic futility (Bein 2023). Intensive care interventions that prolong life without achieving effective patient-centred care are futile. Futile treatment brings harm to patients and caregivers, to the payer/taxpayer and to our environment. Ethical, ecological, and best clinical practice principles are often synonymous. Futility undermines human dignity and ecological ethics.
- Detection of areas for improvement in our daily life as hot spots (**Table 4**).
- On-call pass: optimising times for assistance and optimising transmission of information. (Salinas 2022)
- Zero waste in the staff room (reusable cups and bottles).
- Minimise staff travels.
- Calculate personal carbon footprint. Training and evaluation with CME/CPD activities for BJA Education subscribers.

Patients, families, and society

- The decision to admit or not a patient to ICU leaves its footprint on the planet either by promoting health (in the case of an appropriate and timely admission) or by deciding not to admit a patient in the case of futility, in the context of "non-maleficence" by avoiding further carbon footprint, waste, expense etc.
- Promote public health to reduce the need for healthcare or use of pharmaceuticals (Bein 2023). Educate on healthy lifestyles. Actively involve patients and families in the prevention of chronic and acute diseases (pandemics).
- Optimise preoperative and postoperative care (Lobo 2020), promote adherence to the Stockholm 'Wise List' of treatments, and not prescribe non-recommended treatments (Eriksen 2017).
- Family and patient education in self-care (diabetes, CVC, stomas, tracheostomies).
- Knowing what or how far a patient wants to be cared for (Popovich 2023), with shared decision-making. Matching patient and family expectations. Consult or offer the possibility of issuing advance directives.

Early identification of delirium, physical deconditioning, and malnutrition	Optimising the use of consumables: number of gloves, gowns, soakers, etc., used per shift
Non-punitive and standardised report of adverse events and immediate registration for immediate resolution in the short term and avoidance in the medium/long term	Reduce the volume of blood drawn for blood tests, which would reduce the need for blood products
Indicate pharmacological and non-pharmacological treatments, monitoring, sustainable diagnostic and therapeutic techniques	Measures to avoid transmission of transmissible diseases with patients: needles with covers; with other professionals: adequate rest areas; vaccination

Table 4: Detecting hot spots

- Accessibility, by using public transport to visit relatives in the hospital or for medical consultations.

Planet

The planet needs ecological management of the energy, waste, and consumables we use in our daily practice. The 10 R's stand for reject, rethink, reduce, reuse, repair, refurbish, remanufacture, reuse, recycle and recover. Globally, medical waste accounts for 4% of all plastic waste. During the COVID-19 pandemic, it accounted for 23% of total NHS waste. For a practical approach, we will break it down into the mantra (Bein 2023) of first, reduce waste; second, reuse if possible; and third, recycle.

Reduce

- Transition from carbonised energy systems to renewables to achieve an energy refurbishment of our buildings.
- Energy efficiency, reduction, and responsible use of energy (**Table 5**) (Hufing 2014).

Reduction of:

- Machines. MV-NIV devices and other machines with the best energy rating. Innovative technologies that cover a real need. Not being hostage to programmed obsolescence. Biomedical engineer available to make repairs.
- Fungibles: less waste generation by reducing the use of gloves and gowns.
- The type of packaging of our products.
- Paper and recycle, information to relatives on large posters at the entrance and Q.R. reading with instructions for visits, etc.
- Protocols and instructions for equipment, accessible by reading Q.R. codes or training pills in the hospital's continuous training app.

Reuse

- Circular management from fibrobronchoscopes, dressing boxes, NIV interfaces to packaging.
- Maximise the reuse of laundry linen for the same or other purposes.

Recycle

- "SIGRE point" SIGRE (non-profit entity in charge of guaranteeing the correct environmental management of the containers and remains of medicines that are generated

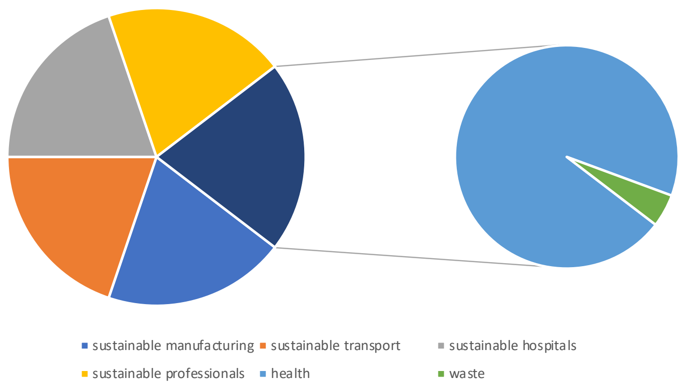

Figure 1. Green teams as a projection of a sustainability chain

Lighting: ICU design; more natural light from windows and non-lower floors, less use of artificial light and can be adapted to ambient light, change to LED lights, electricity from solar panels or other renewable energy.	Ventilation and air conditioning. Power-up and down ICU air exchange rates according to differing ICU patient numbers, and power down unoccupied single-use/ negative pressure rooms.
Heating: individual thermostats, doors closed, less loss of heat/ cold needed in the unit.	Transfers and electric car charging points in the garage to reduce fossil fuel consumption.

Table 5. Reduction and responsible use of energy

in homes). Launched in 2001, the result of collaboration between the pharmaceutical industry, pharmacies, and pharmaceutical distribution companies, to be an effective and efficient model for medicines in solid or liquid formulations following safe disposal protocols, especially for antibiotics.

- Differentiated disposal in containers for glass, paper/card-board, plastic, organic, batteries, and toners.
- Safe disposal of toxic materials, biohazardous materials, sharps, etc.
- Safe disposal of stool, diuresis (especially 24 hours after administration of contrasts), and patient bleeding, by means of appropriate filtering and treatment prior to disposal.
- Use of biodegradable materials
- Safe incineration

Conclusion

People have created the problem, and people must commit themselves to solving it. It is an ambitious plan that requires a mobilised society because of the scale of this crisis to be able to solve it successfully. Healthcare professionals, in addition to caring for our patients, can care for our planet in our day-to-day work by developing zero-carbon ICUs immersed in sustainable, more efficient, and cost-effective healthcare systems. There should be no ethical dilemma between the beneficence of health promotion and the non-maleficence of avoiding the deterioration of our planet.

We must plan and execute better processes to bring about real change in the quality of life for present and future generations in balance with the planet. To maintain that balance, we must move towards this shared goal. It is not an option to not accomplish it.

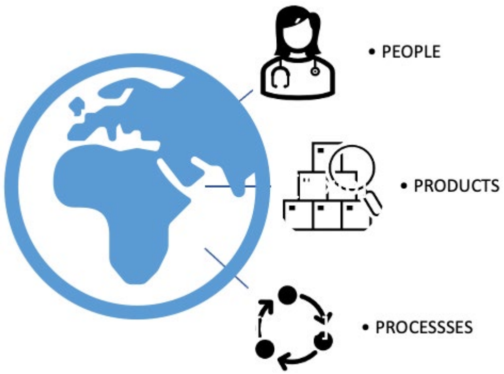

Figure 2. ICU-4P´s: Planet, people, processes, and products

Conflict of Interest

None. ■

Abbreviations

ANZICS: Australian and New Zealand Intensive Care Society
BTEX: benzene, toluene, ethylbenzene, and xylene.
CME/CPD: Continuing Medical Education/ Continuing Professional Development
CO_2: carbon dioxide
CO_2e: Carbon Dioxide Equivalent
CVC: central venous catheter
EDTA: Ethylenediaminetetraacetic acid
GHGs: Greenhouse gases
GOSHs: Gloves Off Campaign of the Great Ormond Street Hospital
GREEN ICU: GREater ENvironmental sustainability in Intensive Care Units
HEWS: Henares early warning score.
ICU: Intensive Care Unit
ISO: International Organization for Standardization
LCA: Life cycle analysis
LED: Light-emitting diode
MDR/MRO: Multidrug-resistant Organisms
MFA: Material flow analysis
MV: Mechanical Ventilation
M.W.: molecular weight
NHS: National Health Service
NIV: Non-invasive ventilation
NMB: Neuromuscular Blockade
PPE: Personal Protective Equipment
SDD: Selective Decontamination of the Digestive tract
UTI: Urinary Tract Infection
VAP: Ventilator-associated Pneumonia

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Call for a Green ICU

Intensive care units are carbon hotspots that contribute three times the GHG emissions as acute care units per bed day. Clinical staff must be aware of GHG production's impact and potential mitigations. This article summarises key points and initiatives to make this happen.

Healthcare contributes approximately 5% of worldwide greenhouse gas (GHG) production (Lenzen et al. 2020). Some regional variation exists. For instance, in the United States, the carbon footprint of the healthcare system is approximately 10% of the national GHG emissions compared to 7% in Australia (Eckelman et al. 2020; Malik et al. 2018). Within healthcare systems, hospitals and pharmaceutical sectors combined have the largest carbon footprint (approximately 60%), and within hospitals, intensive care units (ICUs) are carbon hotspots contributing three times the GHG emissions as acute care units per bed day (Prasad et al. 2022). The reasons are high staff activity, high use of technical and non-technical resources, and high energy demands. Further, approximately 10% of healthcare is considered harmful, and 30% is low-value care (Barratt et al. 2022), and yet they contribute to GHG emissions.

It is vital for clinical staff to be aware of the impact of GHG production and potential mitigations. Very timely, the journal Intensive Care Medicine launched a new series, "My Green ICU", led by Professor T Bein and Professor F McGain (Bein and McGain 2023). In their introductory editorial, they highlighted several important points and initiatives:

1. Green Teams

The development of integrated, multifaceted, collegial 'Green teams' in ICU has proven to be very successful and integral to sustainability (Trent et al. 2023; Huffling and Schenk 2014). Such initiatives often started with one or two individuals who addressed a particular issue (e.g. use of gloves, cessation of intravenous antibiotics) and then expanded to larger teams and sometimes up to hospital administrators and beyond (bottom-up approach). Where implemented, they have been shown to be vital to harnessing employee expertise, motivating, educating and finding new and better ways to a more sustainable practice (Trent et al. 2023).

> **the development of integrated, multifaceted, collegial Green teams in ICU has proven to be very successful and integral to sustainability**

2. Reduction of Energy Use

In general, a significant long-term reduction of the intensive care carbon footprint will be achieved by preventing serious illnesses and reducing people's need for ICU admission. Thus, preventive medicine per se is an important strategy towards sustainability. In addition, ICUs should be provided with regular information on their energy expenditure, from heating, lighting and ventilation to air-conditioning (Bein and McGain 2023). This offers opportunities to identify both initiatives to save energy and water and strategies to reduce waste. Patient care may improve, too. For instance, there is a correlation between noise levels and sleep disturbance and ICU delirium.

3. Life Cycle Assessments

Life cycle assessments (LCAs) are scientific methods to analyse the environmental and financial footprints of products and processes (Bein and McGain 2023). LCAs already exist for specific ICU devices, e.g. face masks and breathing circuits, and also for ICU medications but should be routinely undertaken. As an example, changes in supply stocking resulted in an 80% reduction in the amount of unused equipment waste in a 16-bed ICU in Canada (Yu and Baharmand 2021).

4. ICU Recycling

Quantification of total ICU waste has not been systematically investigated, but data from specific areas exist. For instance, half of the drugs drawn up for emergencies end up being discarded unused (Atcheson et al. 2016). Further, it is estimated that approximately 50% of waste could be recyclable (McGain et al. 2009). The introduction of recycling stations and improved waste practices in a 14-bed ICU in Australia resulted in 5 tonnes of comingled resources to be diverted from landfill (Department of Health and Human Services, Melbourne, Victoria 2016)

5. Less is More

A 'less is more' philosophy has been advocated in recent years, including calls for daily consideration of measures to de-escalate therapies, prescription of sensible therapeutic goals, and avoidance of inappropriate tests and therapies (Department of Health and Human Services, Melbourne Victoria 2016; Singer 2022; Darmon et al. 2019; Zampieri and Einav 2019). To achieve this, regular audits of clinical practice are needed to evaluate compliance with the latest evidence and standards. Further, more research and scientific evidence are required to identify ''less of what", for instance, to support a transition from over-testing and over-treating to effective and appropriate testing and treating, in line with more sustainable clinical practice (Darmon et al. 2019).

6. Avoidance of Futility

Critical care interventions that prolong life without achieving effective patient-centred care are considered futile and expensive. Avoidance of futile treatment is beneficial, saves money that can be used to support other patients, and is climate protective (Bein and McGain 2023).

The "My Green ICU" series in Intensive Care Medicine serves to encourage all healthcare staff, particularly those who work in the ICU, to join the race to zero carbon emissions and to promote planetary health as a framework for sustainable health systems (Bein and McGain 2023).

Conflict of Interest

None. ■

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Carbon Footprint in ICU: A New Meaningful Outcome in Research Trials

Reducing the carbon footprint in healthcare is a requirement for guaranteeing the best future for humanity. Here we suggest that the carbon footprint be assessed as a potential endpoint for future trials in critical care.

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Environmental Impact in Critical Care

The climate crisis is a threat to global health. The temperature of the atmosphere has been rising exponentially since the industrial revolution due to anthropogenic greenhouse gas emissions. The Intergovernmental Panel on Climate Change special report estimates that a drastic reduction in these emissions is required to limit global warming and its consequences on human health. The Paris Agreement, which was signed in 2015 proposed to limit warming in 2050 to +1.5°C compared to the pre-industrial era.

While the Hippocratic oath to "first do no harm" guides physician practice, the healthcare system is a major contributor to climate change (Lenzen et al. 2020). In industrialised countries, it is responsible for 3 to 10% of national greenhouse gas emissions. The carbon footprint of health systems should be calculated in each country in order to implement targeted measures to reduce it (Booth 2022). An Australian study performed from 2014 to 2015 highlighted that the carbon footprint attributed to healthcare in Australia was 7% (Malik et al. 2022). This covers a broad range of activities such as building supplies, patient travel, staff commute, medicines and chemicals, medical devices, non-medical equipment, and other supply chain actions. NHS England estimated that pharmaceuticals and medical devices represented around 20% and 10% of the total carbon footprint of their healthcare system (NHS England 2020).

The reference unit used to account for greenhouse gas emissions is the carbon dioxide (CO_2) equivalent (CO_2-e). This corresponds to the warming power of each greenhouse gas relative to CO_2, which is the reference gas. In the hospital, efforts are required in all sectors. In the operating room, halogenated gases are strong producers of greenhouse gas emissions. Chambrin et al. showed that the setup of sustainable anaesthesia groups, providing information meetings about the carbon footprint of inhaled halogenated anaesthetics, was associated with a significant decrease in the carbon footprint related to halogenated anaesthetics (Chambrin et al. 2023). In the field of pulmonary diseases, the change in pressurised metered dose inhalers provided better treatment and outcomes while reducing greenhouse gas emissions (Pernigotti et al. 2021).

Intensive care units (ICUs) are important consumers of material and energy resources. Their greenhouse gas emissions are thus particularly high, representing, in an observational study conducted in a U.S. hospital, 1% of the hospital total by relative staffing intensity (Prasad et al. 2022). In a study of patients in septic shock, McGain et al. (2018) calculated the average daily greenhouse gas emissions in ICUs at Barnes Jewish Hospital, St. Louis, MO, U.S. and Footscray Hospital, Melbourne, Vic, Australia (McGain et al. 2018). They found that the daily greenhouse gas emissions were 178 kg CO_2-e and 88 kg CO_2-e in the U.S. and Australian ICUs, respectively. They concluded that the carbon footprints of the ICUs were mainly dependent on the energy used for heating, ventilation and air conditioning. Another estimate of the carbon footprint in a U.S. hospital showed 138 kg CO_2-e per bed day for ICU patients (Prasad et al. 2022). This corresponds to the emissions of a car driven 500 to 1000 km per patient per day (**Figure 1**). This made consumables, which have been regarded in non-ICU studies, relatively less important in this setting.

Beyond CO_2, other environmental factors should be considered: air, soil and water pollution, ecotoxicity of drugs, and excessive water consumption. In an ICU of a U.S. hospital, it was calculated that 300L of water usage and 4 m^2 of agricultural land occupation were used per patient and per day (Hunfeld et al. 2023). Five practices were clearly identified as having a strong impact on the environment: non-sterile gloves, isolation gowns, bed liners, surgical masks and syringes. Regarding those multiple categories of pollution, decision-makers have to rank their importance and choose their poison. As climate change is an existential risk to each of us, it has been ranked as the impact category of greatest concern in a long-term perspective. At a time of climate crisis, we consider that this impact should no longer be ignored when evaluating our practices (Muret et al. 2019). The scientific literature should include it as an outcome in its own right.

Figure 1. One day in the ICU corresponds to the carbon footprint of a car driven at a range of 500 to 1000 km per patient

Towards a New Meaningful Outcome in Clinical Research

Clinical research needs to assess procedures, treatments, and strategies based on defined outcomes. For critically ill patients, mortality – in-ICU, in-hospital, at day-28, at day-90 – is the most often measured outcome. In a recent study, ICU mortality was approximately 20%, with an additional mortality rate of 17% in the year after ICU discharge, making this outcome really accurate (Atramont et al. 2019). However, other outcomes can also be relevant. Indeed, quality of life may be impaired after surviving a critical illness; hence, quality of life should be considered among potential outcomes in ICU patients (Herridge and Azoulay 2023). To integrate this aspect in the analysis of outcomes, days at home could be considered an important patient-centred outcome in future critical care trials (Martin et al. 2023). For specific treatments, procedures or strategies, the measure of costs of the ICU stay, under the labelling pharmaco-economic studies, served as an outcome (Oude Lansink-Hartgring et al. 2023). The choice between two strategies that are similar in terms of clinical outcomes may be driven by a reduction in costs associated with one of these strategies.

In our view, the carbon footprint of an ICU stay - actually, the carbon footprint of each treatment or procedure during an ICU stay - should be considered as a potential outcome in future critical care trials to affect the medical decision. A think tank - the Shift Project - suggested that the purchase of pharmaceuticals and medical devices should be based on the least environmental impact for a similar level of quality of care. This would make it possible to choose the same quality of care and the most efficient strategy in terms of the environment.

In medical ethics, two different approaches help guide medical decisions. In the deontological approach, individual dignity is at the heart of the process. Everything must be done to respect it. In the utilitarian approach, the aim should be the well-being of the largest number of individuals, even if it means limiting the care of a single individual. This is usually the approach preferred in a health crisis, such as the COVID-19 crisis. In fact, we are crossing a climate crisis, which is confirmed by a series of evidence. Applying the utilitarian approach to this crisis should lead us to think about the excessive environmental impact of strategies which do not systematically affect patient outcomes.

Barratt and McGain (2021) elegantly put into question the impact of overdiagnosis - detection of harmless conditions that could be safely left underdiagnosed and untreated - on the environment, suggesting that climate change requires efforts to improve the relevance of care. In a comparative non-randomised clinical trial, the use of a portable ultrasound device increased the rate of immediate adequate diagnosis from 80% to 94%. In parallel, there was a decrease in supplemental examinations and the number of interventions, probably reducing the carbon footprint for each patient associated with improved outcomes (Zieleskiewicz et al. 2021). The balance between the benefit and risks of each decision should be assessed on an environmental scale. Obviously, it is unthinkable at this time to reduce the quality of care to reduce our environmental impact. Nevertheless, we believe that, for the same quality of care, the least polluting strategy should always be preferred in the management of intensive care patients.

In the long term, this approach also has a positive impact on public health. Indeed, recent data show that there are health co-benefits to implementing environmental policies. These data show that the implementation of environmental policies is accompanied by co-benefits on the health of the population (Milner et al. 2023). For example, some modelling-studies have shown that reducing the use of coal for electricity generation will result in health benefits that exceed the economic cost of decarbonisation policies through reduced local air pollution.

Whereas its goal is to ameliorate the global health of populations, healthcare systems participate in increasing GHG emissions, which have, in turn, detrimental effects on the health of populations. Our generations have to break this vicious circle by reducing these emissions without deteriorating the level of care. This dual accountability invites reassessing the procedures in critical care under the light of GHG emission reduction. This implies not only choosing the less consuming procedures but also improving the diagnosis accuracy and avoiding overdiagnosis, leading to no unnecessary investigations and treatments. Finally, we propose to include the carbon footprint as a pharmaco-ecological outcome for future clinical trials to determine the best strategies both at the patient and collective levels.

Conflict of Interest

None. ■

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For full references and other links of interest, please email editorial@icu-management.org or visit https://iii.hm/1kts

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Intravenous Fluids in Critically Ill Patients: When Less is Better

While intravenous fluids have traditionally been a routine treatment for most critically ill patients, many severe pathologies now suggest a preference for conservative fluid therapy over liberal fluid administration.

Introduction

Intravenous fluid resuscitation began in 1832 during the cholera pandemic, improving intravascular volume and electrolyte recovery in patients with severe hypovolaemic shock secondary to dehydration from severe diarrhoea. In critically ill patients, the aim of intravenous fluid therapy is to increase cardiac output to improve macro and microcirculation and the delivery of oxygen to tissues (DO_2). However, volume status is only one of the determinants for DO_2, and paradoxically, there is dilution of oxygen with fluid overload, in addition to multiple adverse effects (Pérez-Nieto et al. 2021; Messina et al. 2022). Therefore, it is important to determine to whom, when, and how much intravenous fluids to administer, as their routine and excessive use is associated with poor outcomes, such as increased mortality, mechanical ventilation (MV) days, and acute kidney injury (AKI) (Pérez-Nieto et al. 2021).

In this review, we will discuss the aspects of intravenous fluid therapy in different scenarios with the aim of promoting rational use. Doing so involves reducing the use of unnecessary resources, resulting in lower expenditure on crystalloid fluids and lower costs due to their possible complications.

Fluids in Sepsis and Septic Shock

The Surviving Sepsis Campaign recommendation for the initial management of septic shock is to administer at least 30 ml/kg of intravenous fluids during the first three hours of resuscitation; however, the quality of evidence supporting this practice is low (Dellinger et al. 2021). Adequate fluid response is commonly defined as an increase in preload induced by a fluid infusion that generates an increase in stroke volume (SV) and hence cardiac output (CO) by more than 10-15%, and one of the major limitations is the lack of continuous CO measuring devices for all critically ill patients (Pérez-Nieto et al. 2019).

Initially, it has been shown that only about 50% of critically ill patients will be adequately responsive to intravenous fluid therapy, and in those sepsis patients who are initially fluid responsive, the probability of a beneficial response decreases rapidly to less than 5% within the first eight hours after resuscitation onset, according to a post-hoc analysis of the ANDROMEDA SHOCK study (Kattan et al. 2020). Patients who do not tolerate fluids adequately may develop congestion and overload with any extra amount of fluids administered (Perez-Nieto et al. 2021).

In recent years, important studies on fluid therapy in sepsis have been conducted. The randomised controlled CLOVERS trial compared a restrictive fluid resuscitation strategy (500 to 2,300 ml) with concomitant use of vasopressors versus a liberal fluid strategy (2,000 to 4,500 ml) before initiating vasopressors. A lower total fluid administration during the first 24 hours was demonstrated in the restrictive group, with no differences in mortality at 90 days. Therefore, higher IV fluid intake was not associated with better outcomes but with increased use of crystalloid solutions. A cost analysis could be suggested to evaluate the economic impact of liberal practice.

Instead of initiating IV fluid resuscitation, early norepinephrine infusion to achieve a mean arterial pressure (MAP) >65 mmHg may be associated with better outcomes when compared to delayed initiation of the vasopressor, including increased survival and less IV fluid input (Colon et al. 2020; Rui Shi et al. 2020).

In terms of fluid preference, despite the theoretical benefits of using balanced solutions (PlasmaLyte, Ringer lactate, Hartmann) that may include lower incidence of hyperchloraemia and metabolic acidosis, multiple studies in the last years have failed to demonstrate superiority in important outcomes such as mortality or development of AKI when comparing 0.9% sodium chloride solution with different types of balanced solutions (Hammond et al. 2020; Monnet et al. 2023), and the cost of the latter is commonly higher (Taylor et al. 2021).

Another circumstance to consider is the source of infection. For example, a patient with abdominal sepsis with nausea, vomiting, and poor fluid intake prior to admission is more likely to

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respond to IV fluids, while a patient with severe viral pneumonia is less likely to benefit from them and is more susceptible to local damage.

In summary, the benefit of administering large amounts of intravenous fluids in patients with sepsis and septic shock has been questioned in the last decade, and the recommendation for this strategy has lost strength. We suggest that the clinical benefit of fluid therapy in each patient should be weighed, considering their comorbidities, haemodynamic status, and source of infection.

Fluids in Acute Respiratory Distress Syndrome

An important pathophysiological characteristic in the development of acute respiratory distress syndrome (ARDS) is an increase in the permeability of the alveolar-capillary membrane, allowing intravascular fluid to leak into the interstitial and alveolar space, causing pulmonary oedema and gas exchange impairment (Vignon et al. 2020). A common problem in these patients is that several causes of ARDS are accompanied by hypotension and shock (e.g., severe pneumonia, septic shock, severe pancreatitis, thoracic trauma, etc.), which implies the use of large amounts of intravenous fluids in some cases to restore intravascular volume, but with the secondary effect of increasing extravascular lung water (EVLW) and worsening hypoxaemia.

Improved lung function and decreased days on mechanical ventilation and ICU have been shown with a conservative fluid therapy approach in patients with ARDS, allowing the use of furosemide versus a liberal therapy. There was no difference in mortality or development of organ failure in the conservative group. There is a positive correlation between cumulative fluid balance and mortality and ICU stay in patients with ARDS (Van Mourik et al. 2019). The current recommendation for fluid management in ARDS is to provide conservative therapy (Griffith et al. 2019).

Fluids in Acute Pancreatitis

Acute pancreatitis is characterised by a significant release of proinflammatory cytokines locally and then systemically, which causes microcirculatory damage due to endothelial injury. Initially, it presents with increased CO, but during its progression, hypotension and shock may develop due to cytokine-mediated vasodilation (Crosignani et al. 2022). Various factors can contribute to fluid loss in pancreatitis, including vomiting, feeding difficulty, abdominal pain, systemic inflammation, and fever, which are associated with increased vascular permeability and outflow of intravascular fluid into the interstitial spaces and serosa (pleura, peritoneum), leading to distributive shock with a hypovolaemic component (Crosignani et al. 2022). This circulatory disturbance contributes to tissue hypoperfusion and favours organ failure (Sureka et al. 2016).

Researchers postulated two decades ago that aggressive intravenous fluid therapy could improve pancreatic perfusion and prevent necrosis in patients with mild and moderate pancreatitis. However, this theory could not be proven, and considering the latest studies, we have strong findings against this type of management.

Ten years ago, management guidelines for acute pancreatitis recommended aggressive intravenous fluid therapy at a dose of 250 to 500 mL of crystalloid solution per hour for the first 12 to 24 hours (Tenner et al. 2013). More recent recommendations suggest using fluid therapy and monitoring patients for signs of fluid overload without specifying the infusion dose during the first 72 hours. Emphasis is placed on replacing volume lost due to intolerance of the oral route and second- or third-space leakage.

However, in patients with pancreatitis, excessive fluid intake can increase the risk of elevated intra-abdominal pressure (IAP) and cause abdominal compartment syndrome, which can worsen cardiovascular, renal, intestinal, and pulmonary dysfunction and increase the risk of mortality (DeLaet et al. 2020). The most recent proposal for the resuscitation of patients with pancreatitis is goal-guided resuscitation, and the use of ultrasonography to identify evidence of venous congestion may be useful (Argaiz et al. 2021).

A recently published randomised controlled trial evaluating a conservative fluid strategy compared to aggressive fluid therapy in the first hours of care for patients with acute pancreatitis could not demonstrate benefit to prevent the progression of disease severity with aggressive fluid intake; however, it did demonstrate a greater quantity of intravenous solutions administered and an increased incidence of rales (de-Madaria et al. 2022).

Other studies report similar findings. A systematic review of randomised controlled trials with meta-analysis found an increase in mortality and complications caused by fluid overload in patients with acute pancreatitis who were managed with aggressive fluid therapy, regardless of its degree of severity, compared to conservative fluid therapy (Li et al. 2023).

Fluids in Diabetic Ketoacidosis

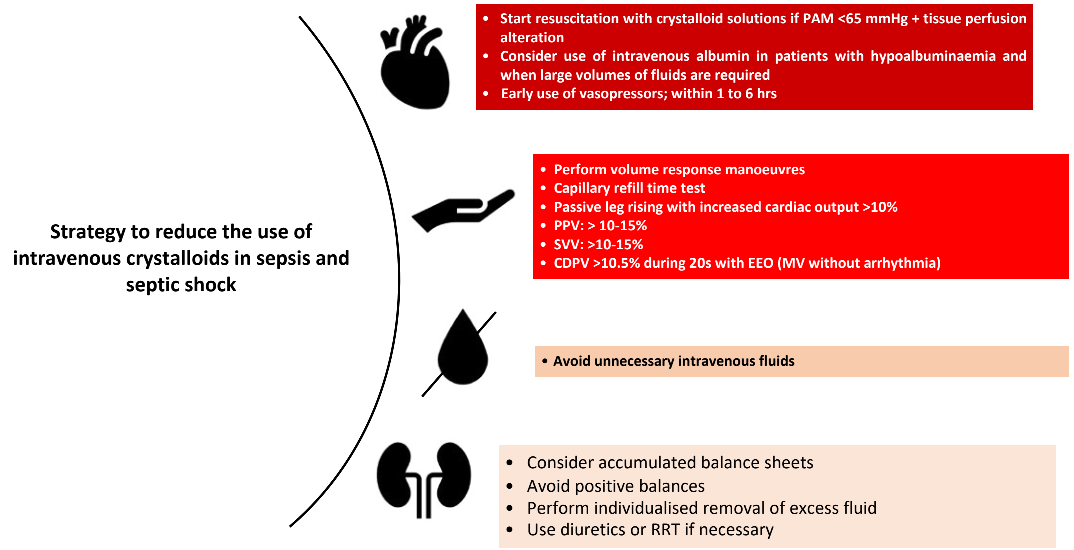
Diabetic ketoacidosis (DKA) is a serious complication of diabetes caused by an increase in serum ketones as a way of obtaining energy during acute stress and a significant decrease in insulin levels, either pancreatic or due to inappropriate treatment, culminating in metabolic acidosis, sustained hyperglycaemia, dehydration from osmotic diuresis, nausea and vomiting. Guideline-recommended treatment includes the aggressive infusion of intravenous fluids, electrolyte replacement, and insulin administration. The current recommendation is to administer an infusion of 500 mL of 0.9% sodium chloride solution to achieve a systolic blood pressure >90 mmHg, followed by 1,000 mL over 1 hour, then 1,000 mL over 2 hours, and finally 1,000 mL over 4 hours, with concurrent potassium replacement. This is based on the replacement of lost fluids, estimated at 100 ml/kg, a completely arbitrary measure. It's worth mentioning that no studies support this recommendation, despite the recommendation being universally approved (Dhatariya et al. 2022). We must remember that patients with DKA are not exempt from complications associated with fluid overload, such as pulmonary oedema (Sprung et al. 1980).

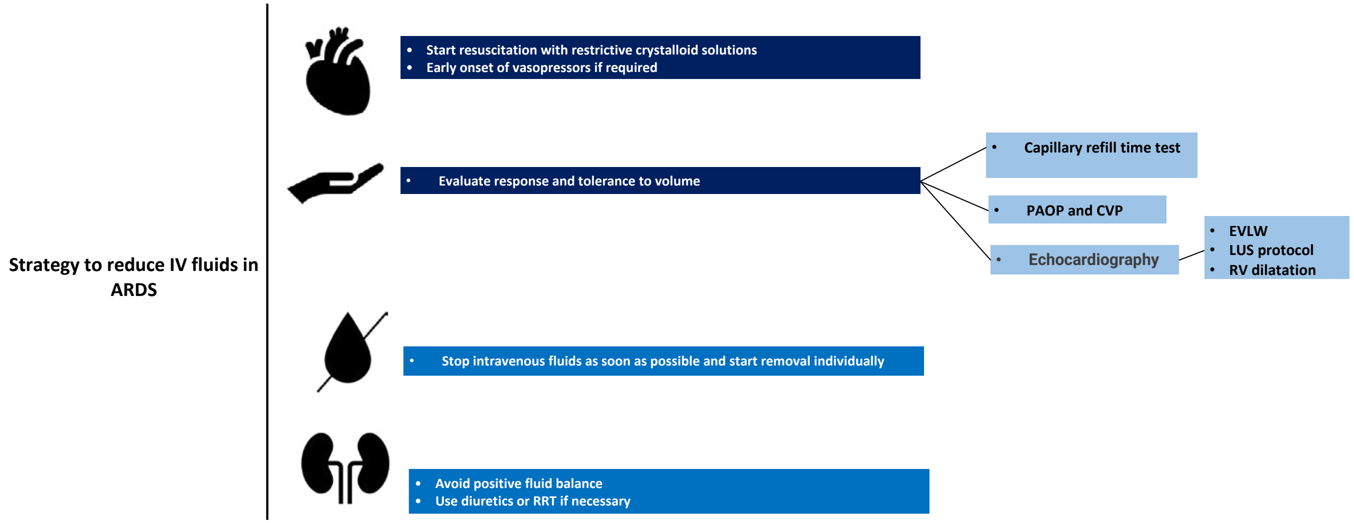
A systematic review of randomised controlled trials on patients younger than 18 years with DKA, comparing liberal and rapid infusions of IV fluids to conservative and slow therapy, found no clear benefit of one therapy over the other nor an increased incidence of major adverse effects like cerebral or pulmonary oedema. However, the liberal group showed a higher incidence of hyperchloraemic acidosis and hypocalcaemia (Long and Gottlieb 2022). No similar studies have been conducted on adult patients.

Regarding the type of solution administered, balanced solutions generate greater benefits for patients with DKA when compared to sodium chloride solution. The SKOPE-DKA study demonstrated a decrease in the resolution time of ketoacidosis symptoms without presenting a significant difference in complications when balanced solutions were compared to saline solution (Ramana et al. 2021). A recent systematic review of randomised controlled trials comparing saline with balanced crystalloids demonstrated a shorter time to resolution of DKA, fewer length of hospital stays, lower serum chloride levels, and higher bicarbonate levels (Alghamdi et al. 2022).

Fluids in Acute Kidney Injury

Acute kidney injury (AKI) is a common occurrence in critically ill patients and is an independent factor in mortality, particularly when presenting as oliguria or anuria. According to the multinational AKI EPI study, 57.3% of ICU patients will experience





AKI symptoms during their stay, with 23.5% of them requiring renal replacement therapy (RRT). The main causes include sepsis, hypovolaemia, the use of nephrotoxic drugs, cardiogenic shock, hepatorenal syndrome, and obstructive urinary tract problems (Hoste et al. 2015).

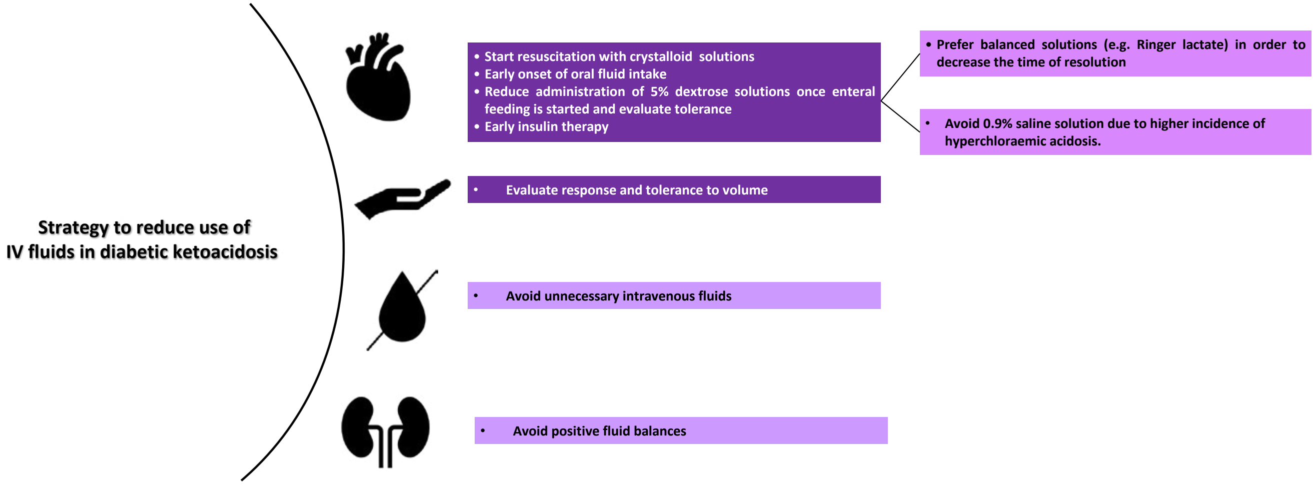
Pathophysiologically, when AKI is caused by absolute or relative hypovolaemia, it may improve with the administration of oral, enteral, or IV fluids. However, the idea that AKI from other causes can be treated with intravenous fluid infusion has led to erroneous practices and worsening prognosis for these patients, particularly those who are unresponsive or unable to tolerate them. In addition, fluid overload can worsen or cause AKI by the following mechanisms (Mårtensson and Bellomo 2015):

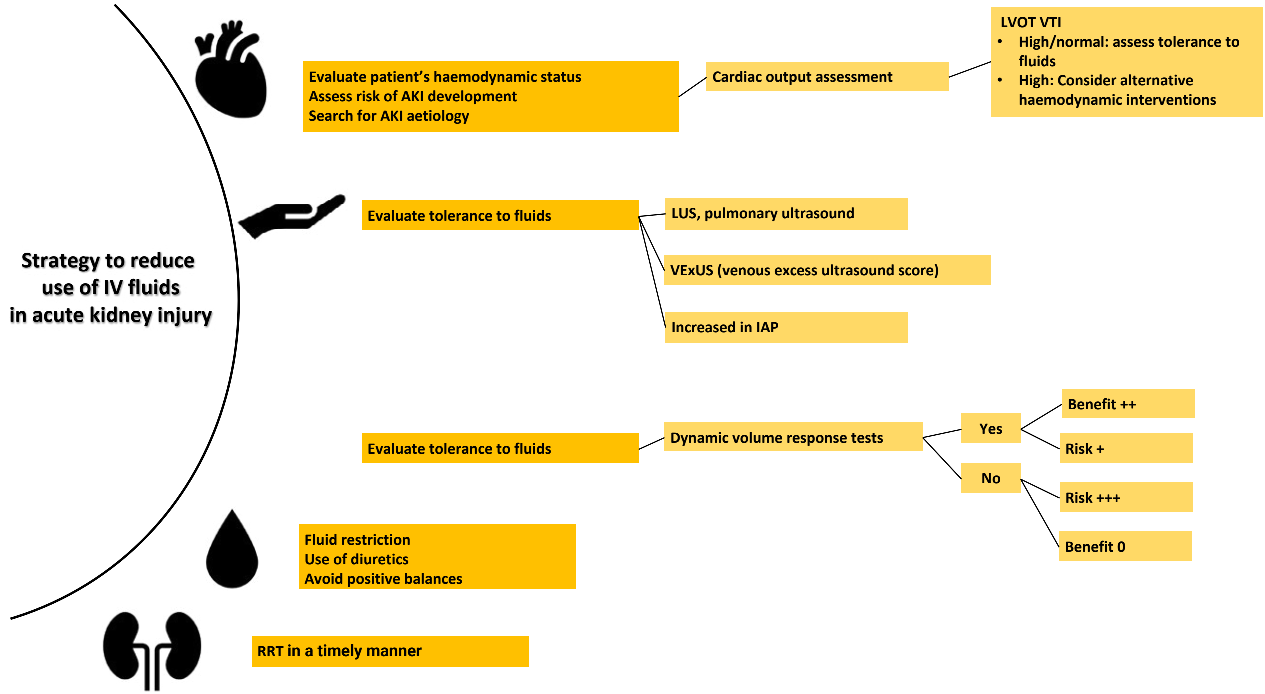
a) Activation of tubuloglomerular feedback: the infusion of saline solutions and subsequent administration of large amounts of chlorine can activate the macula densa, which secretes vasoconstrictor substances from the afferent arteriole. This can decrease renal blood flow and, subsequently, the glomerular filtration rate.
b) Increased intravascular oncotic pressure: This is generated by the administration of osmotically active substances.
c) Osmotic nephrosis: This condition is characterised by vacuolisation and oedema of the proximal tubular cells. The most related causal substances are mannitol and hydroxyethyl starch (a synthetic colloid currently not recommended).
d) Oedema of the renal parenchyma: This generates an increase in the distance needed for the diffusion of oxygen in the nephron, promoting renal ischaemia.

Conclusion

Studies have shown that large amounts of intravenous solutions administered to critically ill patients are of no benefit and are commonly associated with adverse effects, such as AKI, more days on mechanical ventilation, longer stays in the ICU and hospitalisation, and increased mortality. However, patients with hypovolaemic shock and severe dehydration may benefit from intravenous fluids.

In addition, the acquisition and administration of large quantities of solutions of different types have an economic and





ecological impact. The approximate cost per 100 mL of 0.9% sodium chloride solution is £0.47 ($0.6 USD), while the cost of balanced solutions is higher, with PlasmaLyte being the most expensive, at £2.25 to £3 ($3-$4 USD) per 100 mL (Taylor et al. 2021).

A conservative approach to intravenous fluids should be adopted for patients with ARDS, acute pancreatitis, and AKI. It should also be carefully considered in septic shock and other critical illnesses, not only to improve prognosis but also to reduce consumption and spending due to unnecessary interventions. In **Figure 1**, we present a proposal for the management of intravenous fluid therapy in common scenarios of critically ill patients.

Conflict of Interest

None. ■

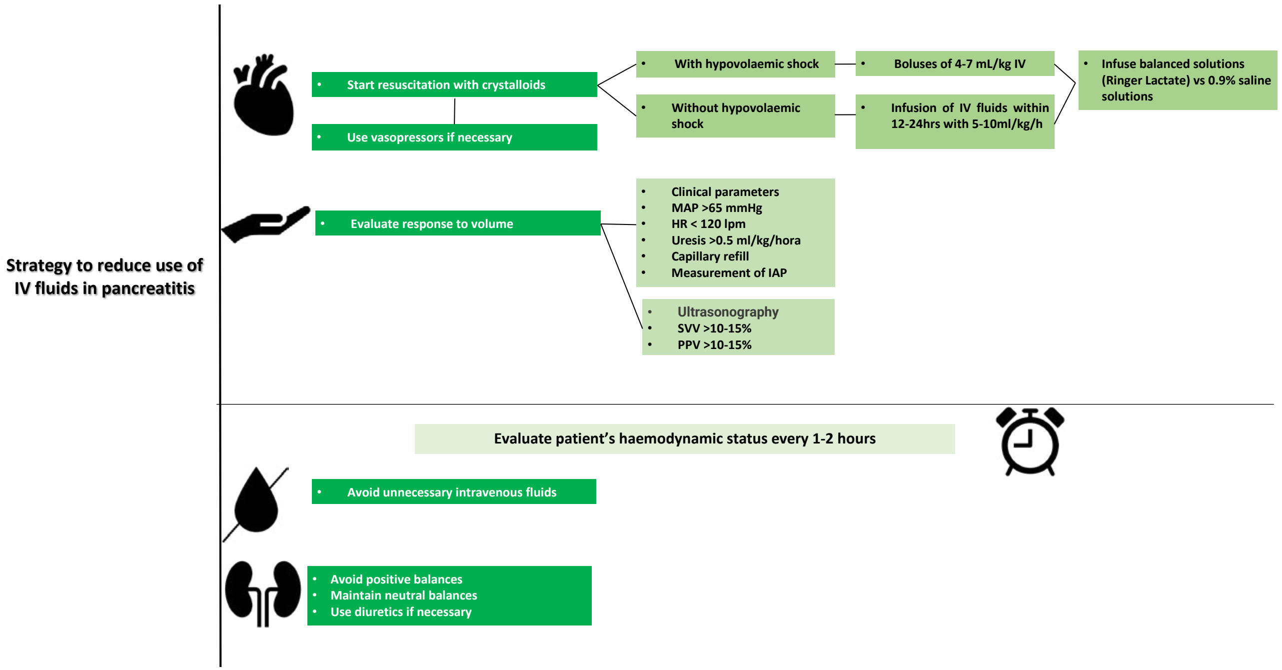


Figure 1. Proposal for the management of intravenous fluid therapy in common scenarios of critically ill patients

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Current Airway Management During Anaesthesia - The STARGATE Study

An overview of the International obServational sTudy on AiRway manaGement in operAting room and non-operaTing room anaEsthesia (STARGATE study) that will collect information on peri-intubation adverse events and airway management procedures in adult patients undergoing general anaesthesia to receive surgery or other diagnostic/ therapeutic procedures.

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Introduction

After two years from the publication of the largest prospective observational study on airway management in critical care, the INTUBE study (Russotto et al. 2021), the same team is launching a new project on airway management during anaesthesia and non-operating room procedures. The International obServational sTudy on AiRway manaGement in operAting room and non-operaTing room anaEsthesia (STARGATE study) will collect information on peri-intubation adverse events and airway management procedures in adult patients undergoing general anaesthesia to receive surgery or other diagnostic/therapeutic procedures (e.g. endoscopy, radiologic or cath lab procedures).

The INTUBE Study collected data from almost 3000 intubations in critical care and highlighted the importance of physiology optimisation prior to intubation, given the high incidence of peri-intubation adverse events, mostly cardiovascular collapse, occurring in up to 43% of patients (Russotto et al. 2022). This study also audited the procedure of airway management in critical care, reporting, among other shortcomings, the underuse of capnography to confirm intubation in only 25% of patients (Russotto et al. 2021).

The National Audit Project 4, published in the U.K. in 2011, increased awareness of airway-related adverse events and boosted research on tools to overcome anatomical challenges along with methods to enhance teamwork and nontechnical skills (Cook et al. 2011).

To date, different trials have been performed on every component of the intubation bundle, from apnoeic oxygenation using high-flow nasal cannula to video laryngoscopy use in different settings of anaesthesia. This amount of evidence has been summarised in several national and international guidelines.

Large international observational studies had the merit of taking a snapshot of real-life practice outside the controlled setting of randomised trials. For different diseases or interventions, they reported heterogeneity of practice across different geographical regions or poor application of current standards of care.

Examples of this are the underrecognition of Acute Respiratory Distress Syndrome (ARDS) and the poor application of the best ventilation strategies, as pointed out by the LUNG-Safe study, or the poor use of protocolised interventions in airway management and the importance of haemodynamics as pointed out by the INTUBE Study (Bellani et al. 2016; Russotto et al. 2021).

Prospective international audits on airway management during anaesthesia are currently lacking. Moreover, airway management in anaesthesia has been traditionally defined as potentially anatomically difficult in contrast to airway management of critically ill patients, whose physiology alterations, such as shock or respiratory failure, add complexity (physiologically difficult airways) and increased risk of peri-intubation adverse events.

With increased scheduled procedures involving older and frail patients, the incidence of peri-intubation hypotension and desaturation may be of clinical relevance. Moreover, despite the availability of guidelines, we expect a significant heterogeneity

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of practice across different geographical areas as the result of different availability of human and economic resources and traditional approaches to airway management in different centres.

We hope that STARGATE study will provide useful data to further increase the safety of airway management in the anaesthesia setting.

For more information about the STARGATE study and if you want to participate as a centre, please visit the study website: www.stargatestudy.com

Conflict of Interest

None. ■

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Medical Errors in the Preanalytical Phase of Blood Gases Test

The preanalytical phase of the blood gases study is the most susceptible to errors, causing increased time and costs for patients and hospitals. Knowledge and training of the involved health personnel must be constant to improve results.

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Introduction

Arterial or venous blood gases test is a frequent tool in the Intensive Care Unit (ICU) commonly used for the respiratory system evaluation during respiratory failure and mechanical ventilation, the study of the acid-base status, or even macro- or micro-haemodynamic monitoring. However, it has been shown that up to 40% of blood gas analyses are in error during the procedure, and 4% of samples are analysed after 30 minutes of being obtained (Wooley et al. 2003). These errors can be ignored and go unnoticed, resulting in inadequate diagnoses and treatments (Davis et al. 2013). The study of blood gases can be divided into three phases of its analytical procedure: 1) the preanalytical phase, in which the supplies (syringe, heparin, antisepsis, etc.) are prepared, the sample is obtained and transported to the blood gas analyser; 2) the analytical phase, which corresponds to the blood gas analyser and includes the analytical processing itself, and 3) the post-analytical phase or interpretation of results by the clinician. Each phase presents errors, but they occur more frequently in the preanalytical phase, probably because it is the least automated and involves more personnel from different areas (Baird 2013). Blood gas analyses are an excellent tool for clinically evaluating critically ill patients, but the interpretation and decision-making based on erroneous results could be worse than not conducting them (Sánchez-Díaz et al. 2020).

Phases of the Analytical Procedure of Blood Gases Test

All the activity conducted in the laboratory is divided into three phases that are perfectly well-identified and delimited but closely related to each other. The analytical process of the blood gases study is divided into the following:

1. Preanalytical phase
2. Analytical phase
3. Postanalytical phase

The majority of so-called laboratory errors usually occur outside the laboratory and are defined as "any defect from ordering tests to reporting and interpretation of results". Of all the errors that occur in the analytical procedure of laboratory studies, up to 75% correspond to the preanalytical phase, 4% to the analytical phase, and 21% to the post-analytical phase (Kulkarni et al. 2020). The percentage difference of each phase is related to the number of manual or automated processes, the number and type of personnel involved, the external and internal quality controls, and the training to conduct all the processes (Sonntag 2009). Recently, through a measuring score applied to 54 undergraduate medical interns and first-year resident physicians, the knowledge of pre- and post-analytical phases of blood gases was assessed. It was documented that none of the participants had the level of knowledge necessary to solve various clinical situations (Ojeda Bello et al. 2020). On the other hand, laboratory errors, mainly in the preanalytical phase, increase the resources and costs necessary for hospital care, accounting for about 2% of the hospital's total operating costs. In addition, the hours lost due to these errors are approximately 24,027 a year (Green 2013).

Preanalytical Phase

The preanalytical phase is characterised by having four steps, each one prone to various errors due to its apparent obviousness:

1. Previous preparation
2. Sampling
3. Sample storage
4. Sample transport

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Step 1. Previous Preparation
It is the step where more mistakes are made and, therefore, where more could be avoided. The first one is due to the type of syringe used. The main difference between glass and plastic is the permeability (which is higher in plastic) to gases (oxygen and carbon dioxide) that increases with low temperature (Rodriguez Fraga et al. 2019). It is recommended to use pre-heparinised plastic syringes (dried calcium-balanced lithium heparin), which reduces the risk of sample dilution and chelation. In hospitals with limited resources, pre-heparinised syringes are not always available, so insulin syringes soaked in liquid sodium heparin are used. However, too much heparin can cause sample dilution (e.g., low haematocrit, no clinical correlation) and chelation (low ionised calcium, no clinical correlation), which translates into altered gasometric variables. Suspicion and lack of clinical correlation are always decisive in the assessment of blood gases. The recommendation is to use 8 to 12 IU or 0.012 to 0.04 ml of liquid sodium heparin per ml of blood. Consequently, in this context, this is impractical (WHO 2010). The implication of the needle diameter should not be overlooked since the smaller the diameter, the greater the haemolysis. This would be reflected in increased serum levels of potassium, magnesium, iron, etc. It is recommended to use needles of ≤ 25 gauge (G) or ≥ 0.5 mm diameter; these are inversely related, i.e., the smaller the gauge, the larger the diameter. Likewise, avoid puncturing a haematoma, let the alcohol used for antisepsis evaporate, avoid transferring the sample, or draw it from a blood test tube (Fang et al. 2008; Ogiso et al. 1983).

Step 2. Sampling
You can always consider a peripheral venous blood gas analysis, which is increasingly used. In this case, consider needles < 25 G in diameter, use a tourniquet for less than 60 seconds, let the antiseptic evaporate, draw the blood slowly, do not puncture through any haematoma, mix the sample gently, and preferably use syringes prefilled with dried calcium-balanced lithium heparin. The peripheral puncture can be obtained from any site, although it is preferred from the antecubital fossa. It is recommended to compress the puncture site after taking the sample for one minute (Kelly 2010; Schütz et al. 2019).

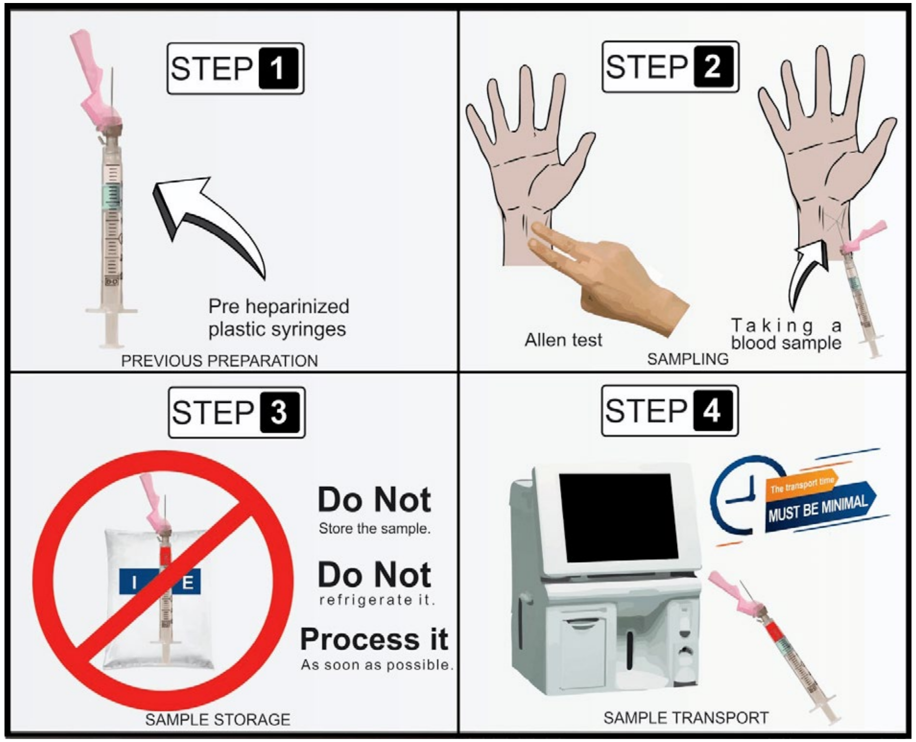

Figure 1. Considerations in the four steps of preanalytical phase of blood gases test

Regarding arterial blood sampling, initially assess collateral blood flow using the Allen test. The radial artery is the most used site for puncture due to its adequate collateral circulation through the ulnar artery. The same considerations as for peripheral venous blood gas analysis should be taken, except that there is no need for a tourniquet, and the compression of the puncture site will be for at least five minutes (WHO 2010).

Finally, the changes that occur in the variables measured in the blood gas analyser with respect to the amount of sample, from 3 to 1 ml, are not greater than 15%, so it is considered that the blood sample should not be less than 1 ml (Hedberg et al. 2009).

Step 3. Sample Storage

In this step, we start with the following key tips: do not store the sample, do not refrigerate it, and process it as soon as possible, preferably within 30 minutes (Montero Salinas et al. 2021). Remember that plastic syringes increase their permeability to gases (oxygen and carbon dioxide) at low temperatures, altering the values measured in the sample (Rodriguez Fraga et al. 2019). Another important and frequent problem is the presence of air bubbles inside the blood sample. Before the next step, they must be removed by homogenising the sample by rubbing gently and preferably within the first three minutes of obtaining the blood sample (Mohammadhoseini et al. 2015).

Step 4. Sample Transport

In a whole blood sample, aerobic metabolism can be maintained for a period of 15 to 30 minutes, after which the amount of oxygen and glucose will be depleted, altering the results. The transport time must be minimal so that these metabolic changes are minor. Transport can be manual (by health personnel) or automated (pneumatic tube). The first is the most used and acceptable. The second increases the incidence of haemolysis and the levels of oxygen partial pressure. The difference lies in the fact that manual transport has a universal gravitational constant (G) of 2G and the pneumatic tube transport of 15G, favouring these changes (Baird 2013). Approximately 40 to 80 ml of blood are used daily for diagnostic purposes, equivalent to one unit of packed red blood cells every 7 to 10 days (López et al. 2018).

The study of blood gases continues to be one of the most requested diagnostic studies in hospitals. Therefore, it is highly necessary that all health personnel involved master perfectly the four steps of the preanalytical phase to guarantee that the patient receives appropriate diagnoses and treatments (Baird 2013) (**Figure 1**). Although this procedure is considered safe with minimal risk, understanding the preanalytical phase would minimise complications such as unnecessary pain, bruising, vessel puncture site thrombosis, vascular or nerve injury, and infections (Castro 2022).

Conclusion

The preanalytical phase of the blood gases study is the most susceptible to errors, causing increased time and costs for patients and hospitals. These errors cause discomfort, complications, wrong diagnoses, or wrong therapeutic actions in patients. Knowledge and training of the involved health personnel must be constant to improve results. It should always be considered if a blood gas analysis is really necessary, so it is not performed routinely. Clinical suspicion is essential to detect errors; if the sample does not match the clinical characteristics of the patient, we advise you to obtain a new and better sample before making any decision.

Conflict of Interest

None. ■

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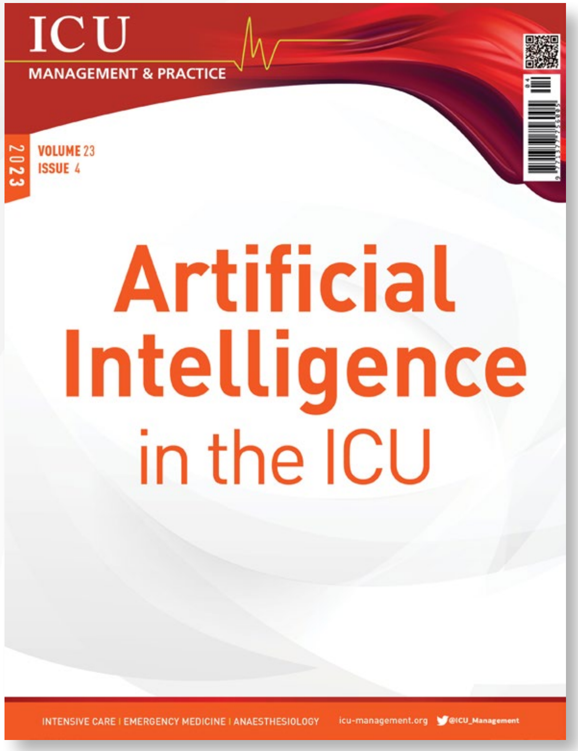
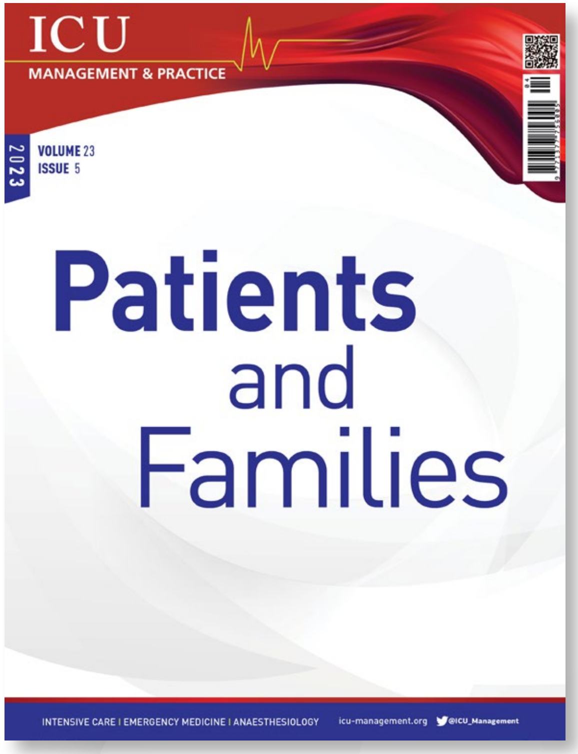


COVER STORY: Artificial Intelligence in the ICU

The intensive care unit handles some of the most complex clinical situations. In this issue, our contributors discuss the benefits of AI and technology and how advanced tools and systems can enable critical care clinicians to manage the complex demands of care, have access to insightful data, streamline workflows, reduce their cognitive workload and give more time to patients.



COVER STORY: Patients and Families

There has been an increased focus on ensuring patient and family engagement in critical care. In this issue, our contributors discuss strategies for clinicians to work with patients and families, rationale for patient and family engagement, opportunities to strengthen this engagement, and promoting greater patient and family involvement.

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