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Real-Time Measures of ICU Strain and their Impact on Patient Outcomes: A Systematic Review

Sing Chee Tan
sing.tan@nh.org.au

Northern Health
Kisal Kirinde
Royal Melbourne Hospital
Matthew Nagel
Royal Melbourne Hospital
Vlada Rozova
University of Melbourne
Daniel Capurro
Royal Melbourne Hospital
David Pilcher
Alfred Health

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Abstract

Background

ICU strain is a growing challenge due to increasing demand for limited healthcare resources. Identifying real-time strain metrics validated against clinically relevant outcomes is essential to support monitoring and intervention.

Objective

To identity ICU strain metrics measured in real-time and associated with clinically relevant outcomes

Methods

We conducted a systematic review searching Ovid Medline, Embase, CINAHL, and Web of Science for studies published between January 2016 and December 2024. We included studies that (1) were conducted in ICU settings (2) described strain metrics measured at a maximum of 24-hour intervals (3) evaluated impact on clinical outcomes. Screening and extraction were performed by 2 reviewers, and quality was assessed using the Newcastle-Ottawa Scale. Analysis was descriptive.

Results

From 1099 studies, 34 met inclusion criteria. All studies were at low risk of bias. 83 strain metrics mapped onto 5 domains – turnover, nursing workload, occupancy, staffing (medical), and staffing (nursing). 76 outcome measures were mapped onto 11 broad concepts (e.g.hospital mortality). 116 strain-outcome analyses were performed, of which 11 types of outcome measures were assessed. 54% (63/116) of analyses demonstrated worse patient outcomes with rising strain. Strain metrics consistently associated with adverse outcomes were nursing staffing (8/9) and workload (6/8), whilst occupancy (33/63) and patient turnover (7/16) demonstrated moderate association. The Activity Index, a composite score of occupancy, workload and staffing, was consistently associated with worse outcomes.

Conclusion

Nursing staffing, nursing workload, occupancy and turnover rates are real-time ICU strain metrics associated with adverse outcomes and could be incorporated into a real-time measurement of ICU strain. Future research should validate metrics for prospective monitoring and prediction modelling, as well as integration into decision support systems.

Introduction

Intensive Care Unit (ICU) strain is a state where available resources are outweighed by clinical demand for these services, and is a growing global health challenge in view of increasing demand [1]. The importance of ICU strain lies in the harmful effect it has on patients, with growing recognition that it is associated with poorer outcomes across a range of measures, for patients as well as providers [2–5]. Although the exact causal link between ICU strain and adverse patient outcomes is unclear, there are suggestions that short-term strain impacts providers' ability to provide care for individual patient [5,6].

Although various indicators of ICU strain have been examined, many of these are indirect or lagging indicators, which describe downstream impacts of strain (such as the need to discharge a patient early) rather than the activity level itself (such as the number of patients needing mechanical ventilation). In addition, few of these indicators have been validated for impact on patient relevant outcomes, raising question of their validity as a target metric for monitoring [7,8]. The ability to directly quantify ICU strain as a dynamic system characteristic that impacts patient outcomes is key to support monitoring and proactive interventions [4,9]. However, there has not been any review of metrics that fit the criteria of being measured in real-time and validated against patient outcomes.

This research aims to address this gap by conducting a review with the aim of identifying measures of ICU strain that are (1) measured in real-time to facilitate contemporaneous monitoring and management, and (2) associated with patient-relevant outcomes.

Methods

This systematic review was conducted using the methodology recommended by the Cochrane Handbook of Systematic reviews of interventions, reported following the PRISMA guidelines, and registered prospectively on Prospero (ID CRD42023492305, 11 Dec 2023). Ethics approval was not required for this study.

Search Strategy

We developed a search strategy in partnership with a research librarian (CG). We searched Ovid Medline, Embase, CINAHL and Web of Science for relevant papers published between January 2016 and December 2024. The search strategy combined three concepts – (1) intensive care services (2) health service

strain or activity (3) patient outcomes (Full strategy in appendix 2). Reference lists from relevant studies were also manually searched for additional studies. Studies were exported to Covidence and Excel for screening and data extraction respectively. NoteBookLM was used to assist with verifying the accuracy of data extracted from the studies by creating structured tables with study characteristics for verification against manually extracted information. No AI tool fulfills authorship criteria of this journal.

Inclusion criteria included both prospective or retrospective studies done in ICU settings (adult or paediatric), and published in peer-reviewed journal articles. Strain metrics must be measured in real-time and validated against clinical outcomes. We defined real-time as metrics being calculated at a frequency of 24 hours or less. ICU Strain metrics were required directly represented contemporaneous, clinical workload and resources, rather than a downstream operational responses to antecedent pressure (i.e. an indirect or lagging indicator). For example, after-hours discharge reflects a response to ICU strain, and is not a measurement of the ICU activity itself. We included studies that examined a clinically relevant outcome, which was defined as any measure that directly reflects the health status or safety of patients. This included mortality or hospital acquired complications such as pressure injuries and excluded administrative measures as cost.

Exclusion criteria included publications that did not conduct any primary data analysis, such as systematic reviews, opinion pieces, conference abstracts, editorials, case reports, letters to editors, and simulation studies without real patient data.

We excluded patient acuity and illness severity scores as strain metrics as they are derived from patient-level mortality risk, using fixed time windows (e.g., first 24 hours for APACHE), and are primarily designed to describe case-mix and care quality, rather than activity level. For example, a patient with significant comorbidities (reflected in a high illness severity score) may be admitted for routine post-operative monitoring and require minimal intervention, contributing minimally to ICU operational strain. Other exclusions include measures that were qualitative (e.g. burnout), and outcomes that were non-clinical (e.g., financial costs).

Papers identified were screened via a multistage process. First, all abstracts were screened by three reviewers (ST, KK, and MN) with each paper screened by two reviewers. The full texts of all selected papers were then screened by three reviewers for eligibility, with each paper undergoing two independent reviews. Disagreements at each stage were resolved by discussion.

Data extraction

Data extraction was conducted by three reviewers (ST, KK, and MN), using standardized data extraction templates. The following data were extracted: publication data including author, journal, year of publication, study design, time frame, identified strain indicator, adjustments for covariates, and outcomes. For each indicator, we extracted the method of calculation and the frequency of measurement.

Quality Assessment

We assessed the validity of studies using the Newcastle-Ottawa Quality Assessment scale (NOS) version for retrospective cohort studies. Studies were rated between 0–9 and graded high quality if they had a total score of 6–9, moderate quality with a score of 4–5, and poor quality if they had a score of 3 or lower.

Data Analysis

We reviewed all strain metrics classifying them into categories based on a classification derived from a previous systematic review [7]. We classified outcomes based on six dimensions of healthcare quality of safety, effectiveness, patient-centredness, timeliness, efficiency and equity ((https://www.ahrq.gov/talkingquality/measures/six-domains.html). Studies that reported multiple strain or outcome metrics within the same domain had each individual metric included in the analysis.

We reported the results from each strain-outcome pairing using proportions and outlined the consistency and direction of effect. Where the different levels of a single strain metric were assessed, we reported the results from the highest level of strain. Due to heterogeneity in study design, exposures and outcome definitions, a formal meta-analysis was not performed.

We harmonized outcome effect directions to ensure results reflected the impact of worsening strain metric. When studies reported protective effects, we reported the reciprocal of reported odds ratios and risk ratios if available. For example, if a study reported a reduction in mortality from improving in nursing ratios, we would report the reciprocal of the Odds ratio for mortality. We preserved the author's original scaling across studies.

Results

Search results

Our initial search identified 1099 studies, of which 198 duplicates were removed, leaving 901 studies for abstract screening. Of these, 61 of the abstracts were identified as relevant for full-text screening; 27 of these were deemed ineligible based on the original inclusion and exclusion criteria, leaving 34 studies in the final review (Appendix 1: list of excluded studies).

Study Quality

Overall quality scores were high, with a total median score of 8 [IQR 7–9] out of a maximum of nine. Median scores for selection criteria, compatibility and outcome were 3, 2 and 3 respectively. No studies were classified as low quality based on Risk of bias scores (Appendix 3: Risk of Bias Scores).

Study Characteristics

Studies were conducted in a range of settings internationally. Most studies were focused on adult populations (32/34), and 28/34 were multicentered. There was wide variation in the sample sizes of studies, with the smallest having only 39 patients, and the largest being 415 584, with a median of 8 666 (Table 1: Study Characteristics)

Table 1
Study Characteristics

Study Name/Year	Country	Setting	Population (Adult/Paed)	No. of Patients
Anesi 2018	USA	Three hospitals (each with one ED and one medical ICU)	Adult	3,067
Anesi 2020	South Africa	Two public hospitals	Adult	2,630
Bagshaw 2018	Alberta, Canada	Nine integrated ICUs	Adult	12,265
Beltempo 2023	Quebec, Canada	Four level III Neonatal ICUs (NICUs)	Paediatric	1,870
Bihari 2021	Australia and New Zealand	137 hospitals	Adult	57,844
Blayney 2018	Scotland, UK	28 adult general Scottish ICUs	Adult	77,209
Campbell 2024	UK, Australia and New Zealand	Critical care units from 248 Hospitals	Adult	19,491
Cardoso 2019	Lisbon, Portugal	Two ICUs (Curry Cabral Hospital and São José Hospital)	Adult	4,141
Choi 2016	Korea	One tertiary hospital (2 medical, 2 surgical ICUs)	Adult	6,380
Choi 2024	South Korea	Nationwide analysis using the K-NHIS database (patients admitted to ICUs at tertiary hospitals)	Adult	72,950
Chung 2024	South Korea	69 NICUs in Korea	Paediatric	4,745
Endo 2024	Japan	65 ICUs in Japan	Adult	46,503
Ergan 2016	Turkey	1 Internal medicine ICU and 1 neurology ICU of a tertiary hospital	Adult	166
Ersoy 2017	Turkey	Three medical ICUs of a university hospital	Adult	39
Fasoi 2021	Greece	Three adult ICUs of two public hospitals	Adult	293
Fergusson 2020	Canada	Single ICU at Vancouver General Hospital	Adult	10,365
Fergusson 2020	Canada	Single-centre ICU	Adult	7,288
Fundora 2021	USA	Single 27-bed paediatric cardiac ICU (CICU)	Paediatric	1,468
Gulin 2024	Brazil	One nine-bed ICU of a university hospital	Adult	50
Hua 2016	USA	Multiple ICUs (part of Project IMPACT database)	Adult	9,891
Johnson 2024	USA	34 facilities	Adult	9,196
Kahn 2023	USA	29 ICUs across 10 hospitals (UPMC health system)	Adult	51,656
Kim 2016	USA	Fifteen hospitals in California	Adult	70,133
Kim 2025	USA	Single 36-bed medical ICU	Adult	2,589
Lee 2017	Hong Kong	Two ICUs	Adult	845
Ohnstad 2023	Norway	NICUs as part of the Norweigian neonatal network (unclear numbers)	Paediatric	316
Parpucu 2024	Turkey	All tertiary ICUs in 8 training and research hospitals	Adult	54,312
Pilcher 2023	Australia	175 public and private hospitals	Adult	277,737
Roos-Blom 2020	Netherlands	13 intensive care units (ICUs)	Adult	8,136
Sagy 2021	Israel	2 General ICU and 1 Cardiac Care Unit	Adult	382
Wilcox 2020	UK, Wales, and Northern Ireland	214 adult general ICUs in 213 hospitals	Adult	142,310
Wilcox 2022	England, Wales, and Northern Ireland (UK)	207 Hospitals	Adult	284125
Wilde 2021	England	89 English hospital trusts (ICUs within)	Adult	7,133
Zajic 2024	Austria	144 ICUs in Austria	Adult	415,584
Zhilkova 2023	USA	47 Hospitals in New York City	Adult	265,329

Strain metric characteristics.

Across 34 studies, 83 unique strain metrics were studied, which mapped onto 5 of the categories previously identified by Rewa [7] – turnover, nursing workload, occupancy (or census), and staffing, which we further divided into medical and nursing. A single study described a novel composite index that aggregated values [2] (Table 2 – strain metric characteristics). The most common metric was ICU occupancy (40/83), defined as a measure of ICU beds available, whether presented as a proportion of a baseline or as an absolute number.

Table 2
Strain Metric Characteristics

Strain Category	Description	Studies / Authors
Turnover (Admission Rate / Patient Flow)	Number of patients admitted/discharged within a given window	['Anesi, 2018', 'Anesi, 2020', 'Bihari, 2021', 'Cardoso, 2019', 'Hua et al. 2016', 'Kim et al. 2024']
Nursing Workload	Nursing interventions or activities	['Ergan, 2016', 'Fasoi, 2020', 'Gulin et al. 2025', 'Lee et al. 2017', ' Ersoy, 2016', 'Zajic et al. 2024']
Occupancy / Capacity (Census)	Number of ICU patients as a proportion of a baseline (e.g., number of occupied beds, or historical average)	['Anesi, 2018', 'Anesi, 2020', 'Bagshaw, 2018', 'Beltempo, 2023', 'Blayney, 2018', 'Campbell et al. 2024', 'Cardoso, 2019', 'Fergusson, 2019', 'Fergusson, 2020', 'Fundora, 2021', 'Hua et al. 2016', 'Johnson et al. 2024', 'Kim et al. 2016', 'Kim et al. 2024', 'Ohnstad et al. 2023', 'Parpucu et al. 2024', 'Roos-Blom et al. 2019', 'Sagy et al. 2020', 'Wilcox et al. 2020', 'Wilcox et al. 2022', 'Wilde et al. 2021', 'Wilson et al. 2024', 'Zajic et al. 2024', 'Zhilkova et al. 2024']
Staffing (Medical)	Number of medical staff (either absolute or as a ratio)	['Chung, 2024', 'Endo, 2024', 'Fundora, 2021', 'Kahn et al. 2023', 'Kahn, 2023', 'Roos-Blom et al. 2019']
Staffing (Nursing)	Number of nursing staff (either absolute or as a ratio)	['Beltempo, 2023', 'Chung, 2024', 'Parpucu et al. 2024', 'Roos-Blom et al. 2019']
Activity Index	Number of ICU patients + number of patients on CRRT/ECMO/Ventilation + number of patients in isolation, divided by number of staffed beds	Pilcher et al. 2023

All studies calculated the strain metrics at least on a 24-hour basis, with some sampling frequencies of up to hourly.

Patient Outcome characteristics

A total of 76 outcome metrics were reported, describing impacts on effectiveness (n = 43), timeliness (n = 19), efficiency (n = 8), patient-centredness (n = 3) and safety (n = 3). These 76 metrics could be grouped into 11 outcome concepts. The most common outcome metric was hospital mortality (24/76) followed by ICU mortality (19/76) (Table 3 – Outcome characteristics).

Table 3
– Outcome characteristics

Outcome Category	Definition	Study Author + Year
Adverse events	Harmful, unintended incidents during care (e.g., falls, infections, pressure injuries).	['Parpucu et al. 2024', 'Gulin et al. 2025', 'Wilson et al. 2024']
Discharge/Transfer	Patient leaving ICU, whether routine, early, or to another facility.	['Pilcher et al. 2023', 'Kim et al. 2024', 'Blayney, 2018', 'Fergusson, 2020']
Health status	Overall acute health status such as physiological derangements	['Kim et al. 2024']
Hospital LOS	Number of days in hospital.	['Anesi, 2018']
Hospital Mortality	Death during hospital admission.	['Pilcher et al. 2023', 'Bihari, 2021', 'Anesi, 2018', 'Lee et al. 2017', 'Beltempo, 2023', 'Endo, 2024', 'Hua et al. 2016', 'Fergusson, 2019', 'Wilcox et al. 2020', 'Wilcox et al. 2022', 'Wilde et al. 2021', 'Zhilkova et al. 2024', 'Bagshaw, 2018', 'Campbell et al. 2024', 'Fergusson, 2020', 'Kahn et al. 2023']
ICU Length of stay	Number of days in ICU.	['Anesi, 2020', 'Bagshaw, 2018', 'Fundora, 2021', 'Kim et al. 2024']
ICU Mortality	Death during ICU admission.	['Anesi, 2020', 'Cardoso, 2019', 'Zajic et al. 2024', 'Bagshaw, 2018', 'Fundora, 2021', 'Parpucu et al. 2024', 'Zhilkova et al. 2024', 'Fergusson, 2019', 'Johnson et al. 2024', 'Ergan, 2016', 'Fasoi, 2020', 'Chung, 2024', 'OrtaÃ§ Ersoy, 2016', 'Wilcox et al. 2020', 'Kahn et al. 2023']
ICU admission	Likelihood of admission to ICU	['Anesi, 2018', 'Anesi, 2020', 'Campbell et al. 2024', 'Kim et al. 2016', 'Sagy et al. 2020']
Pain management	Assessment and treatment of pain.	['Roos-Blom et al. 2019']
Readmission	Return to hospital within a set timeframe after discharge.	['Pilcher et al. 2023', 'Fergusson, 2020']
Ventilation outcomes	Results of mechanical ventilation (duration, success, complications).	['Ohnstad et al. 2023']

A total of 116 analyses between strain metrics and outcomes were conducted, of which 53% (62/116) demonstrated a statistically significant worsening of patient outcomes with increasing strain, while 84% (97/116) of point estimates from analyses (regardless of statistical significance) suggested worse patient outcomes with increasing ICU strain.

The most common analyses involved ICU mortality (41/116) and hospital mortality (32/116). An increase in any strain measure was associated with higher ICU mortality in 44% (18/41) of analyses, and with higher hospital mortality in 66% (21/32) of analyses. Point estimates demonstrated an association in 88% (36/41) of ICU mortality analyses and in 91% (29/32) of hospital mortality analyses (Appendix 4 Figs. 1 and 2).

Strain metrics with a consistent association with adverse outcomes were nursing staffing (8/9), and nursing workload (6/8). The ICU activity index was a composite score comprising occupancy, nursing workload, and staffing, was associated with patient outcomes across all assessed measures(5/5). (Fig. 2; Table 4: Strain metric and Outcome analyses).

Table 4
– Strain metric -outcome analyses (significant association / total analyses)

Strain Metric	Outcome Domains									
	Adverse events	Discharge/Transfer	Health status	ICU admission	Pain management	Readmission	Ventilation outcomes	Hospital Mortality	ICU Mortality	Hospital Length of stay
Activity Index		3/3				1/1		1/1		
Turnover		0/1	0/1	1/2				4/4	1/5	
Nursing Workload	1/1							0/1	5/6	
Occupancy / Capacity	2/2	3/4	0/1	3/6	0/1	0/1	0/3	12/21	8/15	1/3
Staffing (Medical)					0/1			1/2	2/11	
Staffing (Nursing)	1/1				2/2			3/3	2/3	

Occupancy and turnover had moderate association with patient outcomes. Across the 63 analyses involving ICU occupancy as a strain metric, 33 of them demonstrated an adverse impact on patient outcome. Turnover was assessed in 16 analyses, of which 7 demonstrated a relationship with adverse outcomes. Across all analyses demonstrating a significant relationship, the direction of the effect was positive (i.e. worsening strain led to a worse outcomes).

Medical staffing was poorly associated with patient outcomes (3/14).

Discussion

Summary of key findings

We have identified a set of real-time ICU strains metrics validated against clinical outcomes. Nursing workload, and nursing staffing were most strongly associated with adverse outcomes, whilst occupancy and turnover were moderately discriminatory.

Relation to Existing Literature

Accurately defining and quantifying ICU strain is a key step to ensure resourcing is proportionally matched to avoid adverse patient outcomes, leading several authors to identified the need for a consensus framework on measuring ICU strain [8,10,11]. To date, there has not been any formal, accepted approach to the definition of ICU strain, creating variability in the acceptability of the reported metric and the characteristics of the data collected. Existing reviews have approached ICU strain as a singular concept [7,10–12], leading to considerable heterogeneity in how strain metrics are defined, measured and validated. Whilst long-term retrospective data may be useful to understand trends to make decisions around service planning, decision making for real-time ICU operations requires timely, regular measurements.

Our review focused on strain metrics calculated at a frequency of 24-hour or higher. There was a high level of consistency in the relationship between these measures and patient outcomes. Although only 54% of evaluations achieved statistical significance, the consistency in effect across estimates suggest a signal of harm from ICU strain, supporting the growing recognition that dynamic fluctuations in ICU strain have important clinical consequences [13]. This is a distinction from other reviews which have included strain metrics measured over longer period, which may be less useful for detecting strain-associated patient impacts [7,10,14].

The importance of ICU nursing staffing and workload on patient outcomes is consistent with a growing body of evidence on the importance of the Critical Care nursing workforce in supporting quality ICU care [15]. This supports our conceptual framework that exposure to ICU strain directly mediates the quality of

care delivered to individual patients. For example, workload factors such as patient interventions impact the capacity for nursing staff to deliver a certain standard of patient care, leading to downstream impacts on patient safety and outcome [16].

Despite the popularity of occupancy as an ICU strain metric, it was only moderately associated with adverse outcomes. This was likely related to variations in definition, with occupancy examined from various perspectives, with some studies even examining various definitions of strain within a single context [17,18]. For example, Zhilkova [19] measured occupancy as a function of pre-pandemic "baseline" levels, whilst Bagshaw[20] used occupancy at the time of admission. A similar challenge affects patient turnover, which can be calculated in range of patterns. Our findings are consistent with other systematic reviews which have flagged the moderate impact of these metrics [7,10], highlighting their importance as strain measurement, but also limitations as a stand-alone measurements.

Several studies also identified ICU turnover (the rate of admissions and discharges over time) as moderately associated with strain-related outcomes. Despite this, ICU turnover is less frequently reported in the literature as strain metrics compared to static measures like occupancy measures, which may reflect greater adoption in decision-making. This highlights the importance of considering temporal dynamics of strain, as ICUs with similar point-in-time occupancy may experience markedly different levels of operational stress depending on patient turnover and admission clustering.

Implications

Our findings suggest that real-time monitoring of ICU strain should be informed by a multi-component measure comprised of nursing staffing, nursing workload, occupancy and turnover. This metric would inform real-time, operational decision-making around resource allocation, and could be further integrated into predictive approaches to identify ICU strain ahead of time, facilitating interventions to avoid the strain states.

These measures may need modifications to meet the feasibility of real-time measurement based on institutional data capability. For example, nursing workload had been measured in several studies using validated tools such as the Nursing Activity Score [21,22]; however, these are multicomponent (up to 23 for NAS) that are cumbersome to calculate. A simplified approach may be considered; for example, Pilcher et al used a simplified intervention score, focusing on patients who requiring high-intensity nursing interventions such as mechanical ventilation[2].

Similarly, turnover rate requires a temporal review of events and may add additional computation to derive. In both cases, the adoption of electronic health records may provide an opportunity to automate derivation of complex metrics for more robust system monitoring [23].

Limitations

Our review has limitations. First, studies were limited to observational designs, so the causality between strain and outcome could not be confirmed. Second, ICU strain, due to lacking a formal consensus definition, did not have a specific term that could be easily mapped. For example, studies included terms such as ICU workload. We addressed this by creating a robust search strategy, utilising a range of concepts to triangulate papers on measures on ICU strain assessed against patient outcomes, and accepting a lower specificity with a higher volume of papers to review.

Third, there was considerable heterogeneity in system factors that may influence the impact of ICU strain. For example, ICUs in Australia are often closed ICUs that have dedicated, specialised ICU staffing, which may ameliorate some of the impact of strain. Unfortunately, the operation structures of each setting were inadequately described, making contextualisation to varied system organisation difficult to define. Fourth, a number of included studies were conducted during the COVID-19 pandemic, during which ICUs experienced extreme levels of strain; it is unclear if pandemic driven strain is represents a different conceptual structure from routine "business as usual" operations.

Conclusions

Nursing staffing, nursing workload, occupancy and turnover rates are real-time ICU strain measures strongly associated with patient outcomes. Monitoring of ICU strain should consider a multi-component metric that incorporates these metrics, with adaptations to support ease of measurement. This would inform the development of a broader framework on the monitoring and management of ICU strain and form the basis of a system for real-time monitoring and proactive intervention to improve patient outcomes. Future research should explore the validity of composite measures for both prospective monitoring and prediction modelling of strain states, as well as integration into real-time ICU decision support systems.

Declarations

Competing Interests

The Authors do not have any competing interests to declare.

Author Contribution

ST conceived the study, and performed independent screening and data extraction with KK and MN. DC, DP, and VR supervised the study and reviewed the manuscript.

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We acknowledge the support of our research librarian (CG).

Data Availability

Data sharing is not applicable as no new datasets were generated. Data extracted and summarised are available in this article and associated appendices.

References

1. Massey, D. & Gillespie, B. M. Rising above the strain? Adaptive strategies used by healthcare providers in intensive care units to promote safety. *BMJ Qual. Saf.* **34**, 67–69 (2025).
2. Pilcher, D. V. *et al.* Measuring the Impact of ICU Strain on Mortality, After-Hours Discharge, Discharge Delay, Interhospital Transfer, and Readmission in Australia With the Activity Index. *Crit. Care Med.* **51**, 1623–1637 (2023).
3. Bravata, D. M. *et al.* Association of Intensive Care Unit Patient Load and Demand With Mortality Rates in US Department of Veterans Affairs Hospitals During the COVID-19 Pandemic. *JAMA Netw. Open* **4**, e2034266 (2021).
4. Starcher, R. Intensive Care Strain Indicators: Recommendations for Critical Care Processes and Research Objectives. *J. Anesthesiol. Pain Ther.* **4**, (2023).
5. Bagshaw, S. M. *et al.* Healthcare Provider Perceptions of Causes and Consequences of ICU Capacity Strain in a Large Publicly Funded Integrated Health Region: A Qualitative Study. *Crit. Care Med.* **45**, e347–e356 (2017).
6. Opgenorth, D. *et al.* Perspectives on strained intensive care unit capacity: A survey of critical care professionals. *PLoS ONE* **13**, e0201524 (2018).
7. Oleksa, R. *et al.* Indicators of intensive care unit capacity strain: a systematic review. *Crit. Care* https://doi.org/10.1186/s13054-018-1975-3 (2018) doi:10.1186/s13054-018-1975-3.
8. Duggal, A. & Mathews, K. S. Impact of ICU strain on outcomes. *Curr. Opin. Crit. Care* **28**, 667 (2022).
9. Douglas, I. S., Mehta, A. & Mansoori, J. Policy Proposals for Mitigating Intensive Care Unit Strain: Insights from the COVID-19 Pandemic. *Ann. Am. Thorac. Soc.* **21**, 1633–1642.
10. Neupane, M. *et al.* Measures and Impact of Caseload Surge During the COVID-19 Pandemic: A Systematic Review. *Crit. Care Med.* **52**, 1097–1112 (2024).
11. Douglas, I. S., Mehta, A. & Mansoori, J. Policy Proposals for Mitigating Intensive Care Unit Strain: Insights from the COVID-19 Pandemic. *Ann. Am. Thorac. Soc.* **21**, 1633–1642 (2024).
12. Oleksa, R. *et al.* Indicators of intensive care unit capacity strain: a systematic review. *Crit. Care* https://doi.org/10.1186/s13054-018-1975-3 (2018) doi:10.1186/s13054-018-1975-3.
13. Opgenorth, D. *et al.* Perspectives on strained intensive care unit capacity: A survey of critical care professionals. *PLOS ONE* **13**, e0201524 (2018).
14. Eriksson, C. O., Stoner, R. C., Eden, K. B., Newgard, C. D. & Guise, J.-M. The Association Between Hospital Capacity Strain and Inpatient Outcomes in Highly Developed Countries: A Systematic Review. *J. Gen. Intern. Med.* **32**, 686–696 (2017).
15. Ross, P., Howard, B., Ilic, D., Watterson, J. & Hodgson, C. L. Nursing workload and patient-focused outcomes in intensive care: A systematic review. *Nurs. Health Sci.* **25**, 497–515 (2023).
16. Almenyan, A. A., Albuduh, A. & Al-Abbas, F. Effect of Nursing Workload in Intensive Care Units. *Cureus* **13**, e12674.
17. Wilcox, M. E., Harrison, D. A., Patel, A. & Rowan, K. M. Higher ICU Capacity Strain Is Associated With Increased Acute Mortality in Closed ICUs*. *Crit. Care Med.* **48**, 709–716 (2020).
18. Anesi, G. L. *et al.* Association of a Novel Index of Hospital Capacity Strain with Admission to Intensive Care Units. *Ann. Am. Thorac. Soc.* **17**, 1440–1447 (2020).
19. Zhilkova A. *et al.* Full title: Hospital segregation, critical care strain, and inpatient mortality during the COVID-19 pandemic in New York City. *medRxiv* https://doi.org/10.1101/2023.12.04.23299393 (2023) doi:10.1101/2023.12.04.23299393.
20. Bagshaw, S. M. *et al.* Association between strained capacity and mortality among patients admitted to intensive care: A path-analysis modeling strategy. *J. Crit. Care* **43**, 81–87 (2018).
21. Ergan B. *et al.* The relationship between nurse workload and mortality in two different ICUs. *J. Med. Surg. Intensive Care Med.* **7**, 21 EP – 27 (2016).
22. Faisy, C. *et al.* Nurse workload and inexperienced medical staff members are associated with seasonal peaks in severe adverse events in the adult medical intensive care unit: A seven-year prospective study. *Int. J. Nurs. Stud.* **62**, 60–70 (2016).
23. Kirilov, N. Capture of real-time data from electronic health records: scenarios and solutions. *mHealth* **10**, 14 (2024).

Figures

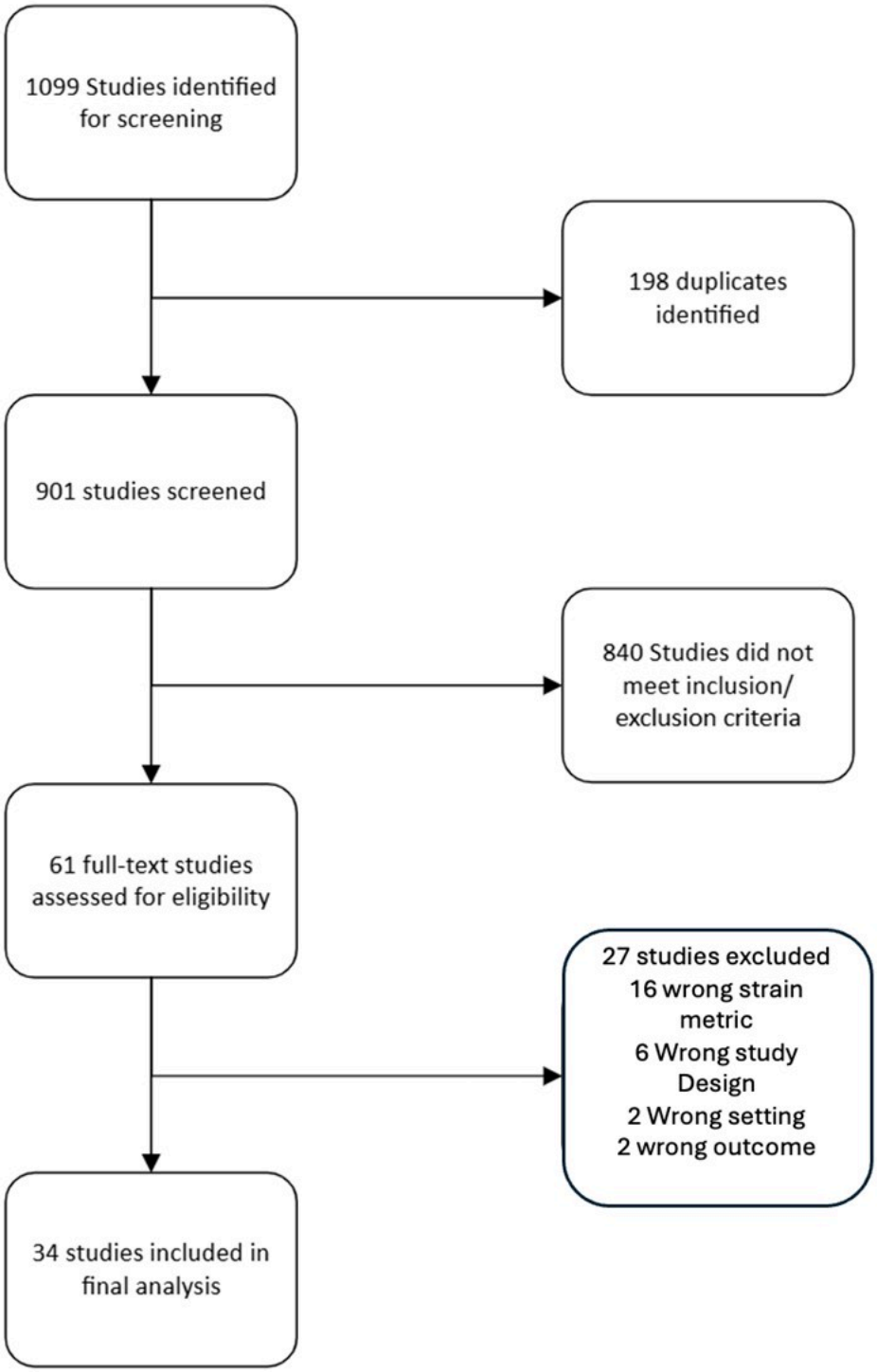


Figure 1

Study flow chart

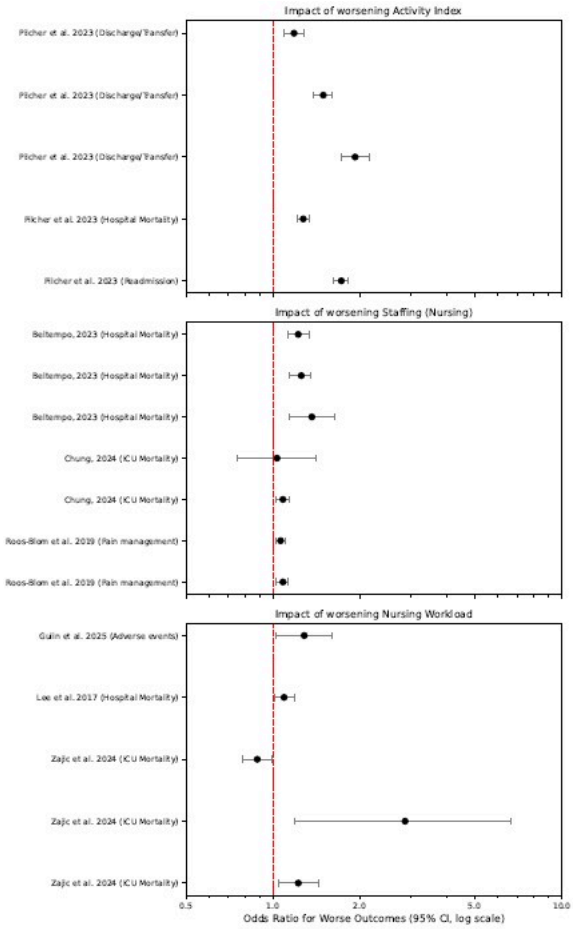


Figure 2

Relationship between worsening Activity Index., Nursing Workload, and Nursing Staffing and outcomes. Individual studies may have multiple strain metrics mapping onto the same category. Higher is worse outcomes.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CombinedAppendices.docx