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REVIEW

Interventions to reduce low-value care in intensive care settings: a scoping review of impacts on health, resource use, costs, and the environment

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Abstract

Purpose: Low-value care is common in intensive care units (ICUs), unnecessarily exposing patients to risks and harms, incuring costs to the patient and healthcare system, and contributing to healthcare's carbon footprint. We aimed to identify, collate, and summarise published evidence on the impact of interventions to reduce low-value care in ICUs.

Methods: We searched MEDLINE, Embase, and Cochrane CENTRAL from inception to 22 September 2023 for evaluations of interventions aiming to reduce low-value care, supplemented by reference lists and recently published articles. We recorded impacts on the low-value target, health outcomes, resource use, cost, and the environment.

Results: From 1155 studies screened, 32 eligible studies were identified evaluating interventions to reduce: routine blood testing ($n=13$), routine chest X-rays ($n=10$), and other types (or multiple types) of low-value care ($n=9$). All but 3 of the interventions found reductions in the immediate low-value care target (usually the primary outcome). Although the small sample size of most included studies, limited their ability to detect impacts on other outcomes, many interventions were also associated with improved health outcomes and financial savings. The only study that reported environmental impacts found the intervention was associated with reduced carbon dioxide equivalent (CO_2-e) emissions.

Conclusions: Interventions to reduce low-value care in ICUs may have important health, financial, and environmental co-benefits. Further research may inform wider scale-up and sustainability of successful strategies to decrease low-value healthcare. More empirical evidence on potential environmental benefits may inform policies to lower healthcare's carbon footprint.

Keywords: Intensive care, Low-value care, Health outcomes, Cost, Environmental impact, Review

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Introduction

Low-value care, also called overuse or unnecessary care, refers to healthcare interventions with very little to no benefit to patients. In the intensive care unit (ICU), thresholds to intervene tend to be lower and patients are more vulnerable to the adverse effects of interventions. As a result, low-value care is common [1–3], with critically unwell patients undergoing frequent diagnostic imaging, pathology testing, treatments, and other procedures that have little or no benefit to them [2].

These interventions fail to improve patient health outcomes, with a recent meta-analysis reviewing interventions to reduce diagnostic tests in the ICU finding that tests could be reduced without significant changes to hospital mortality [4]. Low-value care also exposes patients to risks and harms, uses up limited nurse and clinician time, has opportunity costs for patients and clinicians, and incurs financial costs for the patient, health facility, and health system [5]. For all these reasons, there is already good reason to reduce low-value care in the ICU.

However, there is also increasing awareness of the environmental impacts of healthcare and the need to deliver sustainable care [1, 6]. The Centre for Sustainable Healthcare's Principles of Sustainable Clinical Practice advocate for lean service delivery by reducing low-value activities and their impacts [7], and this is a compelling way to make ICUs more sustainable [8]. To the best of our knowledge, no review has sought to include the environmental benefits of reducing low-value care in the ICU.

To inform further intervention and implementation research to reduce low-value care in ICUs, we undertook a scoping review of published evidence on the topic. Specifically, we aimed to identify, collate, and summarise evidence on the impacts of interventions to reduce low-value care in hospital ICUs on health, resource use, financial costs, and the environment.

Take-home message

We aimed to identify, collate, and summarise published evidence on the impacts of interventions to reduce low-value care in intensive care units (ICUs). Multiple evidence-based interventions may reduce low-value care in ICUs with important health, financial, and environmental co-benefits. Further research may inform wider scale-up and sustainability of successful strategies to decrease low-value healthcare. More empirical evidence on potential environmental benefits may inform policies to lower healthcare's carbon footprint.

Methods

Protocol and registration

This scoping review was conducted in accordance with the Joanna Briggs Institute Manual for Evidence Synthesis [9] and the protocol was registered with Open Science Framework registry [10]. We report our findings according to the Preferred Reporting Items for Systematic Reviews and Meta Analyses Extension for Scoping Reviews (PRISMA-ScR) (electronic supplementary material, ESM, 1) [11].

Eligibility criteria

Studies reporting on the effectiveness of interventions to reduce low-value care in hospital intensive care settings were included in this review if they met the following participant, concept, and context (PCC) criteria:

- Participants: all critically unwell patients, including all health conditions and ages.
- Concept: the effectiveness of interventions self-identifying to reduce the use of low-value care, including outcomes related to health, resource use, costs, and environmental impact. Resource use is broadly defined and considered to include efficiency and more effective use of clinical staff's time (which may include continuing education to achieve this).
- Context: general intensive care settings, including medical and surgical intensive care units (but not cardiac or cardiothoracic units).

We identified peer-reviewed publications of intervention studies, including randomised trials, non-randomised trials, and quality improvement studies, to identify the effectiveness of interventions to reduce low-value care. Conference abstracts were excluded. Studies published at any time and in any language were eligible and translated using Google Translate (https://www.google.com/translate) as required.

Information sources

We used the following automated tools from the Systematic Review-Accelerator [12] to develop our search: Word Frequency Analyser (uses pre-identified target papers to identify common text words and MESH terms), Search Refinery (supports refinement of the search strategy so that it is more efficient in finding relevant literature and leaving out irrelevant literature) [13], and Polyglot Translator (translates searches for MEDLINE to other databases) [14]. We searched MEDLINE, Embase, and Cochrane CENTRAL to identify potentially relevant studies on 22 September 2023. The full search strategy for each database is included in electronic supplementary material, ESM, 2. This was supplemented by reference lists from two recently published journal articles by Baid et al. (references cited in "Avoid and reduce: tackling low-value care" section) [1] and Hooper et al. (all references)

[4]. We also included two recently published journal articles by Pilowsky et al. and Siegal et al. [15, 16].

Selection of sources of evidence

We collated all potentially relevant records in EndNote X9 (Clarivate Analytics, PA, USA) and uploaded them to Covidence (Veritas Health Innovation, Australia; https://www.covidence.org) where duplicate studies were automatically removed, with additional duplicates manually removed by a reviewer. One reviewer screened titles and abstracts (FMM) and two reviewers screened full texts (FMM and JTWW). Disagreements were resolved by a third reviewer (KJLB).

Data charting

Two authors developed a data extraction tool and extracted relevant data after pilot testing and refining the tool (JTWW and KJLB). The extraction tool included authorship and publication information, objectives of the study, study design, intervention and comparator, and impact on health outcomes, resource use, cost, and the environment. The full data charting tool is included in ESM 3. The quality of individual studies was rated using the Oxford Centre for Evidence-Based Medicine Levels of Evidence rating system, from 1 to 5 [17].

Synthesis of results

We grouped studies by the type of low-value care they examined and undertook qualitative synthesis of the results. The outcomes of each study were classified into the following categories: low-value care outcomes, health outcomes, resource use outcomes, financial outcomes, and environmental outcomes. The low-value care outcomes were the specific target that the intervention aimed to reduce, such as unnecessary blood tests or X-rays. Health outcomes included direct patient relevant outcomes such as morbidity and mortality, as well as surrogates for these such as ICU length of stay and number of blood transfusions. Financial outcomes included all costs, and environmental outcomes included any environmental impacts that were reported.

Results

Selection of sources of evidence

Figure 1 summarises the selection of source of evidence processes. We identified 1155 unique records from online database searches and other sources. Based on the title and abstract, we excluded 1046 of these records and sought 99 for full-text review. Three of these records were not retrieved because no full text was identified. Of the remaining 96 records, 64 were excluded (for reasons see Fig. 1), leaving 32 records that were included in the review. Two of these reported on the same study [18, 19].

Characteristics of sources of evidence

Included records are summarised in Table 1. Records were published between 1993 and 2024 in the United States ($n=12$), France ($n=5$), Australia ($n=4$), Canada ($n=4$), the Netherlands ($n=2$), New Zealand ($n=2$), Japan ($n=1$), Italy ($n=1$), and Switzerland ($n=1$). Studies used quality improvement ($n=26$), cohort ($n=2$), or randomisation-based ($n=4$) methods in adult ($n=32$) or paediatric ($n=2$) intensive care settings. The quality of included records was rated as Level 4 ($n=26$), Level 3 ($n=3$), or Level 2 ($n=3$).

Records described interventions to reduce routine blood tests ($n=13$; 41%) [16, 18–29], routine chest X-rays ($n=10$; 31%) [30–39], and multiple or other types of low-value care ($n=9$; 28%) [15, 40–47]. Interventions had multiple components, which commonly included education programmes for staff, implementation of testing guidelines, modifications to test ordering processes, and staff feedback pathways. Of the 32 records, 29 reported effects on the low-value care outcome targeted by the intervention, 24 reported effects on health outcomes, 17 reported financial savings, and 1 reported effects on environmental outcomes. Details are provided in ESM 4.

Reducing routine blood tests

Thirteen studies described interventions to reduce blood tests [16, 18–29] and 11 of these were associated with an improvement in a low-value care outcome [16, 18, 20–26, 28, 29]. Interventions were associated with reductions in the number of overall and unnecessary tests per patient-day ($n=19$) [16, 18, 21–26, 29], the number of blood collection tubes used ($n=1$) [20], and an increase in the proportion of appropriate tests ($n=1$) [28]. Nine studies reported on surrogate or direct health outcomes [16, 20–23, 25, 26, 28, 29]. Interventions were associated with a decrease in the volume of blood taken for testing ($n=2$) [20, 26], the number of red cell transfusions ($n=1$) [20], the proportion of patients requiring mechanical ventilation ($n=1$) [16], and length of stay in the ICU ($n=1$) [16]. There were no adverse health effects found in the other six studies reporting on health outcomes. Eight studies reported financial outcomes, which suggested savings per year, per patient, and per patient-day [16, 18, 21, 23, 25–27, 29]. Only one study reported an environmental outcome. This study reported a decrease in carbon dioxide equivalent (CO_2-e) emissions associated with pathology testing over the study period, largely

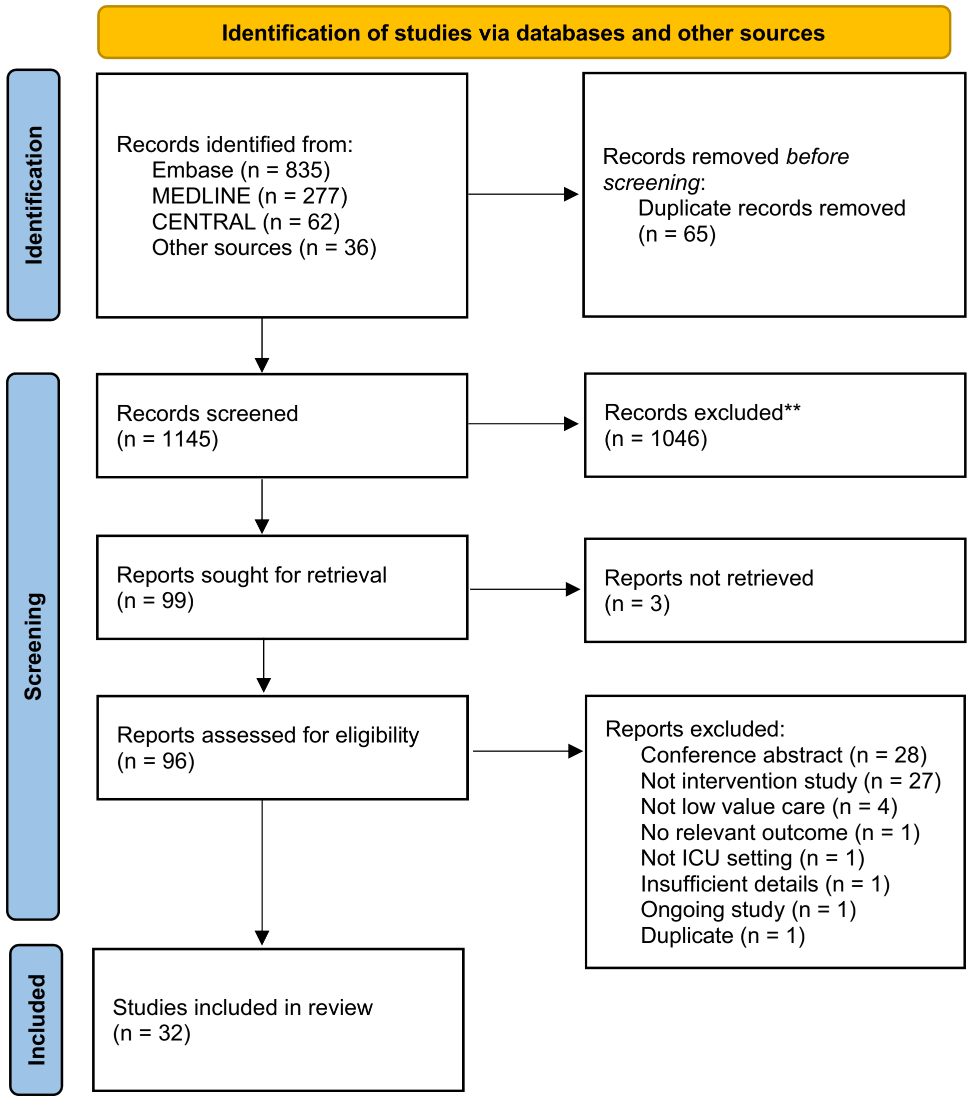

Fig. 1 PRISMA flow diagram

attributed to reduction in use of arterial blood gas tests [16]. Details are provided in Table 2 and ESM 4.

Reducing routine chest X-rays

Ten studies described interventions to reduce routine chest X-rays, all of which were associated with an improvement in a low-value care outcome [30–39]. Three high-quality randomised studies reported fewer X-rays per patient-day (1.09 vs 0.75) [38], and per patient (6.8 vs 4.4) [31], and an improvement in the proportion of tests with new findings (7.2% vs 66%) [37] that prompted a change in management (5.5% vs 56%) [37]. The remaining seven studies reported interventions associated with fewer X-rays per patient or patient-day ($n=6$) [30, 32, 34–36, 39] or an increase in the proportion of X-rays that resulted in a change in patient management ($n=1$) [33]. All ten studies reported surrogate or direct health outcomes [30–39] and most ($n=9$) reported no changes [30–34, 36–39]. In one study, the intervention was associated with a decrease in the proportion of patients requiring pulmonary artery catheters [35]. Five studies reported financial outcomes, all of which suggested cost savings [30, 33–36]. No environmental impacts were reported. Details are provided in Table 3 and ESM 4.

Table 1 Characteristics of 32 included studies

Author, year	Quality	Country	ICU setting	Study design	Type of low-value care	Sample size
Pilowsky (2024) [16]	Level 4	Australia	Adult	QIS	Routine pathology tests	22,210 patients
Siegel (2023) [15]	Level 2	Canada	Adult	Stepped-wedge cluster-randomised trial	Blood tests (volume)	27,411 patients
Bodley (2023) [20]	Level 4	Canada	Adult	QIS	Blood collection volume, including for pathology testing and waste	2096 patients
Malin (2023) [36]	Level 4	USA	Child	QIS	CXR	668 patients
Conroy (2021) [22]	Level 4	USA	Adult	QIS	Routine pathology tests	24 bed ICU
Ogasawara (2020) [45]	Level 4	Japan	Adult and Child	QIS	Stress ulcer prophylaxis	100 patients
Clouzeau (2019) [21]	Level 3	France	Adult	Prospective cohort study	Laboratory tests	5707 patients
Dhanani (2018) [23]	Level 4	Australia	Adult	QIS	Laboratory blood tests	3250 patients
Yorkgitis (2017) [46]	Level 4	USA	Adult	QIS	Blood tests, CXR	307 patients
Brogi (2017) [30]	Level 3	Italy	Adult	Retrospective cohort study	CXR	4134 patients
Kotecha (2017) [24]	Level 4	USA	Adult	QIS	Unnecessary laboratory tests	207 patient-days[a]
Keveson (2017) [34]	Level 4	USA	Adult	QIS	CXR	2 × 21 bed ICUs
Raad (2017) [41]	Level 4	USA	Adult	QIS	Blood tests	18 bed ICU
Rachakonda (2017 [27]	Level 4	Australia	Adult	QIS	Laboratory tests	2778 patients
Resnick (2017) [39]	Level 4	USA	Adult	QIS	CXR	197 patients
Musca (2016) [26]	Level 4	Australia	Adult	QIS	Coagulation blood tests	253 patients
Murphy (2016) [40]	Level 4	USA	Adult	QIS	Blood tests, CXR	22,563 patients
Merkeley (2016) [25]	Level 4	Canada	Adult	QIS	Blood tests	1140 patients
Gutsche (2013) [43]	Level 4	USA	Adult	QIS	Blood transfusions	495 patients
Hejblum (2009) [38]	Level 2	France	Adult	Cluster randomised crossover study	CXR	849 patients
Prat (2009) [44]	Level 4	France	Adult	QIS	CXR, blood tests	1175 patients
Kumwilaisak (2008) [28]	Level 4	USA	Adult	QIS	Blood tests	1117 patients
Graat (2007) [32]	Level 4	Netherlands	Adult	QIS	CXR	1376 patients
Hendriske (2007) [33]	Level 4	Netherlands	Adult	QIS	CXR	736 patients
Clec'h (2007) [37]	Level 2	France	Adult	Randomised controlled trial	CXR	165 patients
Krinsley (2003) [35]	Level 4	USA	Adult	QIS	CXR	2564 patients
Krivopal (2003) [31]	Level 3	USA	Adult	Pseudo-randomised study	CXR	94 patients
Seguin (2002) [47]	Level 4	France	Adult	QIS	Blood tests, CXR	289 patients
Mehari (2001) [19][b]	Level 4	NZ	Adult	QIS	Blood tests	94 patients
Merlani (2001) [29]	Level 4	Switzerland	Adult	QIS	Blood tests	549 patients
Mehari (1997) [18][b]	Level 4	NZ	Adult	QIS	Blood tests	199 patients
Roberts (1993) [42]	Level 4	Canada	Adult	QIS	blood tests, CXR, ECG	1883 patients

CXR chest X-Ray, *ECG* electrocardiogram, *ICU* intensive care unit, *NZ* New Zealand, *QIS* quality improvement study, *USA* United States of America

[a] Number of participants not reported

[b] Report on the same study

Reducing other types of low-value care or multiple types of low-value care

Six studies aimed to reduce both laboratory testing and diagnostic imaging, [40–42, 44, 46, 47] of which five were associated with an improvement in a low-value care outcome [40–42, 44, 47]. Two studies aimed to reduce blood transfusions [15, 43], and one aimed to reduce use of stress ulcer prophylaxis [45], all of which were associated with an improvement in a low-value care outcome. A large high-quality stepped wedge randomised controlled trial found that smaller volume blood test tubes resulted in 10 fewer blood units transfused per 100 patients during their ICU stay [15]. In the seven studies that measured health outcomes, these were no worse under intervention than control [15, 40–43, 45, 46]. Four studies reported financial outcomes, all of which suggested cost savings [40, 42, 44, 47]. No environmental impacts were reported. Details are provided in Table 4 and ESM 4.

Table 2 Impacts of 13 studies reporting interventions to reduce routine blood testing

Author	Quality	Intervention	Low-value care outcomes	Health outcomes	Financial outcomes	Environmental outcomes
Pilowsky (2024) [16]	Level 4	Education, audit, feedback	1.7 fewer pathology tests per patient-day (8.68 vs 6.98)	12% fewer patients receiving mechanical ventilation (37.8 vs 33.1; $p<0.001$) 1.5 less hours in ICU (50.6 vs 49.1; $p=0.032$)	AUD 918,497.50 saved per year (group results not reported)	1.83 less tonnes CO_2-e emitted per year (12.88 vs 11.05)
Bodley (2023) [20]	Level 4	Education, bedside checklist, electronic order modifications, audit, feedback	1.4 fewer blood collection tubes per patient-day (6.3 vs 4.9; $p=0.005$)	2.2 fewer red cell transfusions per 100 patient-days (10.5 vs 8.3; $p=0.01$) 7 mL less blood collected for testing per patient-day (41.1 vs 34.1; $p=0.009$)	NA	NA
Conroy (2021) [22]	Level 4	Education, adjusting test ordering set	1.2 fewer laboratory tests per patient-day (9.5 vs 8.3)	No change	NA	NA
Clouzeau (2019) [21]	Level 3	Education, new ordering policy	22.1 fewer tests per ICU-patient-day (37.3 vs 15.2; $p<0.001$)	No change	Euro 135 saved per patient-day (239 vs 104; $p<0.0001$)	NA
Dhanani (2018) [23]	Level 4	Prescribing guidelines, new laboratory form, education	1.3 fewer pathology tests per patient-day (4.7 vs 3.4)	No change	AUD 28.26 saved per patient per day (group results not reported)	NA
Kotecha (2017) [24]	Level 4	Guidelines, education	2.1 fewer tests per patient-day (3.5 vs 1.4)	NA	NA	NA
Rachakonda (2017) [27]	Level 4	Authorisation of blood tests by ICU specialist	NA	NA	No change	NA
Merkeley (2016) [25]	Level 4	Education, ICU checklist, a rubber stamp indicating tests not indicated, prompt in electronic ordering system	0.14 fewer routine complete blood count tests per patient-day (0.97 vs 0.83) 0.13 fewer routine electrolyte/renal panel tests per patient-day (0.96 vs 0.83)	No change	CAD 11,200.24 saved per year (group results not reported)	
Musca (2016) [26]	Level 4	Guideline, education	0.529 fewer coagulation profile tests per patient-day (1.068 vs 0.539; $p<0.001$) 0.437 fewer coagulation profile, activated partial thromboplastin time, international normalised ratio tests per patient-day (1.088 vs 0.651; $p<0.001$) 0.685 fewer full blood count, urea, electrolytes and creatine, and liver function tests per patient-day (5.367 vs 4.682; $p=0.003$)	1.79 mL less blood collected for coagulation testing per patient-day (group results not reported)	USD 17.23 saved per bed-day (28.47 vs 11.24)	NA

Table 2 (continued)

Author	Quality	Intervention	Low-value care outcomes	Health outcomes	Financial outcomes	Environmental outcomes
Kumwilaisak (2008) [28]	Level 4	Guideline	4.3 fewer tests per patient-day (20.7 vs 16.4; $p < 0.001$)	No change	NA	NA
Mehari (1997) [18] (2001) [19]	Level 4	Guideline	7.7 fewer tests per patient in general ICU (61.04 vs 53.34) [18] Intervention effects sustained post-implementation (1997 to 2001) [19]	NA	NZD 64.61 saved per patient for general ICU (group results not reported) [18] NZD 71.33 saved per patient for cardiac ICU (group results not reported) [18]	NA
Merlani (2001) [29]	Level 4	Guideline, education, feedback	3.4 fewer blood gas analysis tests per patient-day (8.2 vs 4.8; $p < 0.001$)	No change	CHF 68.4 saved per patient-day (group results not reported)	NA

AUD Australian Dollar, *CAD* Canadian Dollar, *CHF* Swiss Franc, *NZD* New Zealand Dollar, *USD* United States Dollar

Discussion

We reviewed 32 studies reporting interventions to reduce low-value care in the ICU, most of which investigated strategies to reduce routine pathology tests and chest X-rays. Studies described interventions that included education programmes, testing guidelines, modifications to test ordering processes, incentives, and audit and feedback. Most studies reported associations with moderate reductions in low-value care (the immediate target of the intervention). In all the studies, the interventions appeared safe, with none reporting adverse health outcomes and some reporting health co-benefits. All studies that measured financial costs reported savings. Only one study reported environmental impacts. Although most of the studies used a before-and-after study design, there were three randomised controlled trials that provided more robust estimates of effect. Only two studies included children. None of the studies was conducted in a low- or middle-income country.

Our findings are generally consistent with other studies. A recent systematic review of the safety and efficacy of interventions to reduce routine diagnostic tests in the ICU found decreases in testing and associated costs without increases in hospital mortality or adverse events, consistent with the findings of this review [4]. We have included an additional nine studies that were not part of that review (seven were published since the end of the study's literature search period) [15, 16, 20–22, 24, 36, 43, 45]. A narrative review of interventions to reduce routine blood testing in the ICU identified six types of intervention that were used: education and guidance, audit and feedback, gatekeeping, computerised physician order entry, multifaceted, and interventions using artificial intelligence (machine learning) [48]. The authors found that all intervention types could effectively reduce testing [48]. Our study described combinations of multiple types of intervention, which makes it difficult to evaluate whether some types were more effective than others. A meta-analysis found interventions to reduce pathology and chest radiograph testing were not associated with increased hospital mortality [4]. A systematic review also found that reductions in routine blood testing of critically ill patients can be associated with reduced blood transfusion rates and costs without any adverse patient outcomes [49].

Health benefits and economic savings provide compelling arguments to increase efforts to limit low-value care in the ICU. Although we did not investigate opportunity costs in terms of clinician time, this is also likely to be significant [50]. Freeing up ICU nurses from spending time on routine tests means they are more able to attend to the acute needs of patients.

Table 3 Impacts of 10 studies reporting interventions to reduce routine chest X-rays

Author	Quality	Intervention	Primary outcomes	Health outcomes	Financial outcomes
Malin (2003) [36]	Level 4	Criteria for CXR	48% absolute difference in proportion of intubated patients receiving daily CXR (79% vs 31%)	No change	USD 300,000 saved to patients over study period (group results not reported) USD 60,000 saved to hospital over study period (group results not reported)
Brogi (2017) [30]	Level 3	Routine use of lung ultrasound	0.55 fewer CXRs per patient (0.97 vs 0.42)	No change	Euro 22,104 saved over study period (47,090 vs 24,986; $p = 0.012$)
Keveson (2017) [34]	Level 4	Clinically indicated CXR, education	589 fewer CXRs per 1000 non-admission and non-procedural days in medical ICU (919 vs 330; $p < 0.001$) 346 fewer CXRs per 1000 non-admission and non-procedural days in surgical ICU	No change	USD 191,600 saved per year in medical ICU (group results not reported) USD 224,200 saved per year in surgical ICU (group results not reported)
Resnick (2017) [39]	Level 4	Guideline, clinically indicated CXR	16.2% fewer CXRs per patient-day (57.1 vs 40.9; $p < 0.01$)	No change	NA
Hejblum (2009) [38]	Level 2	Clinically indicated CXR	0.34 fewer CXRs per patient-day of mechanical ventilation (1.09 vs 0.75; $p < 0.0001$)	No change	NA
Clec'h (2008) [37]	Level 2	Clinically indicated CXR	58% absolute difference in proportion of CXRs with new findings (7.2% vs 66%; $p < 0.0001$) 50.9% absolute difference in proportion of CXRs prompting change in management (5.5% vs 56.4%; $p < 0.0001$)	No change	NA
Graat (2007) [32]	Level 4	Clinically indicated CXR	0.5 fewer CXRs per patient-day (1.1 vs 0.6; $p < 0.05$)	No change	NA
Hendrikse (2007) [33]	Level 4	Clinically indicated CXR	16% absolute difference in proportion of CXRs prompting change in management (1.9% vs 17.9%; $p < 0.001$)	No change	Euro 82,500 saved per year (group results not reported)
Krinsley (2003) [35]	Level 4	Form indicating the reason every CXR was ordered	0.135 fewer CXRs per patient-day (0.606 vs 0.471; $p < 0.0001$)	4.5% absolute difference in proportion of patients requiring pulmonary artery catheters (8.5% vs 4%; $p < 0.0001$)	USD 109,968 saved over study period (group results not reported)
Krivopal (2003) [31]	Level 3	Clinically indicated CXR	2.2 fewer CXRs per patient (6.8 vs 4.4; $p = 0.007$)	No change	NA

CXR chest X-ray, *USD* United Stated Dollar

Table 4 Impacts of nine studies of interventions to other types of low-value care or multiple types of low-value care

Author	Quality	Intervention	Low-value care outcomes	Health outcomes	Financial outcomes
Siegal (2023) [15]	Level 2	Small-volume tubes	Standard-volume tubes in ICU storage areas post-intervention were 0.02%-2.9% of total tubes counted	9.84 less red blood cell units transfused per 100 patients during ICU stay (0.8 vs 0.71; $p = 0.04$)	NA
Ogasawara (2020) [45]	Level 4	Checklist, change to ordering system	62% absolute difference in the proportion of patients receiving stress ulcer prophylaxis (100% vs 38%; $p < 0.001$)	No change	NA
Raad (2017) [41]	Level 4	Education, electronic medical record changes	12.48 fewer laboratory tests per patient-day (39.43 vs 26.95; $p < 0.001$) 6.21 fewer iSTAT laboratory tests per patient-day (7.37 vs 1.16; $p < 0.001$)	No change	NA
Yorkgitis (2017) [46]	Level 4	Daily checklist change	No change	No change	NA
Murphy (2016) [40]	Level 4	Education, financial incentives, feedback	1.6 fewer arterial blood gas tests per encounter (3.9 vs 2.3; $p < 0.005$) 1.1 fewer CXR per encounter (3.5 vs 2.4; $p < 0.005$) 0.1 fewer utilised red blood cell units per encounter (0.6 vs 0.5; $p < 0.005$)	1.7% lower absolute risk of ICU mortality (6.3% vs 4.6%; $p < 0.005$) 1.8% lower absolute risk of hospital mortality (7% vs 5.2%; $p < 0.005$)	USD 772,048 saved per year
Gutsche (2013) [43]	Level 4	Clinical practice guideline, education, feedback	6.6% absolute difference in unnecessary transfusions (14.7% vs 8.1%; $p = 0.0016$)	No change	NA
Prat (2009) [44]	Level 4	Guideline, education, feedback	0.3 fewer CXRs per patient-day (0.75 vs 0.45; $p < 0.001$) 0.11–0.56 fewer routine laboratory tests per patient (varied depending on the type of test, see ESM 4)	NA	Euro 58 saved per patient ICU day (114 vs 56)
Seguin (2002) [47]	Level 4	Inform physicians of test costs	0.63 fewer urinary electrolyte tests per admission (1.16 vs 0.53; $p < 0.01$) 0.8 fewer arterial blood gas tests per admission (1.84 vs 1.04; $p = 0.01$)	NA	Euro 75 saved per admission (341 vs 266; $p < 0.05$)
Roberts (1993) [42]	Level 4	Policy change	18% fewer tests per ICU day (42.6 vs 34.9)	No change	CAD 121.84 saved per admission

CAD Canadian Dollars, *ICU* intensive care unit, *iSTAT* laboratory tests available though point of care

Only one of the included studies investigated environmental benefits from limiting low-value care. There is increasing recognition that not only does climate change impact health, but that health care itself is polluting and contributes substantially to the greenhouse gas emissions driving the climate crisis [51]. Most of these emissions come directly from healthcare products and the delivery of healthcare services. This means that to achieve net zero health systems, we must lower the footprint of clinical care itself [2, 3]. The ICU is a carbon hotspot within hospitals, which themselves account for a large proportion of healthcare's total footprint [1]. Interventions that are effective in reducing low-value care in the ICU will, therefore, help reduce healthcare's CO_2-e emissions. Increased implementation of "less is more" interventions are likely to have significant co-benefits across health, costs, and environmental outcomes [52].

Strengths of this scoping review are the multidisciplinary author team, which includes ICU clinicians, comprehensive search of large databases supplemented by reference searches, and a review process involving two authors for most steps. Our study also has limitations. Many of the studies were designed to detect a difference in the low-value outcome but not differences in other outcomes such as mortality. This issue of low-quality evidence based on before-and-after comparisons was also noted previously [4]. While the evidence appears to show no adverse health impacts from interventions targeting low value care, larger studies using robust designs (ideally randomised controlled trials) are needed to confirm this. There was only one reviewer for the title and abstract screening stage, which may have meant some relevant studies were missed. In addition, the search for relevant articles relied on studies to include the term low-value care or similar. This means that studies that may be about reducing low-value care, but not using this term, would have been missed. Our search only identified studies from high-income counties despite medical overuse being a problem in low- and middle-income countries and other low-resource settings [53–55]. Given the high carbon intensity of these settings, the environmental impact of low-value care may be significant [56].

Future research may investigate ways to reduce low-value care in paediatric ICUs, and in ICUs in low- and middle-income countries [53]. More empirical evidence is also needed on the impact of reductions in low-value care in ICUs on environmental outcomes such as CO_2-e [8]. Where feasible, large intervention studies may include life cycle assessments, as has been proposed for randomised clinical trials [57]. Further research is needed to define the best implementation strategies to inform wider scale-up and sustainability of interventions to decrease in low-value care. To achieve this, studies may also investigate if a particular type of intervention is more effective than others and whether this varies by type of low value care, and by setting. Such evidence would enable policy makers and clinicians to choose the most effective and efficient strategy that best addresses their needs.

Supplementary Information
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Data availability
No new data were created or analysed in this study. Data sharing is not applicable to this article. Data extracted from included studies in available in the Online Appendix.

Declarations

Conflict of interest
The authors declare no other conflicts of interest.

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