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Intensive Care Strain Indicators: Recommendations for Critical Care Processes and Research Objectives

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Abstract

Intensive care units (ICU's) are particularly susceptible to resource and personnel strain given the complexity and unpredictability of care. This featured prominently in the early course of the SARS-CoV-2 (COVID-19) pandemic, where poor patient outcomes were clearly linked to the increasing severity of ICU strain associated with decreased ICU capacity. Despite attempts at measuring ICU strain, there exists no operational model that ICU directors can implement to monitor strain or researchers can use to examine its effects.

This article reviews ICU strain indicators including census load (census, acuity, and admissions), ICU flow characteristics (admission/discharge criteria, sufficient staffing levels, and ICU performance), and consequence mediators (ICU queuing time and high-risk discharges) with attention to common themes and measures. Census load data suggests mortality risk is greater when ICU census starts higher, has high overall acuity, and with greater numbers of admissions especially when they arrive close together. Optimal ICU flow depends on maintaining a "strain mindset" when prioritizing patients, optimal ICU professional staffing, and maintaining high level ICU performance processes. Finally, delaying ICU admissions beyond six hours, or "after hours" or rushed ICU discharges result in increased mortality risk. Incorporating these ICU strain factors into an outcomes-focused model is proposed based on a conceptual framework with future research objectives recommended.

Introduction

Intensive care unit (ICU) strain is defined as a dynamic discordance between available ICU resources and clinical demand[1]. It can result in denied or delayed admissions, substandard care, and premature discharges which can lead to increased risk of disability and death[1,2]. The swiftness with which SARS-CoV-2 (COVID-19) overwhelmed intensive care units (ICUs) highlights the importance of responding to ICU strain[3,4].

The response to ICU strain confronts two challenges: identifying objective measurements accurately reflecting strain and compiling them into an operational model tied to patient outcomes[5]. Components of ICU strain are ICU census, admissions, and acuity which together we define as census load[6-10]; flow characteristic including ICU admission and discharge criteria, and staffing; and the impact of ICU queuing time and high risk discharges (Figure 1) which we define as consequence mediators.

This article will review ICU strain from clinician and leadership perspectives, with recommendations for future research priorities.

Measurements of ICU Strain

Hospitals should routinely accommodate up to 120% of their baseline critical care capacities due to emergency activations or routine severe surge episodes[11,12]. ICU surge capacity is the ability to mobilize physical and human resources to meet greater demand for patient care needs (Figure 1)[6,7,13-17], but setting a binary threshold for "strain" does not describe the surge continuum[15,16]. Though current published ICU strain data is of association level quality much of it comes from large databases where even small statistically significant differences have substantial impact on large populations[6,7,18].

Census load

From the Project Impact Database (264,401 patients), ICU admissions during higher census periods were associated with significantly increased mortality, which persists on succeeding days 1-3 if ICU census remains high. Mortality risk was slightly less when beds were available but demonstrated increased risk on succeeding days if ICU census again rose[7]. In a smaller resource-limited setting, ICU mortality was also associated with increased ICU census on admission day[8].

ICU acuity is the second component of census load. From the Project Impact Database study, mortality due to acuity was observed only for the highest acuity ("sickest") 20% of ICU admissions, and remarkably, this risk was more significant in closed ICUs[7]. That closed ICU's may have greater risk suggests provider resources may be insufficient during severe strain compared to their open ICU counterparts.

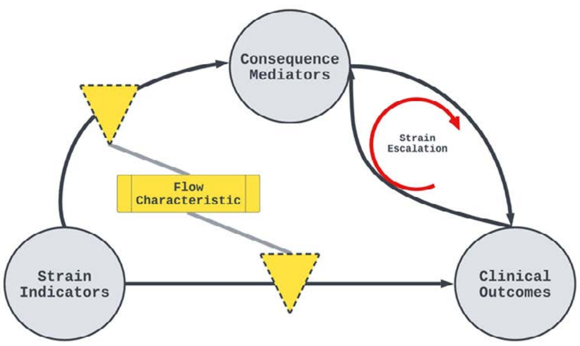

Figure 1: Outcomes-focused strain model

Strain outcomes (the associated increased risk for worse clinical outcomes due to strain) result primarily from increasing census load, including ICU census, admissions, and acuity; and secondarily from consequence mediators, factors that mediate outcomes at ICU admission and discharge. Escalating strain worsens outcomes, lengthens admission time, and rushes discharge time in a potentially cyclical manner. The flow characteristic provides opportunities to intervene on strain through staffing, and admission and discharge protocols. This complex system of interactions calls for multivariate modeling to account for both direct and indirect effects of strain on clinical outcomes. (Figure designed with Lucidchart at www.lucidchart.com)

Similarly, from the United Kingdom's (UK) Intensive National Audit and Research Centre's (ICNARC) Case Mix Program (142,310 patients), increased mortality was significantly associated with increasing ICU census and ICU acuity. Mortality also increased with higher census weighted strain where new admissions were weighted twice and discharges half as those ICU patients already present on a given day. ICUs in this study were closed models[6].

Finally, admissions within 55 minutes of each other (near simultaneous back-to-back) demonstrated significant risk of increased hospital mortality, which increased further as the admissions drew closer together in time[9].

Together, these data suggest mortality risk is greater when ICU census starts higher with a greater number of admissions especially when they arrive close together, and overall unit acuity likely contributes at the high end but may not predict the impact of strain in all cases. We have termed this combination of factors ICU "census load," (Figure 1 and Table 1)[10]. These concepts are routinely used qualitatively by bedside clinicians in ICU practice[6] and reflect the personnel resources necessary to provide quality care. Measurement of ICU acuity is more complex and deserves further comment.

Measurement of ICU Acuity

Strain models assessing total or average ICU acuity have utilized well-validated systems that predict individual patient mortality[19-21] as surrogates for total ICU acuity[6-8,13,22], and have been adjusted for the presence of mechanical ventilation and/or vasopressors, typical ICU resource-intensive therapies[7,13]. Perhaps due to relative simplicity and that it relies only on data acquired during the first hour of admission, the Mortality Probability Model$_0$-III[21] has been commonly implemented in strain measurement models including the Project Impact Database[7,8,13,22]. Other mortality prediction models include the Acute Physiology and Chronic Health Evaluation (APACHE) II, III, IV; Simple Applied Physiology Score (SAPS III); and sequential organ failure assessment score (SOFA)[19,20,23]. Most require data generated over the first 24 hours after ICU admission making them less useful at the admission timepoint.

For hospitals lacking access to prognostic scoring systems, use of individual organ failures as independent assessments of acuity and/or prognosis in the setting of scarce resources was recommended during the COVID-19 pandemic, and can also be used under routine circumstances (Table 1)[24-26].

Table 1: Recommended strain ICU indicators, process metrics, and outcomes of care

Strain indicator	Process Metrics
Census Load	**Combined census, admission timing, and unit acuity dashboard**
Census	• Occupied intensive care unit (ICU) beds, **or** • Available staffed ICU beds per shift (8 or 12 hours)
Admission	• Number of ICU admissions per shift (8 or 12 hours) **and** • Time (Minutes) between ICU admissions
Unit Acuity	• Mortality prediction models (e.g. MPM_0[a] III, APACHE[b] II, III, IV; SAPS[c] 2; SOFA[d])[19-21,23] at admission, or averaged over ICU admissions during the immediate preceding 24-48 hours to establish a daily baseline acuity **or (if unavailable)** • The number of organ systems receiving ongoing support (per patient and averaged for all ICU patients at time of measurement; daily or per shift)[24-26] * Respiratory: Use of mechanical ventilator, bilevel positive airway pressure (BIPAP), continuous positive airway pressure (CPAP), or high flow nasal cannula (HFNC). * Cardiovascular (shock): Use of vasopressors or other vasoactive medications. * Cardiac: Use of invasive cardiovascular devices including intra-aortic balloon pump (IABP); Impella device; pulmonary artery catheter; and/or aggressive vascular therapies/infusions not otherwise accounted for. * Renal: Use of renal continuous replacement therapy or acute hemodialysis. * Central Nervous System (CNS): Need for aggressive monitoring and/or adjustment of care, e.g. presence of invasive devices including intracerebral pressure (ICP) monitor and/or need for frequent monitoring or metabolic or infusion therapies. * Metabolic support including titratable therapies for other organ system support (e.g Insulin, hypertonic saline, aggressive volume replacement to prevent tumor lysis syndrome or management of diabetes insipidus, etc. * Tertiary or quaternary care facilities may have unique populations that require high level monitored care.
Flow characteristics	**Protocols for efficient staffing, admission, and discharge criteria**
Admissions consistent with admission criteria	• The number of patients admitted consistent with ICU admission criteria • The number of patients with goals of care discussion completed before ICU admission
Response to unit surge in a timely manner with appropriate staffing	• Institution defined criteria and process for routine and surge staffing including potential tiered staffing model with "extenders" • Availability of critical resource and float nurses • ICU quality of care processes consistent with established standards of care
Discharges consistent with discharge criteria	• Discharging patients who are physiologically stable and medically maximized; discharge decisions not determined by bed or staffing needs • Operate in a "strain mindset" at all times to optimize timely discharges • The number of patients with goals of care discussion completed prior to ICU discharge • Monitor ICU readmissions within 48 hours
Consequence Mediators	**Results of strain that compound its effects**
Queuing Time	• Time from ICU acceptance to patient admission (goal ≤ 6 hours) • Number of admissions taking > 6 hours • Number of patients currently waiting in queue • Number of patients transferred to other ICUs or hospitals
High Risk Discharges	• Number of after-hours and/or unplanned ICU discharges with explicit motivation to increase bed capacity (goal = 0) • The number of readmissions within 48 hours
ICU Outcomes	• Mortality (hospital and ICU) • Length of stay (LOS): hospital and ICU • ICU readmission (within 48 hours) • Hospital discharge disposition • Physical and cognitive functional level at ICU and hospital discharge • Duration of organ system support (each organ)

[a]Morbidity Prediction Model (time 0), 3rd revision
[b]Acute Physiology and Chronic Health Evaluation Models, 2nd, 3rd, and 4th revisions
[c]Simplified Acute Physiology Score Model, 2nd revision
[d]Sequential Organ Failure Assessment Model

ICU Flow Characteristic

ICU flow characteristic is defined as criteria by which ICU admission and transfer decisions are determined and how patient care is optimized while in the ICU (Table 1).

This includes optimal staffing and published literature clearly demonstrates higher intensity nursing, physician, and pharmacy staffing decreases ICU and hospital length of stay LOS and mortality[27-31].

ICU nurse staffing requires optimizing both sufficient numbers of nurses and appropriate workload, both of which contribute to decreasing mortality risk, and with lapses in either causing significant degradation of care[27,28,32,33]. In addition, experienced nursing teams have greater resilience for reallocating nursing resources, co-locating nursing assignments, and functioning with higher autonomy[27,29,32]. Finally, nursing leadership strongly advocates for having dedicated personnel to fill shift based responsibilities, such as critical resource and float nurses to optimize quality, safety, and cost[34].

Appropriate full time intensivist staffing decreases ICU and hospital mortality risk though night-time staffing is less supported by published data[28,29,31,35]. There is little data to recommend maximum ratios of patients to intensivists, and the Society of Critical Care Medicine suggests acknowledgement that staffing impacts care, staffing patterns should factor in surge capacity, and decreases in performance indicators may be markers of intensivist overload[29-32].

Pharmacist presence as part of the ICU team has been demonstrated to decrease ICU mortality, LOS, and adverse drug events[30]. Inordinate pharmacist workload has also been demonstrated to result in decreased amount of care, may contribute to increased ICU LOS and adverse drug events, and argues for implementation of electronic tools that assess medication regimen complexity to help inform staffing[36].

Preventing adverse consequences during routine surge requires having sufficient levels of all professional staff and readily available staff resources to rapidly escalate and deploy in response to surge intensity[9]. In some instances, demand for staff exceeds available supply. Increasing patient volume during the COVID-19 Pandemic clashed with higher rates of staff absences due to quarantine or personal reasons, and insufficient staff, especially nurses contribute to a vicious cycle of staff burnout[37,38].

In these cases, “extenders” from acute care backgrounds were often pulled into the ICU through tiered staffing models to help cover ICU and non-ICU medical and nursing needs[25,39-41]. Due to the multitude of confounding factors, it is unclear whether this approach was effective at improving clinical outcomes, but it did expand bed capacity[42].

As ICU capacity approaches 100%, admissions decline, ICU LOS decreases often by 6-7 hours with minimal readmission risk (1%) and no change in mortality[13,18,43]. This pressure to discharge ICU patients is familiar to critical care clinicians, and likely represents efficiency in appropriate ICU discharges[13,42]. Strain is also associated with greater numbers of DNR orders in patients referred for ICU admission[17], and shorter times to DNR orders and death for patients in closed model ICUs[43]. In both circumstances, these decisions have not been associated with increased expected mortality, suggesting additional care would not have been beneficial and lending support for addressing goals of care, ideally prior to seeking ICU admission[43,44].

For ICU leaders this data suggests that disciplined adherence to admission and discharge criteria is important for optimal patient flow irrespective of bed availability and time of day, and maintaining a focus on a “strain mindset” will facilitate rapid admission and appropriate, safe, and timely discharge. ICU bed availability is the sole non-clinical variable recommended by the Society of Critical Care Medicine’s (SCCM) guidelines for triage, and lower bed census may lead to higher numbers of admissions with less stringent barriers[45].

Optimal ICU flow also depends upon adherence to performance improvement processes as previously recognized[1].

Consequence Mediators

The upstream and downstream consequences of ICU strain create risk for patients having their admission delayed and/or having their ICU discharge be premature[11,46]. (Table 1)

Queuing time

In the prospective study from the UK (ICNARC) Case Mix Program, inpatients admitted to critical care under the strain of decreasing numbers of ICU beds had corresponding significantly increased times to prompt admission[18]. Patients admitted promptly to ICU (≤ 4 hours) had significantly decreased 90-day mortality, not unexpected given the foundational critical care principle that early care prevents or lessens acute organ damage[18,47].

Insufficient ICU beds may result in admission delays or refusals from the ED, inpatient areas including PACU, and medical/surgical ward areas[1,6,18,48]. The longer a critically ill patient remains in the ED awaiting ICU admission, the higher predicted probability of persistent organ dysfunction or death which may increase hourly[48-50], a finding also noted in ward and PACU patients[50-52]. The consequence of delayed ICU admission has previously led to the recommendation for establishing a limited incident command structure to escalate resolution with time from ICU acceptance until arrival ≤ 6 hours[1,52].

High risk discharges

Discharging patients from the ICU “after hours” has been associated with increased ICU readmission[53], in-hospital mortality[53-55], length of stay[54], and cost[45]. It is unclear whether these risks are due to pre-emptive discharges

Table 2: Recommended best practices to proactively mitigate the effects ICU strain

- Admit all queued patients within 4-6 hours, or ensure transfer processes to other units or hospitals
- Proactively contribute Intensivist management of patients awaiting ICU admission when waiting ≥ 4 hours
- Formulate proactive strategy to manage inter-hospital patient transfers when hospital/health system ICUs are at full capacity
- Complete admission of all ICU patients within 60-90 minutes of ICU arrival including placement of invasive procedures (e.g. central line, arterial line, intubation, etc.)
- Formulate strategy for securing additional staffing resources when ICU census inordinately high and/or concurrent admissions arriving
- Address each patients' goals of care prior to, or upon ICU admission as a standard expectation; readdress ongoing or at ICU discharge as appropriate.
- Adhere to formal ICU discharge process and avoid after hours discharges unless anticipated or planned

prior to medical stability or subsequent decompensation due to missed care items. SCCM recommends avoiding after hours discharges but importantly having a standard discharge process with written and oral formats to ensure safe discharges and reduce readmission risk[45].

The consequence of delaying appropriate ICU admissions or rushing ICU discharges is increasing risk of mortality, and we define consequence mediators as actions that effectively and safely facilitate these processes (Figure 1 and Table 1).

COVID-19 Pandemic

The COVID-19 pandemic placed the risks of ICU strain on the forefront of care worldwide and retrospective data from surge models depict the bleak mortality trends and the heroic adaptations evolved to confront them[10,25,56-59].

The COVID-19 pandemic resulted in severe ICU strain which may have accounted for excess mortality of 25-100% of COVID-19 patients, particularly those requiring mechanical ventilation or renal replacement therapy[10,56,57]; the non-COVID-19 ICU population was equally affected[60].

Published studies demonstrate a powerful influence of severe surge and ICU strain on mortality, and needed future planning[10,56,57,61]. Equipment shortages, including ventilators and dialysis equipment were limiting primarily during the first wave of the pandemic (March and April 2020); thereafter, the most significant limiting resource were healthcare staff[25,62,63]. Foremost among response strategies are tactics for intensifying surge capabilities include integrating non-ICU professionals as force multipliers, as discussed above[25,39-41,56].

Developing a model for ICU strain

The composites of census load including unit census, admissions, and acuity are currently used by clinicians to assess available resources, especially when evaluating prospective admissions. For clinician leaders, dashboard tracking of this data will help inform resource planning. Future research should quantitatively account for all three census load variables' individual and cumulative effect on ICU processes and outcomes (Table 1), a balance which further impacts resource planning and response to unforeseen large events.

Optimal ICU flow, in addition to disciplined adherence to admission and discharge criteria and goals of care discussions, depends upon matching the number of clinical staff to routine and intermittent severe surge demands. Specific clinical staffing guidance is incomplete and future research should help quantify staffing needs and impact on unit outcomes and the impact of each disciplines' process and performance objectives.

Consequence mediators are routinely prioritized and managed by ICU clinicians. Strategies that limit queuing time and result in disciplined formal completion of ICU discharges help mitigate the consequences of increasing strain. Clinical leadership should have a dashboard of pertinent data and performance standards for consequence mediators (Table 2), and future research should more precisely define parameters and impact on outcomes.

The purpose for ICU strain indicators is to recognize when ICU surge is increasing and mobilize more resources—often quickly—or transfer patients to more resourced ICUs or hospitals, when necessary. When surge rises, mortality also rises, catastrophically so in the case of the COVID-19 pandemic. The quality of ICU care may be dramatically improved as future knowledge of the level of strain is recognized, understood, defined, and solutions operationalized in responding to ICU strain promptly and effectively.

Conflicts of Interest

The authors have no conflicts of interest to disclose regarding this manuscript.

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