The impact of resource limitations on care delivery and outcomes: routine variation, the coronavirus disease 2019 pandemic, and persistent shortage

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Purpose of review
Resource limitation, or capacity strain, has been associated with changes in care delivery, and in some cases, poorer outcomes among critically ill patients. This may result from normal variation in strain on available resources, chronic strain in persistently under-resourced settings, and less commonly because of acute surges in demand, as seen during the coronavirus disease 2019 (COVID-19) pandemic.

Recent findings
Recent studies confirmed existing evidence that high ICU strain is associated with ICU triage decisions, and that ICU strain may be associated with ICU patient mortality. Studies also demonstrated earlier discharge of ICU patients during high strain, suggesting that strain may promote patient flow efficiency. Several studies of strain resulting from the COVID-19 pandemic provided support for the concept of adaptability – that the surge not only caused detrimental strain but also provided experience with a novel disease entity such that outcomes improved over time. Chronically resource-limited settings faced even more challenging circumstances because of acute-on-chronic strain during the pandemic.

Summary
The interaction between resource limitation and care delivery and outcomes is complex and incompletely understood. The COVID-19 pandemic provides a learning opportunity for strain response during both pandemic and nonpandemic times.

Keywords
capacity strain, coronavirus disease 2019, critical care, ICU, pandemic

INTRODUCTION
The resources dedicated to the care of critically ill patients has long been under scrutiny through various lenses. At a national level, researchers and policy experts have noted the high degree of variability in the number of ICU beds per capita [1] – one measure of critical care resource utilization – and elucidated the tradeoffs of high access to critical care and low-value resource utilization. The United States has been criticized for having too many ICU beds [2]; however, the coronavirus disease 2019 (COVID-19) pandemic has provided a striking example of how countries with even the highest critical care capacity can become strained, reigniting debate about optimal capacity.

A commonly used framework for describing capacity and resource utilization organizes critical care delivery into ‘the three S’s’ – space, staff, and stuff [3,4]. Space refers to the physical space where critical care occurs, defined during normal times by the number of existing ICU beds, for example, in a hospital, region, or country. However, critical care delivery can happen virtually anywhere, as exemplified recently as hospitals expanded ICU footprints into other areas to respond to high patient volume during the COVID-19 pandemic [5,6]. Second, critical care delivery requires staff with expertise in bedside care, operations, and support services, and across many disciplines of healthcare [7]. Last, ‘stuff’ refers to the specialty equipment

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KEY POINTS

- Circumstances where demand for critical care services threatens to or exceeds supply is associated with ICU triage decisions and possibly increased mortality.
- ICU strain is also associated with earlier ICU discharge, potentially without harm, and further studies of the relationship between ICU strain and ICU discharge may provide insights to improve patient flow efficiency.
- The COVID-19 pandemic is a generational event that has caused acute, severe, and widespread strain on available ICU resources that has both caused detriment and increased knowledge about how to respond to strain in pandemic and nonpandemic times.
- Persistent resource-limited settings must carefully utilize referral practices to optimize efficiency and access to care, even more challenging in circumstances of acute-on-chronic strain.

required for critical care – telemetry monitors, mechanical ventilators, and dialysis machines, as core examples.

Resource limitations, which we equate to ‘capacity strain’, occur when demand rises relative to supply in any or all of these domains. This mismatch can represent a challenging but temporary deviation from the usual supply–demand ratio of care resources, or an overt shortage of supply, or both. Demand can increase because of more patients, patients of higher acuity, and patients with special care requirements. Supply can diminish because of infrastructure loss, clinician shortages, or disrupted supply chains. In this article, we will review recent literature about ICU and hospital capacity strain. We will discuss strain related to routine ebbs and flows in critical care demand; because of surges of critical care demand, using the COVID-19 pandemic as a salient and current example; and in persistently resource-limited settings. We considered the impact of capacity strain and resource limitation on both care delivery and clinical outcomes, as the extent to which documented care delivery modifications have influenced outcomes is still under widespread investigation and changes in care delivery are often important patient-centered and clinician-centered outcomes in and of themselves [8].

CAPACITY STRAIN AND OUTCOMES WITHIN ROUTINE VARIATION

Although available resources for critical care are typically fixed – an ICU with its allotted beds, supplies, and staffed teams – demand for those resources routinely fluctuates, depending on the time of day, day of week, and season, and several studies have sought to elucidate the effects of this variability on capacity strain. Early studies of patients in emergency departments defined hospital strain according to delays in transfer to ward or ICU beds and had inconsistent results regarding association of emergency department boarding time with patient mortality [9]. Later studies of ICU patients refined definitions of capacity strain, including not only measures of patient census and volume but also measures of turnover, acuity, and workload [10,11]. Observational studies have demonstrated relationships between strain on ICU resources with care and outcomes along the continuum of care of critically ill patients. For example, ICU capacity strain is associated with differences in triage decisions, such that marginal patients (such as patients with sepsis but not requiring vasoactive medications) are more likely to be admitted to a general ward bed than an ICU bed during periods of higher ICU strain [12*,13]. High strain at the time of admission to the ICUs is associated with lower quality of care in the ICU, such as reduced adherence to evidence-based prophylaxis for venous thromboembolism [14]; with changes to end-of-life care, including shorter time to establishing do-not-resuscitate status [15]; and, under certain circumstances, with worse clinical outcomes, such as slightly higher mortality [16]. Together, these findings suggest that these normal fluctuations in supply–demand balance of ICU resources have small but potentially important effects on patient care and outcomes.

Strain at the time of ICU discharge has a more complex relationship with patient care and outcomes. One prior study demonstrated that higher ICU strain at the time of discharge was associated with shorter duration of ICU stay and higher likelihood of ICU readmission but without any differences in subsequent mortality, likelihood of discharge home, or hospital length of stay [17]. Together, these findings suggest that higher strain, while potentially troubling to ICU and ward clinicians and sometimes patients, may promote more efficient ICU bed utilization via earlier ICU discharge without significant adverse consequences. Understanding, which patients are safely discharged under high strain conditions may inform policies to improve patient flow even during times of lower strain.

In the past year, there have been a few notable studies of ICU capacity strain resulting from usual variations in critical care demand. First, Wilcox et al. expanded on previous studies demonstrating an association of ICU capacity strain with small differences in short-term mortality [18**]. Specifically, in
their large observational cohort study that included 149,310 patients admitted to 215 adult general ICUs in the United Kingdom, Wales, and Northern Ireland, they found that patients admitted when the ICU census was lower than ‘typical’ had lower risk of mortality (odds ratio, 0.94; 95% confidence interval (CI) 0.90–0.99), and that patients admitted when the ICU census was higher than typical and the census was composed of higher acuity patients had higher mortality (odds ratio 1.05; 95% CI 1.01–1.10).

Second, our research group developed a novel index of hospital strain that confirmed previous work demonstrating an association of hospital strain with triage decisions. In a retrospective cohort study utilizing over nine million patient admissions in 27 hospitals, we developed a hospital-wide measure of capacity strain, incorporating hourly measurements of strain metrics across emergency departments, wards, step-down units, and ICUs [12]. Hospital strain measured by this novel index was inversely associated with likelihood of admission to the ICU among patients with sepsis or acute respiratory failure who did not require vasoactive medications or other life-supporting therapies. There is a small but growing body of literature that the choice of ICU versus floor admission for these marginal patients in some cases may impact outcomes and in other cases may not [19,20]. However, these studies have important limitations and future work with less susceptibility to bias and stronger causal inference is required.

Third, Blayney and colleagues performed a large retrospective cohort study of ICU patients in Scottish ICUs to evaluate the relationship between strain on ICU resources and early ICU discharges. As in the earlier study, the authors found that higher census was associated with transferring patients out of the ICU ‘early’ [21]; however, they did not report other clinical outcomes to understand the ultimate impact of these early discharges. If, as in prior studies, patients were unharmed by this care delivery change, this relationship between higher strain and ICU discharge may shed some light on how to safely improve patient flow and efficiency and increase value of ICU care.

Finally, a small number of studies in the past year have focused on ideas to preserve ICU capacity, so as to avoid strain in usual times or accommodate surges in demand in unusual times. Shank et al. [22] reported implementation of a program to reserve beds for specialty patients in a neurointensive care unit often utilized by nonspecialty patients. They found that the bed reservation was associated with a significant improvement in service-line operations, regional access to care, and resource efficiency (e.g. decreased emergency department boarding time). In another recent study, Poeran et al. [23] estimated the contribution of elective surgeries to demand on ICU resources using New York State data. They found that of all ICU admissions, 13.4% included an elective surgery, and that of the 26.4% of all ICU patients who underwent mechanical ventilation, only 6.4% were patients who underwent elective surgery, contributing data to an ongoing debate, discussed further below, of the role of cancelling elective surgery in response to acute surge events [24].

**ACUTE CAPACITY STRAIN AND RESOURCE LIMITATION DURING THE CORONAVIRUS DISEASE 2019 PANDEMIC**

The COVID-19 pandemic, a generational event in human history, represents the most extreme end of the capacity strain spectrum across a number of domains [3]. The pandemic has produced a huge influx of patients, patients with high acuity (i.e. patients requiring ICU admission and advanced respiratory support), and patients with special care requirements (i.e. novel diagnostic testing, isolation precautions, and personal protective equipment) [25]. It has also led to simultaneous resource loss in the form of lost hospital revenue from disrupted non-COVID-19 care delivery (e.g. cancelled surgeries, delayed treatments, and reduced acute care utilization) [6,24,26–28], and all of the above at broad scale nationally and globally. As such, the pandemic has induced massive operational and care delivery changes [6].

Evaluation of the relationship between capacity strain and related acute resource limitation and clinical outcomes during the COVID-19 pandemic is complex because of two competing phenomena. There is a clear risk of detrimental impact of severe capacity strain on outcomes – essentially the extreme end of the strain spectrum introduced as ‘routine capacity strain’ above. However, a counterforce is the surge event phenomenon of adaptation [8], in which acute care delivery and outcomes improve over time for primarily affected patients – those with COVID-19 pneumonia – because of clinical and organizational real-time learning [29,30,31,32,33,34,35,36,37,38]. In this latter phenomenon, the COVID-19 case volume and acuity has not only an experience-building but also a strain-inducing role. In parallel to the relationship between capacity strain and COVID-19 outcomes, at least of equal importance is the relationship between capacity strain because of the COVID-19 pandemic and delivery and outcomes of non-COVID-19 care – what has been termed resiliency [8,39].
Asch et al. [32**] demonstrated both the dual potential detrimental and experience-building impact of COVID-19-related capacity strain. As evidence of adaptation, COVID-19 risk-standardized hospital mortality improved over time during the pandemic and higher early community case rates were associated with lower hospital mortality. As evidence of burden and strain, on the other hand, increasing county-level case rates over time were associated with higher hospital mortality. Bigiani et al. [40*] furthermore showed that hospital stress – as measured by the ratio of regional COVID-19 cases to hospital beds – was associated with increased COVID-19 death rates including both in-hospital and out-of-hospital and that this finding was consistent across 25 countries, albeit largely well resourced.

ICUs were particularly stressed during the COVID-19 pandemic, as the specialized personnel, equipment, and care coordination of the ICU were both in high demand and are more difficult to expand into traditionally non-ICU settings compared with the expansion of general medical wards. Bravata and colleagues analyzed a large sample of US Department of Veterans Affairs COVID-19 ICU patients and found that increased COVID-19 ICU load (defined as the mean census of ICU patients with COVID-19 during the patient’s hospitalization) and increased COVID-19 ICU demand (defined as the ratio of COVID-19 ICU load to maximum hospital COVID-19 ICU census) were both associated with increased 30-day mortality [34**]. This association, albeit attenuated, extended also to noncritically ill COVID-19 patients treated only outside of the ICU.

The fact that there is among-hospital variation in COVID-19 outcomes in the Asch study, through the lenses of both adaptation and burden/strain, suggests there may also be hospital-level organizational factors that modify hospital adaptation and resiliency. In that study, the authors found no relationship between ICU bed number, academic status, profit status, or urban/nonurban setting and mortality but there are certainly numerous more micro-organizational features – staffing models, leadership structures, quality and innovation cultures, to name just a few – yet unstudied that may be particularly influential in this relationship. This is an important future line of inquiry that will require in-depth mixed-methods investigations and prospective interventional testing, and ideally will ultimately identify organizational factors that can be exported from highly adaptable and resilient hospitals to those less, so to raise the tide for all ships.

In parallel to COVID-19-related care, the demands and fears of the COVID-19 pandemic had profound impacts on the delivery of non-COVID-19 care in both acute care and ambulatory settings. This included significant reductions – delays or cancellations – in surgical and nonsurgical procedures including even life-saving procedures, such as organ transplantation [6*,24,41]. Preventive medicine, in general and cancer prevention and screening specifically are of particular concern with emerging data clearly demonstrating reduced screening procedures and cancer diagnoses across breast, colon, cervical, lung, and prostate cancers [42*,43,44]. Those nondiagnosed cancers are not simply disappearing, of course; they instead will be diagnosed later at more advanced stages portending worse outcomes [45]. Similar phenomena are being observed across numerous non-COVID-19 care domains. Underlying all of this demand for diverted resources is that clinicians and administrators, even in fields essentially entirely unrelated to COVID-19, were forced to consider operationally, financially, and ethically challenging decisions about allocating resources to non-COVID-19 care in parallel to pandemic efforts [28].

Finally, in its most terrifying moments, the COVID-19 pandemic forced us to consider a potential real-world situation of extreme shortages requiring the allocation of scarce life-saving resources including ICU beds, mechanical ventilators, and dialysis machines [46–48]. Although in the United States, only a minority of hospitals were ultimately forced to adopt such policies and none reportedly used them [6*], overt rationing may have occurred elsewhere including in Italy during the first surge of the pandemic [49], and in India under dynamic circumstances at the time this article went to press [50].

**CAPACITY STRAIN IN PERSISTENTLY RESOURCE-LIMITED SETTINGS**

In addition to experiencing episodes of acute strain that occur in settings of any resource level, persistently resource-limited settings have a basal level of strain that does not exist in well resourced settings [3]. This chronic strain exists because of a longitudinally persistent mismatch in the supply and demand of care resources such that at any given time or most of the time, there is demand for care that outstrips standing supply in at least one domain (e.g. hospital beds, clinical and support personnel, equipment and drugs, etc.). Resource-limited settings can, therefore, experience two phenomena of strain that may impact care delivery and outcomes: chronic strain or acute-on-chronic strain, the latter in which a surge event occurs on top of longitudinal baseline strain.
Resource-limited health systems often operate via a tiered referral network such that patients may be transferred based on complexity from community to district to central hospitals. Although capability for clinical complexity increases at each higher level, beds and personnel also become more limited by design, where a central hospital will accept referrals from a larger number of district hospitals who in turn have accepted referrals from an even wider catchment of community hospitals. Greater demand than supply for care at central hospitals – a shortage – induces increasing wait times for transfer, which are associated with poorer outcomes, or outright prevention of transfer for some patients who need expertise only offered at the central hospital. Improving efficiency of such systems requires that each level deliver care at the top of its capabilities and not refer patients within their scope to a higher level of care [51*,52,53].

The COVID-19 pandemic is an extreme example of acute-on-chronic strain within persistently resource-limited settings. The acute insult of COVID-19 to low-income and middle-income regions was amplified by less robust public health funding and infrastructure, less access to diagnostic testing, reduced ability for adherence to mitigation strategies, such as social distancing and universal masking, and lack of capabilities to expand capacity especially for high acuity patients requiring high-level respiratory support [54–56]. With an exaggerated acute insult from COVID-19, there was also likely an exaggerated impact on non-COVID-19 processes of care requiring even greater deviations from routine care delivery across a variety of patient populations [57].

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Conflicts of interest

There are no conflicts of interest.

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