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Discarded intravenous medication in the ICU: the GAME-OVER multicenter prospective observational study

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Abstract

Background Medication waste is a contributor to the healthcare environmental footprint and impacts ecosystems. Data on medication waste in the intensive care unit (ICU) are scarce, and therefore are essential to develop new sustainable strategies.

Methods The GAME-OVER French multicenter prospective observational study was conducted from November 2022 to March 2023, over a 24-h period of choice, at the discretion of each participating center. Adult ICUs were enrolled in the study on a voluntary basis and hospitalized patients who did not express opposition were included in the analysis. The primary endpoint was the percentage of discarded intravenous (IV) medication in the ICU, defined as the ratio of the discarded volume to the total volume of IV medication prepared. Secondary endpoints included identifying risk factors and main reasons for medication waste and estimating its related healthcare cost.

Results Among the 81 ICUs and the 1076 enrolled patients, 408.9 L of 130 IV medications were prepared. The discarded volume was 43.8 L, resulting in a 10.7% discarded IV medication (95% Confidence Interval (CI), 9.9–11.5). Number of daily admissions/discharges in the ICU, as admission for elective surgery, Sequential Organ Failure Assessment score ≥ 7, endotracheal intubation, renal replacement therapy and body mass index were independently associated with increased discarded IV medication. Ninety percent of pharmaceutical waste was attributed to 25 key drugs, with an estimated national annual cost of 2,737,163€.

Conclusions Discarded intravenous medication in the ICU is considerable and results in significant costs for the health care system, without obvious patient-centered value. Risk factors associated with medication waste were largely nonmodifiable, emphasizing the need for sustainable practices in patient care and resource management.

Trial Registration ClinicalTrials.gov: NCT05553054. September 23, 2022.

Keywords Sustainable healthcare, Ecodesign of healthcare, Pharmaceutical waste, Drug waste, Healthcare cost, Environment

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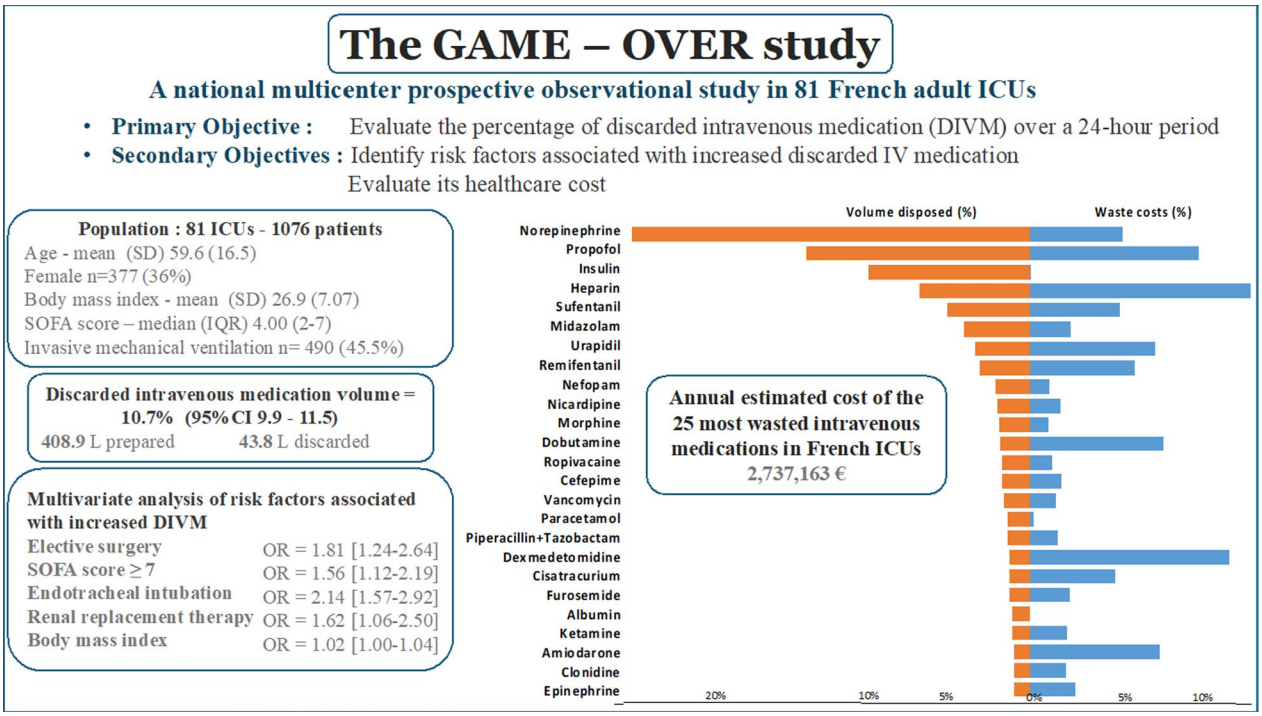
Graphical Abstract



Introduction

Worldwide, healthcare systems are playing an active role in greenhouse gases (GHG) production as well as in water, air, and soil pollution [1–4]. Climate change is increasingly impacting human health, requiring healthcare professionals to assess their practices, take responsibility, and implement strategies to reduce their environmental footprint [5–8].

Pharmaceuticals represent an important share of healthcare GHG emissions [9, 10]. Medication supply chain directly induces loss of natural resources and participates in global warming [11]. Medication waste, aside to its unnecessary cost, has been shown to significantly impact the environment [12, 13]. Pharmaceutical residues, by contaminating wastewater, contribute to aquatic environment pollution and disrupt ecosystems [14]. Improper antimicrobial waste disposal also significantly influences antibiotic resistance, resulting in potential life-threatening consequences on human health [15].

Implementing new practices, and adjusting containers volume and size are known to reduce pharmaceutical waste and costs [16, 17]. In the intensive care unit (ICU), critical care pharmacist interventions enhance quality of care while decreasing pharmaceutical consumption and costs [18, 19]. Thus, medication waste can be limited by integrating the ecodesign of healthcare concept in our daily clinical practice, without altering safety nor quality of care. Preventing and minimizing pharmaceutical waste could then help to reduce the environmental impact of healthcare while decreasing associated costs.

However, to address this issue and implement sustainable practices, medication waste assessment in various healthcare settings is essential. Pharmaceutical waste data in the ICU are scarce. Few studies have investigated discarded intravenous medication (DIVM) in the ICU, and primarily focusing on antimicrobials waste and its sustainability impact [20, 21]. Other data arise from anesthesia and the operating theater (OT), where intravenous (IV) medications preparation and administration share some similarities with the ICU [10, 22]. However, ICU activity displays very specific features compared to the OT, notably a longer length of stay; a decreased patient turnover; continuous care and monitoring for a higher number of patients, which can directly impact DIVM.

The aim of our study was to assess DIVM in the ICU, and to identify areas for improvement in our daily practices to limit any avoidable wastage and reduce healthcare costs.

Methods

Study design and oversight

We conducted a one-day French multicenter prospective observational study in adult ICUs. The protocol was approved by an institutional review board (IRB) on September 15, 2022 (Centre Hospitalier Intercommunal de Toulon–La Seyne-sur-Mer, France, IRB 12962) and registered in the clinicaltrials.gov database (NCT05553054). Inclusions and data collection were performed during one working day in each ICU, anytime between November 08, 2022, and March 06, 2023, at the discretion of each participating team. Demographical and clinical data were collected at inclusion. The study did not involve clinical follow-up. The database was approved by all the participating centers and by the sponsor's Data Protection Officer, in accordance with the European Union general data protection regulation. The «Strengthening the Reporting of Observational studies in Epidemiology» (STROBE) statement checklist, the protocol, and the statistical report containing source code are available in Additional files 1, 2 and 3, respectively. The Centre Hospitalier Intercommunal de Toulon–La Seyne-sur-Mer funded and sponsored the study.

Participating ICUs and patients

All the participating centers were recruited through the French Society of Anesthesia & Intensive Care Medicine (SFAR) Research Network, the Sustainability Committee and the Critical Care Committee. University hospitals, tertiary centers, and private hospitals with ICU beds were eligible to participate. Intermediate care units were excluded from the study. In accordance with French law, all the adult patients hospitalized in the participating ICU on inclusion day, or their next of kin if the patients were unable to provide consent, were informed of the study protocol and included unless they explicitly objected to data collection.

Data collection

Data were collected over a 24-h period in each ICU. The characteristics of the participating ICUs were recorded, as well as clinical and demographical data of the enrolled patients. A full list of the data recorded is available in the protocol and in the Additional file 1. For each patient, throughout the day of the study, all the IV medication containers (syringes, bottles, fluid bags) from continuous or bolus infusions were discarded in a personal waste container. All the medications either prepared directly in the ICU or compounded by the central pharmacy were collected and included in the analysis. If residual volume (defined as a volume greater than 2 mL) was present in the discarded container, reason for disposal was reported by the attending nurse, as follows: prepared medication remained unused, systematic change at a predefined time, prescription modification, forward-planned changes, no longer required medication due to clinical evolution, medication preparation error, or other. Forward-planned changes were defined as changes made by the attending nurse earlier than prescribed to accommodate other duties. When DIVM were not assigned to a specific patient, they were collected in a container shared for all the ICU. Whether at the end of the study day, or at patient discharge, the investigator reported the contents of the containers: medication names, dilution of the DIVM (in mg/mL or International Units/mL) and container types and volume (syringes/bags). The number of discarded containers, the number of containers containing unused medication, the number of containers discarded while full (defined by a volume greater than 90% of the total prepared volume), as well as the initial volume prepared and the residual discarded volume for each container were also collected. Preparation and administration of IV medications were performed by the nursing staff. Primary vials (containing freeze dried-powder or liquid), used to reconstitute medication solutions, as well as their residual volume/medication, were not included in waste analysis. The medication volume, obtained after dilution from the primary vial, was collected for each IV medication container. Electrolyte solutions, crystalloids, colloids, and blood products were excluded from DIVM. Additionally, a survey regarding medication preparation and pharmaceutical waste management by the attending nurses was simultaneously conducted in each participating center. Additional methods are provided in Additional file 1.

Outcomes

The primary endpoint was the percentage of DIVM, defined as the ratio of the discarded volume to the total volume of medications prepared. Key secondary endpoints included the identification of causes and risk factors associated with DIVM, and the evaluation of healthcare costs related to DIVM.

Statistical analyses

Quantitative variables are reported as median and interquartile range, or mean ± standard deviation, depending on the normality of their distribution, which was tested by a Shapiro–Wilk normality test. Categorial variables are reported as numbers (percentages). The primary endpoint is reported as percentage and 95% confidence interval (95% CI) established by the bootstrap resampling method, using 1000 iterations (R package boot V1.3–28.1). Quantitative variables were compared using Student's *t* test, or Wilcoxon-Mann–Whitney test, as appropriate. Categorical variables

were compared using semi-parametric Chi-square. Yates correction was used if expected frequency was under 5. To identify associated risk factors for DIVM, ICUs as well as patients were each divided into two groups ("low DIVM" and "high DIVM") by the median DIVM threshold. Multivariate analyses were performed using a backward stepwise logistic regression model after selecting variables with a p-value < 0.2 in univariate analysis. Odds ratio (OR) are expressed with their 95% CI. The validity of the model was tested by a Hosmer–Lemeshow test. The optimal categorization of the continuous variable into separate categories was obtained with the CatPredi model as previously described by Barrio et al.[23]. To estimate DIVM cost, we excluded medical devices and preparation time, and we averaged the prices of the 25 most discarded drugs from three different participating centers and extrapolated the healthcare cost per year using the number of ICU hospitalization days in France in 2022, obtained from the French national medico-economic hospital database [24]. Statistical analyses were performed by the last author using R statistics (CRAN), version 4.1.1.

Results

Study population and ICUs characteristics

Eighty-one French ICUs were enrolled in the study, including 1218 ICU beds. Data on DIVM were recorded in 1076 patients. Clinical data were analyzed for 1048 patient, as 28 patients (2.6%) did not consent to data collection. The survey was completed by 823 out of the 988 nurses (83%) who were working during the study-day. General characteristics regarding ICUs and the overall cohort are provided in Tables 1 and 2, respectively. Participating ICUs were mainly mixed (56%), and surgical (36%). Overall, 348 patients (33.3%) were under continuous sedation, and 507 (48.4%) had an endotracheal tube. The median number of admissions and/or discharges per ICU was 4 (IQR, 1–6).

Primary endpoint

In total, 408.9 L (liters) of 130 medications were prepared in all participating ICUs. The median discarded volume per ICU was 477 mL (IQR, 235–729 mL) (eFigure 1). Overall, 6519 containers were collected, representing a median of 6 (IQR, 3–10) containers per patient per day (eFigure 2). The total discarded volume of IV medication was 43.8 L, resulting in a 10.7% DIVM (95% CI, 9.9–11.5). Residual volume greater than 2 mL was found in 2007

Table 1 ICUs characteristics, in the overall cohort, and in the "low DIVM" and "high DIVM" ICU groups

ICU characteristics	Overall ICUs (N = 81)	Low DIVM ICU (N = 40)	High DIVM ICU (N = 41)	*p*
Hospital type—n (%)				0.16
University hospital	44 (54)	18 (45)	26 (63)	
Public hospital	25 (31)	13 (33)	12 (29)	
Private hospital	7 (9)	6 (15)	1 (2)	
Military teaching hospital	5 (6)	3 (8)	2 (5)	
ICU main activity—no. (%)				0.79
Mixed	45 (56)	24 (60)	21 (51)	
Surgical	29 (36)	12 (30)	17 (42)	
Medical	5 (6)	3 (8)	2 (5)	
Burn patients	2 (3)	1 (3)	1 (2)	
Available beds per ICU—median (IQR)	13 (10–16)	12 (10–16)	15 (12–17)	0.07
Patients hospitalized per ICU—median (IQR)	12 (9–15)	10.5 (8–13)	13 (10–17)	0.03*
Admissions and/or discharges—median (IQR)	4 (1–6)	2 (1–4)	4 (3–6)	< 0.01*
Bed-to-nurse ratio (day)—median (IQR)	2.4 (2.0–2.7)	2.4 (2–2.7)	2.4 (1.9–2.5)	0.45
Bed-to-nurse ratio (night)—median (IQR)	2.7 (2.4–3.0)	2.7 (2.5–3.0)	2.5 (2.1–3.0)	0.11
Bed-to-intensivist ratio (day)—median (IQR)	5.0 (4.0–6.7)	5.0 (4.0–6.8)	5.0 (4.0–6.7)	0.40
Presence of student nurses—no. (%)	44 (55)	19 (48)	25 (63)	0.26
Presence of residents—no. (%)	77 (95)	36 (90)	41 (100)	0.06
Median % of DIVM (IQR)	9 (6–16)	6 (3–8)	16 (11–26)	< 0.001*

Univariate analyses of ICUs characteristics were performed between the two groups, divided by the median DIVM. The "low DIVM ICU" group was defined as the first and second quartiles and the "high DIVM ICU" group was defined as the third and fourth quartiles. Median DIVM was calculated for 1076 patients hospitalized in the 81 enrolled ICUs. $p < 0.05$* was considered statistically significant

ICU, Intensive Care Unit; IQR, Interquartile Range; DIVM, Discarded IntraVenous Medication

Table 2 Population characteristics, in the overall cohort, and in the "low DIVM" and "high DIVM" patients' groups

Population characteristics	Overall cohort (N = 1048)	Low DIVM patients (N = 519)	High DIVM patients (N = 529)	*p*
Age, yr—mean (SD)	59.6 (16.5)	58.9 (16.7)	60.3 (16.4)	0.18
Sex female—no. (%)	377 (36)	187 (36)	190 (36)	1.0
Body mass index (kg/m^2)—mean (SD)	26.9 (7.07)	26.5 (6.6)	27.4 (7.4)	0.04*
Indication for ICU admission—no. (%)				0.04*
Elective surgery	165 (15.8)	67 (13)	98 (18.6)	
Emergency surgery	246 (23.6)	133 (25.8)	113 (21.4)	
Medical	546 (52.3)	277 (53.7)	269 (50.9)	
Traumatology	87 (8.33)	39 (7.6)	48 (9.1)	
SOFA score—median (IQR)	4 (2–7)	3 (1–6)	5 (2–8)	< 0.001*
Continuous sedation—no. (%)	348 (33.2)	122 (23.6)	226 (42.7)	< 0.001*
Upper airway access—no. (%)				< 0.001*
None	540 (51.6)	318 (61.4)	222 (42.0)	
Endotracheal intubation	443 (42.3)	161 (31.1)	282 (53.3)	
Tracheostomy	64 (6.1)	39 (7.5)	25 (4.7)	
Oxygen therapy—no. (%)				< 0.001*
None	215 (20.0)	146 (27.1)	69 (12.8)	
Invasive mechanical ventilation	490 (45.5)	187 (34.8)	303 (56.3)	
Non-invasive ventilation	70 (6.5)	35 (6.5)	35 (6.5)	
High-flow nasal cannula oxygen therapy	57 (5.3)	33 (6.1)	24 (4.5)	
Standard oxygen therapy	244 (22.7)	137 (25.5)	107 (19.9)	
Renal replacement therapy—no. (%)	125 (12.0)	45 (8.7)	80 (15.2)	< 0.01*
Enteral route available—no. (%)	873 (83.3)	442 (85.7)	431 (81.5)	0.08
Patient discharges on D-day—no. (%)	141 (13.5)	79 (15.3)	62 (11.7)	0.11
Number of ICU days—median (IQR)	5 (1–14)	6 (2–16)	4 (1–11)	< 0.01*
ICU length of stay < 48 h—no. (%)	367 (35.0)	166 (32.2)	201 (38.2)	0.05
Median % of DIVM (IQR)	4 (0–18)	0 (0–0.8)	18 (9–36)	< 0.001*

Univariate analyses of the population characteristics were performed between the two groups, divided by the median DIVM. The "low DIVM patients" group was defined as the first and second quartiles and the "high DIVM patients" group was defined as the third and fourth quartiles. Median DIVM was calculated for 1076 patients hospitalized in the 81 enrolled ICUs. Demographical and clinical data were available in 1048 patients. $p < 0.05$* was considered statistically significant

ICU, Intensive Care Unit; IQR, Interquartile Range; DIVM, Discarded IntraVenous Medication; SD, Standard deviation; SOFA score, Sequential Organ Failure Assessment score

containers (30.8%). Moreover, 429 (6.5%) containers were considered full when being thrown away, representing a volume of 21.0 L and 5.1% of the total prepared medication volume.

Risk factors associated with increased discarded intravenous medication

To identify risk factors for pharmaceutical waste, both ICUs and patients were split in two groups by the median DIVM, which was 9.1% (IQR, 6.1–16.3) for the overall ICUs and 3.8% (IQR, 0.0–17.8) for the cohort of patients. Multivariate analysis on ICU characteristics showed that the number of admissions/discharges was the only factor significantly associated with increased DIVM (OR 1.27; 95% CI, 1.08 to 1.55; $p < 0.01$, Hosmer–Lemeshow test $p = 0.54$). When focusing on patient characteristics, multivariate analysis showed that ICU admission for elective surgery (OR 1.81; 95% CI, 1.24–2.64; $p = 0.02$), SOFA score ≥ 7 (OR 1.56; 95% CI 1.12–2.19; $p < 0.01$), endotracheal intubation (OR 2.14; 95% CI, 1.57–2.92; $p < 0.001$), renal replacement therapy (RRT) (OR 1.62; 95% CI, 1.06–2.50, $p = 0.03$), and body mass index (OR 1.02;95% CI, 1.0–1.04), were significantly associated with increased DIVM (Fig. 1). Risk factors associated with the number of discarded containers are presented in in the supplemental results section of Additional file 1.

Reasons for intravenous medication waste

Of the 2007 discarded containers with residual pharmaceuticals, attending nurses provided explanations for the presence of leftover medications in 1788 cases (89%) (eFigure 3). Prescription modification (n = 477/1788, 27%) and medications no longer required (n = 352/1788, 20%) were the main reasons for discarding a container

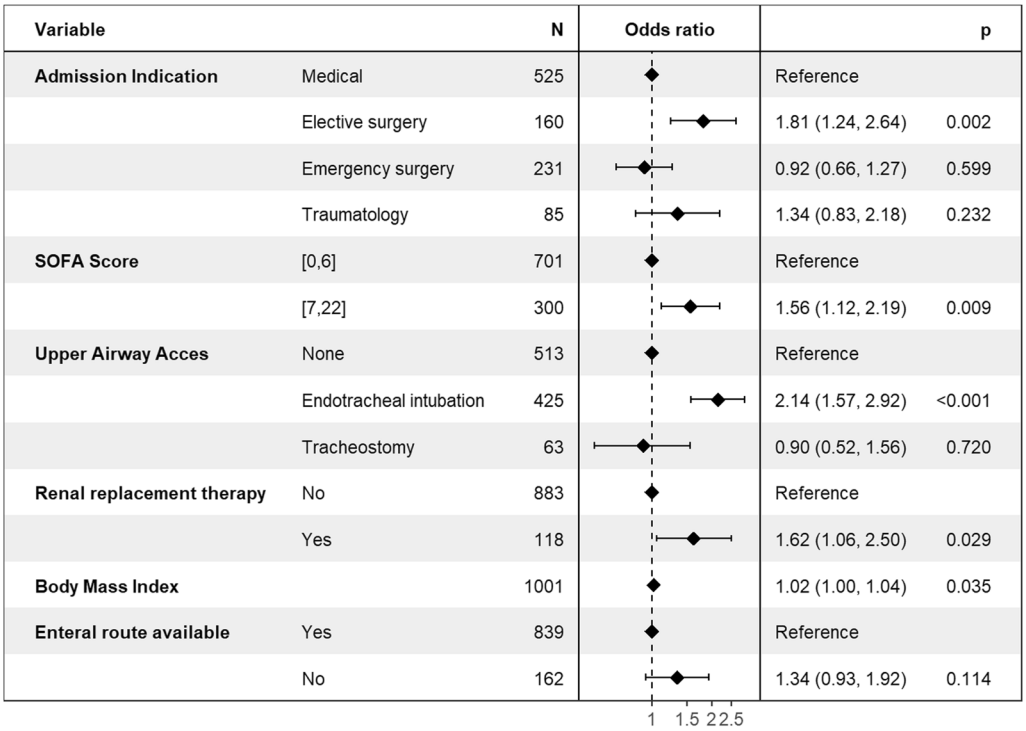


Fig. 1 Multivariate analysis of patients-related risk factors for discarded intravenous medication. An Odds Ratio greater than 1.0 indicates an association with increased discarded intravenous medication. Multivariate analysis was performed using a backward stepwise logistic regression model after selecting variables with a *p*-value < 0.2 in univariate analysis: age, body mass index, indication for intensive care unit (ICU) admission, total Sequential Organ Failure Assessment (SOFA) score, continuous sedation, upper airway access, oxygen therapy, renal replacement therapy, enteral route available, patient discharges on the study day, ICU length of stay. The optimal categorization of the SOFA score, a continuous variable into separate categories was obtained with the CatPredi model (Hosmer–Lemeshow test $p = 0.18$). A p value < 0.05 was considered significant

with residual volume. Interestingly, 10% of the containers (n = 182) were discarded because the medications were prepared in advance to provide care and remained unused. In the survey, 504 out of 823 nurses (61%) acknowledged that they sometimes prepared medications which were not prescribed, and 166 (20%) indicated that they systematically changed all the syringes at a predefined time of the day.

Wasted pharmaceuticals and associated healthcare costs

Excluding electrolytes, crystalloids, and colloids, over 90% of the total discarded volume was represented by 25 intravenous medications. Epinephrine had the highest waste ratio with 68% of the prepared volume remained unused (or the prepared drug quantity), followed by norepinephrine (30%) and dobutamine (30%) (eTable 1). The total discarded volume of norepinephrine was 10.1 L, representing 26% of the disposed volume of the 25 most DIVM, followed by propofol (15%) and insulin (10%) (Fig. 2). However, even though heparin accounted for only 7% of the DIVM volume, it was associated with the highest waste cost (13% of the total estimated cost). Dexmedetomidine, and propofol also represented an important share of the DIVM costs (Fig. 2). Finally, the daily median cost of the 25 most discarded medications per ICU was 15.9€ (IQR, 8.2–30.7) (eFigure 4), and the total daily cost of DIVM was estimated at 1760€ for the 81 ICUs (eTable 1), representing 1.64€ per patient per ICU-day. Considering that 1,673,402 ICU days were recorded in France in 2022 [24], the national total DIVM in ICU was estimated at 68,118 L. Focusing on the 25 most discarded IV medications, the national DIVM in ICU was evaluated at 60,552 L, representing a healthcare cost of 2,737,163€ annually.

Discussion

In the GAME-OVER French multicenter prospective ICU study, we reported that DIVM accounted for more than 10% of the total volume of medications prepared. Over one third of the containers were discarded with residual medication and 6.5% were thrown away while being full. We also showed in multivariate analyses that the daily number of admissions and/or discharges per ICU, as well as ICU admission for elective surgery or patients severity factors (SOFA score ≥ 7, RRT or endotracheal intubation) were significantly associated with DIVM. Finally,

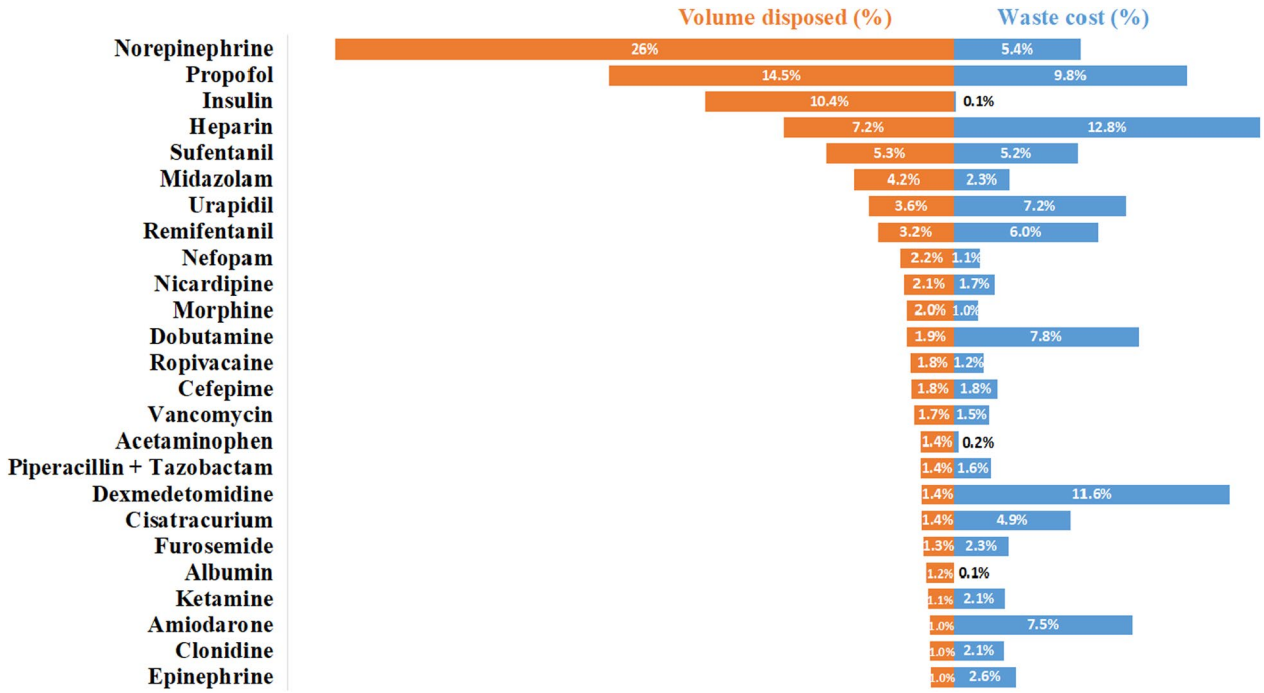


Fig. 2 The 25 most discarded medications in the overall cohort. The percentage of volume disposed (orange bars) represents the ratio of the volume disposed of the molecule to the total discarded volume of the 25 most discarded medications. The average price of each medication per milligram (or international unit (IU) for insulin and heparin) was calculated using prices obtained from 3 different hospitals. Solvents, medical devices, and preparation time were excluded from the estimated cost. The percentage of waste cost (blue bars) represents the price of the amount of mg (or IU) thrown away per molecule to the total cost of the 25 most discarded medications

we extrapolated that, in addition to its environmental impact, DIVM in the ICU represented over 2,500,000€ annual healthcare costs in France.

Interestingly, the percentage of DIVM in the ICU was lower than what we expected, considering that a medication waste rate over 30% has been reported in the OT [13, 22, 25, 26]. This could be explained first by the exclusion of electrolytes and vials in our study, as well as differences in daily practice. In our study, the six medications contributing the most to DIVM were norepinephrine, propofol, insulin, heparin, sufentanil, and midazolam, which can be easily explained by the frequent use of continuous sedation, vasopressors, or anticoagulation in critically ill patients. These discarded medications, although daily used in the OT, are partially different from those identified in anesthesia [22, 27], mostly represented by epinephrine, atropine, and phenylephrine. Nevertheless, propofol, which is known for its significant impact on aquatic ecosystems, is highly wasted in both settings [22, 25, 26, 28].

We identified several risk factors associated with increased DIVM. Multiple patient severity criteria (SOFA score ≥ 7, endotracheal intubation and RRT) were significantly associated with DIVM. Patients with multiorgan failure often require continuous sedation, both factors being also significantly associated with an increased number of discarded containers. Although intermediate care units were excluded from the GAME-OVER study, the population median SOFA score was quite low (4 (IQR 2–7)), which could partially explain the limited DIVM in our study (10.7% (95% CI, 9.9–11.5)). Interestingly, postoperative admission for elective surgery was also identified as a risk factor for waste. Early sedation interruption or IV medication changes after ICU admission could partly explain this association. Moreover, in patients requiring renal replacement therapy, dosage adjustment (i.e. antimicrobials) might also lead to more DIVM although not studied in the literature. However, patient-related risk factors do not allow development of targeted strategies to reduce DIVM. Our results therefore emphasize the need for implementing sustainable practices in daily patient care. Thus, medications with a waste rate over 25% (epinephrine, norepinephrine, dobutamine) could benefit from several specific actions: decreasing the volume of medication prepared in advance, using smaller containers, or using prefilled syringes. Prefilled syringes containing emergency medications, although produced at a higher unit cost than conventional preparations, reduce overall costs by cutting down on wastage while reducing medication administration errors [29, 30].

Clinical pharmacist presence in the ICU, while not being routine in France, could also help decrease DIVM [19, 30].

In this study, prescription modification was reported as the main reason for disposing of containers with residual volume, highlighting the importance of communication between prescribers and nurses to optimize medications preparation and decrease associated waste. Optimizing medication prescription also contributes to the ecodesign of healthcare and can significantly reduce the environmental impact of pharmaceuticals by applying the principle of "right prescription": the right patient––the right medication––the right route––the right time––the right dose––and now the right environmental impact [31]. Finally, raising awareness on our practices is essential. Systematic syringe changes at a predefined time of the day, although not supported by any national policy, was reported in the survey by 20% of the nurses. This practice may therefore represent a major area for improvement in decreasing DIVM in the ICU in France.

In our study, healthcare cost associated with the 25 most discarded medications was evaluated at 1.64€ per patient per ICU-day and more than 2,500,000€ annually. This is lower than the estimated cost of $1.9 (1.77€) to $10.9 (10.15€) per case of anesthesia described in the literature [27, 32]. However, this estimated annual cost, which represents a minor share of annual healthcare expenditure in France, may have been under evaluated in our study, as only the 25 most discarded medications (based on volume measurement) have been included in the estimated healthcare cost calculation. Thus, the financial implications could have significantly differed if the calculation were based on the cost of the most expensive drugs discarded rather than the most discarded in volume. Moreover, we excluded the additional costs of syringes, needles, solvents, preventable medical waste, and preparation time by the nursing staff [22] from the cost analysis. These results underline the need to adopt cost-effective practices through waste reduction initiatives. In addition to financial savings, these strategies to decrease DIVM may present other advantages. Combating wastage by optimizing medication preparation and administration can help limit the risk of medications shortage in the ICU, as the ones observed during the COVID-19 [33, 34]. It could also help decrease plastic use, which is recognized as a major environmental pollutant having direct negative impact on human health [35–37]. Thus, the median number of plastic containers needed for the administration of ICU medications was six per patient per day of hospitalization, lower than the 10 syringes (IQR, 4,5–18) per patient per 12-h shift thrown away reported by Anstey et al.[38]. Nonetheless, we did not evaluate syringe reuse nor include in this study the many syringes used daily for "saline vectors" or for gastrointestinal tube administration.

We also acknowledge that our study presents several limitations. First, we conducted a one-day observational study, enrolling French ICUs on a voluntary basis, which may have induced a self-selection bias driven by the teams' interest in sustainability. Indeed, this study was performed right after the COVID-19 pandemic, when the French healthcare system committed to reducing its environmental impact. Nevertheless, it seems unlikely that this recent political decision may have impacted the caregivers' practices on the study-day. Furthermore, since data were collected on one chosen day over a 4-month period in the different ICUs, the population described in our study may not be representative of the overall population of critically ill patients admitted to French ICUs. Moreover, heterogeneity between centers is likely, particularly due to local protocols and practices. Indeed, different pharmaceutical dilution practices may exist across the 81 participating ICUs, which could have influenced the list of the 25 most discarded medications, as well as the risk factors associated with DIVM. Ultimately, difference in practices may have impacted the estimated annual cost of discarded pharmaceuticals for the French health system. We also acknowledge that some patients might have spent some time out of the ICU (OT, imaging) on the study day, which was not accounted for in our study. We did not include data on pharmaceutical vials, although Jarrett et al. demonstrated that residual drug in vials after reconstitution can be substantial [20]. Moreover, IV fluids waste were excluded from the study, especially for feasibility constraints. IV bag residual volume is difficult to assess accurately without a precision scale. Removal of the perfusion lines often makes the bag permeable, which would have required dedicated healthcare providers to weight it just after removal. Although not having a major direct environmental impact [39], resuscitation fluids are largely used in critically ill patients and represent important volumes of DIVM and plastic bags or containers [39, 40]. We concede that this may have resulted in an underestimation of DIMW. DIVM due to CVC and peripheral perfusion replacement, or CVC tubing change was not accounted for in our study, although these hygiene associated limitations may generate medication waste [41–43]. Finally, the average price was calculated from 3 different institutions where prices are negotiated independently, with potential variations over time that were not considered. The financial aspects of wasted resources could therefore be more significant in institutions or countries where drug prices are substantially higher.

Conclusions

Overall, this first large-scale study highlights the extent of DIVM in the ICU, as well as its contributing factors. To decrease DIVM, raising awareness of all the caregivers and implementing sustainable strategies in daily patient care are critical. Further research is therefore warranted to help integrate sustainable practices in the ICU, and may focus on drug residue disposal, resuscitation fluid waste (crystalloids and colloids), or drug preparation methods (volumes, dilutions, container types and sizes). These results may help building evidence-based ecodesign of ICU healthcare, leading to human, environmental, and financial savings.

Abbreviations

CI	Confidence interval
DIVM	Discarded intravenous medication
GHG	Greenhouse gases
ICU	Intensive care unit
IQR	Interquartile range
IRB	Institutional review board
IV	Intravenous
OR	Odds ratio
OT	Operating theater
SFAR	French society of anesthesia & intensive care medicine
SOFA score	Sequential organ failure assessment score
RRT	Renal replacement therapy

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13054-025-05299-6.

Additional file 1

Additional file 2

Additional file 3

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Author Contributions

ED, SP, JC, EA, LB, CDF, FG, OC, EB, MS, NM, PE, MC, PJC contributed to the study conception and design. Acquisition, analysis, or interpretation of data were performed by all authors. The first draft of the manuscript was written by ED and SP. Critical revision of the manuscript was performed by JC, EA, CDF, TK, PE. PJC performed the statistical analysis. Administrative and technical support were performed by RC and MC. All authors read and approved the final manuscript.

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Availability of data and materials

The first and the last authors had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The protocol was approved by an IRB on September 15, 2022 (Centre Hospitalier Intercommunal de Toulon – La Seyne-sur-Mer, France, IRB 12962). The study did not involve clinical follow-up. The database was approved by the sponsor's Data Protection Officer, in accordance with the European Union general data protection regulation. In accordance with French law, all the adult patients hospitalized in the participating ICU during the day of inclusion, or their next of kin if not able to consent, were informed of the study protocol and included if they did not express opposition to data collection.

Consent for publication

Not applicable.

Competing interest

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