CURRENT OPINION

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 counter force 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.

Table 1. Recent key capacity strain research advances and related knowledge gaps and future research targets

Key advances	Related knowledge gaps and future research targets
ICU capacity strain in nondisaster scenarios is sometimes and sometimes not associated with poorer outcomes	Identification of ICU and hospital organizational factors that modify the ICU strain–outcomes relationship
Increased hospital-wide capacity strain is associated with decreased probability of ICU admission	Identification of patient subgroups who receive a true net benefit from ICU admission or who may be harmed by ICU compared with ward admission
ICU bed subspecialty reservation benefits subspecialty patients and service lines	How to utilize ICU bed specialization versus bed sharing/pooling to optimize critical care delivery for all patient types
Strain in the setting of acute surges can be associated with increased mortality	Identification of organizational factors that build hospital resiliency and can be exported from highly adaptable and resilient hospitals to those less so
Suboptimal use of central referral hospital beds in resource-limited settings may block indicated transfers for higher level of care	Identification of cost-effectives methods for local resource-limited hospitals to function across the full spectrum of their capabilities

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].

CONCLUSION

Our understanding of the interaction between dynamic resource limitation and care delivery and outcomes continues to expand. We not only have more data but also have knowledge gaps: how to optimally measure strain specific to different circumstances; how strain is causally related to outcomes; how strain may induce improved efficiencies or unmask existing inefficiencies; and how to build hospital and health system resiliency (Table 1). And this past year, the COVID-19 pandemic, a paradigm surge event, pushed the boundaries of strain across numerous domains providing insight for both disaster and nondisaster circumstances.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
▪ of special interest
▪▪ of outstanding interest

1. Wunsch H, Angus DC, Harrison DA, *et al*. Variation in critical care services across North America and Western Europe. Crit Care Med 2008; 36:2787–2793. e1–9.
2. Anesi GL, Admon AJ, Halpern SD, Kerlin MP. Understanding irresponsible use of intensive care unit resources in the USA. Lancet Respir Med 2019; 7:605–612.

3. Anesi GL, Lynch Y, Evans L. A conceptual and adaptable approach to hospital preparedness for acute surge events due to emerging infectious diseases. Crit Care Explor 2020; 2:e0110.
4. Toerper MF, Kelen GD, Sauer LM, *et al.* Hospital surge capacity: a web-based simulation tool for emergency planners. Disaster Med Public Health Prep 2018; 12:513–522.
5. Wahlster S, Sharma M, Lewis AK, *et al.* The coronavirus disease 2019 pandemic's effect on critical care resources and health-care providers: a global survey. Chest 2021; 159:619–633.
6. Kerlin MP, Costa DK, Davis BS, *et al.* Actions taken by US hospitals to prepare
▪ for increased demand for intensive care during the first wave of COVID-19: a national survey. Chest 2021. [Epub ahead of print]
This article reports the results of a survey administered to a US national sample of hospitals regarding organizational actions taken in response to the first wave of the COVID-19 pandemic. Key findings included that almost all hospitals cancelled elective procedures that there was high variability in staffing strategies, and that few hospitals opened ICU beds outside of existing clinical spaces.
7. Kim MM, Barnato AE, Angus DC, *et al.* The effect of multidisciplinary care teams on intensive care unit mortality. Arch Intern Med 2010; 170:369–376.
8. Anesi GL, Sevransky JE, Cobb JP, Evans L on behalf of the Society of Critical Care Medicine Discovery Severe Acute Respiratory Infection - Preparedness (SARI-PREP) Study Group. Hospital stress, adaptation, and resiliency during respiratory viral acute surge events. Critical Connections. 2021;20;22–23.
9. Boudi Z, Lauque D, Alsabri M, *et al.* Association between boarding in the emergency department and in-hospital mortality: a systematic review. PloS One 2020; 15:e0231253.
10. Rewa OG, Stelfox HT, Ingolfsson A, *et al.* Indicators of intensive care unit capacity strain: a systematic review. Crit Care 2018; 22:86.
11. Eriksson CO, Stoner RC, Eden KB, *et al.* The association between hospital capacity strain and inpatient outcomes in highly developed countries: a systematic review. J Gen Intern Med 2017; 32:686–696.
12. Anesi GL, Chowdhury M, Small DS, *et al.* Association of a Novel Index of
▪ Hospital Capacity strain with admission to intensive care units. Ann Am Thorac Soc 2020; 17:1440–1447.
This retrospective, multicenter cohort study of over nine million patient admissions reports a novel, time-updating measure of hospital capacity strain and demonstrates that the level of strain is inversely associated to the likelihood of ICU admission for patients with sepsis and acute respiratory failure who do not require life-supporting therapies.
13. Anesi GL, Liu VX, Gabler NB, *et al.* Associations of intensive care unit capacity strain with disposition and outcomes of patients with sepsis presenting to the emergency department. Ann Am Thorac Soc 2018; 15:1328–1335.
14. Weissman GE, Gabler NB, Brown SE, Halpern SD. Intensive care unit capacity strain and adherence to prophylaxis guidelines. J Crit Care 2015; 30:1303–1309.
15. Hua M, Halpern SD, Gabler NB, Wunsch H. Effect of ICU strain on timing of limitations in life-sustaining therapy and on death. Intensive Care Med 2016; 42:987–994.
16. Gabler NB, Ratcliffe SJ, Wagner J, *et al.* Mortality among patients admitted to strained intensive care units. Am J Respir Crit Care Med 2013; 188:800–806.
17. Wagner J, Gabler NB, Ratcliffe SJ, *et al.* Outcomes among patients discharged from busy intensive care units. Ann Intern Med 2013; 159:447–455.
18. Wilcox ME, Harrison DA, Patel A, Rowan KM. Higher ICU capacity strain is
▪▪ associated with increased acute mortality in closed ICUs. Crit Care Med 2020; 48:709–716.
This large retrospective cohort study demonstrated that admission to an ICU when census is lower than 'typical' is associated with lower risk of mortality, and ICU admission when census is high and patients are of high acuity is associocated with higher risk of mortality.
19. Valley TS, Sjoding MW, Ryan AM, *et al.* Association of intensive care unit admission with mortality among older patients with pneumonia. JAMA 2015; 314:1272–1279.
20. Valley TS, Sjoding MW, Ryan AM, *et al.* Intensive care unit admission and survival among older patients with chronic obstructive pulmonary disease, heart failure, or myocardial infarction. Ann Am Thorac Soc 2017; 14:943–951.
21. Blayney MC, Donaldson L, Smith P, *et al.,* Scottish Intensive Care Society
▪ Audit Group. Intensive care unit occupancy and premature discharge rates: a cohort study assessing the reporting of quality indicators. J Crit Care 2020; 55:100–107.
In this retrospective study of patients admitted to Scottish ICUs, higher census was associated with transferring patients out of the ICU 'early'; however, clinical outcomes of early discharges were not analyzed.
22. Shank CD, Erickson NJ, Miller DW, *et al.* Reserved bed program reduces
▪ neurosciences intensive care unit capacity strain: an implementation study. Neurosurgery 2020; 86:132–138.
This article describes the implementation of a program to reserve beds for specialty patients in a neurointensive care unit that was often utilized by non-specialty patients and reported that the bed reservation program increased capacity to accept outside hospital transfer requests and decreased wait times in the emergency department.
23. Poeran J, Zhong H, Wilson L, *et al.* Cancellation of elective surgery and
▪ intensive care unit capacity in New York State: a retrospective cohort analysis. Anesth Analg 2020; 131:1337–1341.
This study estimated the ICU utilization attributable to elective surgery cases in New York State. 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.
24. Nurok M, Kahn JM. Intensive care unit capacity, cancellation of elective surgery, and the US pandemic response. Anesth Analg 2020; 131:1334–1336.
25. Vlachos S, Wong A, Metaxa V, *et al.* Hospital mortality and resource implications of hospitalisation with COVID-19 in London, UK: a prospective cohort study. Crit Care Res Pract 2021; 2021:8832660.
26. Levy JF, Ippolito BN, Jain A. Hospital revenue under Maryland's total cost of care model during the COVID-19 pandemic, March-July 2020. JAMA 2021; 325:398–400.
27. American Hospital Association. Hospitals and health systems face unprecedented financial pressures due to COVID-19. May 2020. Available at: https://www.aha.org/guidesreports/2020-05-05-hospitals-and-health-systems-face-unprecedented-financial-pressures-due. (Accessed 15 March 2021)
28. Lockey SD, Nelson PC, Kessler MJ, Kessler MW. Approaching 'elective' surgery in the era of COVID-19. J Hand Surg Am 2021; 46:60–64.
29. Anesi GL, Halpern SD, Delgado MK. Covid-19 related hospital admissions in the United States: needs and outcomes. BMJ 2020; 369:m2082.
30. Anesi GL, Jablonski J, Harhay MO, *et al.* Characteristics, outcomes, and trends of patients with COVID-19-related critical illness at a learning health system in the United States. Ann Intern Med 2021; 174:613–621.
31. Armstrong RA, Kane AD, Cook TM. Outcomes from intensive care in patients
▪ with COVID-19: a systematic review and meta-analysis of observational studies. Anaesthesia 2020; 75:1340–1349.
This meta-analysis including 24 studies and 10 000-patient demonstrated global reduction of ICU mortality for COVID-19-related critical illness over time.
32. Asch DA, Sheils NE, Islam MN, *et al.* Variation in US hospital mortality rates for
▪▪ patients admitted with COVID-19 during the first 6 months of the pandemic. JAMA Intern Med 2020; 18:471–478.
This 398-hospital, 27 000-patient US cohort study demonstrated that COVID-19 hospital mortality improved over time, higher early community case rates associated with lower hospital mortality, and increasing county-level case rates over time were associated with higher hospital mortality.
33. Auld SC, Caridi-Scheible M, Robichaux C, *et al.* Declines in mortality over time for critically ill adults with coronavirus disease 2019. Crit Care Med 2020; 48:e1382–e1384.
34. Bravata DM, Perkins AJ, Myers LJ, *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 network open 2021; 4:e2034266.
This large cohort study of US Department of Veterans Affairs COVID-19 ICU patients found that increased COVID-19 ICU load and increased COVID-19 ICU demand were both associated with increased 30-day mortality.
35. Dennis JM, McGovern AP, Vollmer SJ, Mateen BA. Improving survival of
▪ critical care patients with coronavirus disease 2019 in England: a national cohort study, March to June 2020. Crit Care Med 2021; 49:209–214.
This cohort study of 188 UK ICUs with 21 000 COVID-19 ICU patients demonstrated ∼10% improved mortality between March and June 2020, which persisted after adjustment for patient characteristics.
36. Doidge JC, Gould DW, Ferrando-Vivas P, *et al.* Trends in intensive care for
▪▪ patients with COVID-19 in England, Wales, and Northern Ireland. Am J Respir Crit Care Med 2021; 203:565–574.
This 10 000-patient UK cohort study of COVID-19 critical illness demonstrated reduced rates of mechanical ventilation and renal replacement therapy use and reduced 28-day in-mortality over spring 2020.
37. Petrilli CM, Jones SA, Yang J, *et al.* Factors associated with hospital admission and critical illness among 5279 people with coronavirus disease 2019 in New York City: prospective cohort study. BMJ 2020; 369:m1966.
38. Prescott HC, Levy MM. Survival from severe coronavirus disease 2019: is it changing? Crit Care Med 2021; 49:351–353.
39. Anderson JE, Aase K, Bal R, *et al.* Multilevel influences on resilient healthcare in six countries: an international comparative study protocol. BMJ Open 2020; 10:e039158.
40. Bigiani L, Bigiani S, Bigiani A. How to minimize the impact of pandemic
▪ events: lessons from the COVID-19 crisis. Int J Health Policy Manag 2020; 9:469–474.
Across 25 well resourced countries, this retrospective study demontrated 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.
41. Sharma V, Shaw A, Lowe M, *et al.* The impact of the COVID-19 pandemic on renal transplantation in the UK. Clin Med (Lond) 2020; 20:e82–e86.
42. Bakouny Z, Paciotti M, Schmidt AL, *et al.* Cancer screening tests and cancer
▪ diagnoses during the COVID-19 pandemic. JAMA Oncol 2021; 7:458–460.
In a single health system study, screening tests for breast, prostate, colon, cervical, and lung cancer were reduced during the pandemic surge by 60–82% from comparator periods.

43. Patel S, Issaka RB, Chen E, Somsouk M. Colorectal cancer screening and COVID-19. Am J Gastroenterol 2021; 116:433–434.

44. Van Haren RM, Delman AM, Turner KM, *et al.* Impact of the COVID-19 pandemic on lung cancer screening program and subsequent lung cancer. J Am Coll Surg 2020; 232:600–605.

45. Sharpless NE. COVID-19 and cancer. Science 2020; 368:1290.

46. Carson RC, Forzley B, Thomas S, *et al.* Balancing the needs of acute and maintenance dialysis patients during the COVID-19 pandemic. Clin J Am Soc Nephrol 2021. [Epub ahead of print]

47. Leclerc T, Donat N, Donat A, *et al.* Prioritisation of ICU treatments for critically ill patients in a COVID-19 pandemic with scarce resources. Anaesth Crit Care Pain Med 2020; 39:333–339.

48. Maves RC, Downar J, Dichter JR, *et al.,* ACCP Task Force for Mass Critical Care. Triage of scarce critical care resources in COVID-19: an implementation guide for regional allocation: an expert panel report of the Task Force for Mass Critical Care and the American College of Chest Physicians. Chest 2020; 158:212–225.

49. Craxi L, Vergano M, Savulescu J, Wilkinson D. Asian Bioeth Rev. Rationing in a pandemic: lessons from Italy 2020; 12:1–6.

50. Frayer, L. NPR All things considered. 'Oxygen Rationing, Test Shortages: India Caught Unprepared In COVID-19 Crisis'. Available at: https://www.npr.org/2021/04/24/990544555/oxygen-rationing-test-shortages-in-dia-caught-unprepared-in-covid-19-crisis. (Accessed 4 June 2021)

51. ▪ Gallaher JR, Chise Y, Reiss R, *et al.* Underutilization of operative capacity at the district hospital level in a resource-limited setting. J Surg Res 2021; 259:130–136.

This analysis of an acute care surgery registry at a district hospital in Malawi demonstrated suboptimal use of local surgical capacity, excess referral volume to a tertiary hospital, and elevated mortality when surgery was delayed at said tertiary hospital.

52. Purcell LN, Robinson B, Msosa V, *et al.* District general hospital surgical capacity and mortality trends in patients with acute abdomen in Malawi. World J Surg 2020; 44:2108–2115.

53. Williams BM, Purcell LN, Varela C, *et al.* Appendicitis mortality in a resource-limited setting: issues of access and failure to rescue. J Surg Res 2021; 259:320–325.

54. Songok E. A locally sustainable approach to COVID-19 testing in Africa. Lancet Microbe 2020; 1:e197.

55. Mboera LEG, Akipede GO, Banerjee A, *et al.* Mitigating lockdown challenges in response to COVID-19 in Sub-Saharan Africa. Int J Infect Dis 2020; 96:308–310.

56. El-Sadr WM, Justman J. Africa in the path of covid-19. N Engl J Med 2020; 383:e11.

57. Carneiro A, Wroclawski ML, Nahar B, *et al.* Impact of the COVID-19 pandemic on the urologist's clinical practice in Brazil: a management guideline proposal for low- and middle-income countries during the crisis period. Int Braz J Urol 2020; 46:501–510.

