Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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REVIEW

Allocation of scarce resources in a pandemic: rapid systematic review update of strategies for policymakers

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Abstract

Objective: In pandemics like COVID-19, the need for medical resources quickly outpaces available supply. policymakers need strategies to inform decisions about allocating scarce resources.

Study design and setting: We updated a systematic review on evidence-based approaches and searched databases through May 2020 for evaluation of strategies for policymakers.

Results: The 201 identified studies evaluated reducing demand for healthcare, optimizing existing resources, augmenting resources, and adopting crisis standards of care. Most research exists to reduce demand (n = 149); 39 higher quality studies reported benefits of contact tracing, school closures, travel restrictions, and mass vaccination. Of 28 strategies to augment resources, 6 higher quality studies reported effectiveness of establishing temporary facilities, use of volunteers, and decision support software. Of 23 strategies to optimize existing resources, 12 higher quality studies reported successful scope of work expansions and building on existing interagency agreements. Of 15 COVID-19 studies, 5 higher quality studies reported on combinations of policies and benefits of community-wide mask policies.

Conclusion: Despite the volume, the evidence base is limited; few strategies were empirically tested in robust study designs. The review provides a comprehensive overview of the effects of strategies to allocate resources and provides critical appraisal to identify the best available evidence.

Keywords: Systematic review; Scarce resources; Mass casualty; policymakers; Rapid review

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What is new?

- The 201 identified studies evaluate strategies to reducing demand for healthcare, optimizing existing resources, augmenting resources, and adopting crisis standards of care.
- Most research exists for countermeasures to reduce demand.
- Of 15 COVID-19 studies, four higher quality studies evaluated combinations of policy interventions and one reported the benefit of community-wide mask policies.
- In pandemics like COVID-19, the need for medical resources quickly outpaces available supply. The review provides policymakers with a comprehensive overview of the effects of strategies to allocate resources and provides critical appraisal to direct them to the best available evidence.

1. Introduction

In a pandemic like COVID-19, the need for medical resources, including staff, stuff (e.g., supplies and equipment), and space or structure (e.g., physical location) [1], quickly outstrips the available supply. policymakers need information and tested strategies to inform important decisions about allocation of scarce resources. Mass casualty events can occur suddenly, as is the case with an earthquake, tornado, or terrorist bombing, or it may evolve over hours to days, as with a hurricane, flood, disease outbreak, or bioterror attack. Regardless of its rate of onset, the scope and complexity of events can severely challenge even highly experienced and well-equipped healthcare providers and systems. When immediately available resources are clearly insufficient to meet patients' needs at the level normally expected in a modern healthcare delivery system, healthcare systems must be prepared to implement contingency plans to deliver needed services. This requires shifting from the individual-centered approach, which is intended to deliver optimal care to each and every patient, to one that that seeks to do the most good for the most people with the resources at hand.

A 2012 Agency for Healthcare Research and Quality (AHRQ) review [2] identified strategies for allocating resources in mass casualty events. In response to the COVID-19 pandemic, we provide a rapid update of the evidence on resource allocation strategies for policymakers.

2. Materials and methods

The review protocol for this update and the 2012 report can be found on the AHRQ Effective Health Care website [3].

2.1. Data sources, searches, and study selection

We searched PubMed, Web of Science, and Cochrane Database of Systematic Reviews through May 4, 2020. The search strategy is documented in Appendix A. The full eligibility criteria are shown in Appendix B. Briefly, included studies addressed:

- Population: policymakers with responsibility for implementing strategies to optimize resource allocation in healthcare; including federal departments and agencies; state, local and international public health officials; state, local and tribal governing officials; state and local emergency management officials.
- Interventions and comparators: Strategies used by policymakers to maximize scarce resources regardless of comparator.
- Outcomes and study design: Studies evaluating strategies with structured data collection and reporting on process, health, or unintended consequences. Empirical evaluations of actual events as well as simulations were eligible.

2.2. Data extraction and quality assessment

Literature reviewers screened citations and full text articles in duplicate. One reviewer abstracted and appraised the data using online data abstraction software and the work was checked by an experienced systematic reviewer.

No formal strength of evidence assessment was undertaken, but we assessed five critical appraisal domains: data collection and data type, description of the strategy, fidelity to the intervention, generalizability of the findings, and discussion of confounders [2].

2.3. Data synthesis and analysis

We provide a summary of findings table to show the evidence base across studies and an evidence table documenting all included studies. The narrative synthesis concentrated on higher quality studies (appraisal score $\geq$4/8). COVID-19 studies were a pre-specified subgroup.

3. Results

The update identified 2,812 citations, increasing total citations to 8,529 across the 2012 report and the current update. Of these 8,529 citations, 1,912 were obtained as full text. In total, 201 studies met inclusion criteria. The study flow is shown in Figure 1 and the data are available in the Systematic Review Data Repository [4].

The methodological quality of the included evaluations varied substantially across studies. Possible critical appraisal scores ranged from 0 to 8. Figure 2 shows the score distribution across the included studies.

We differentiated four general approaches for policymakers: strategies reducing and managing demand for healthcare services (n = 149); augmenting

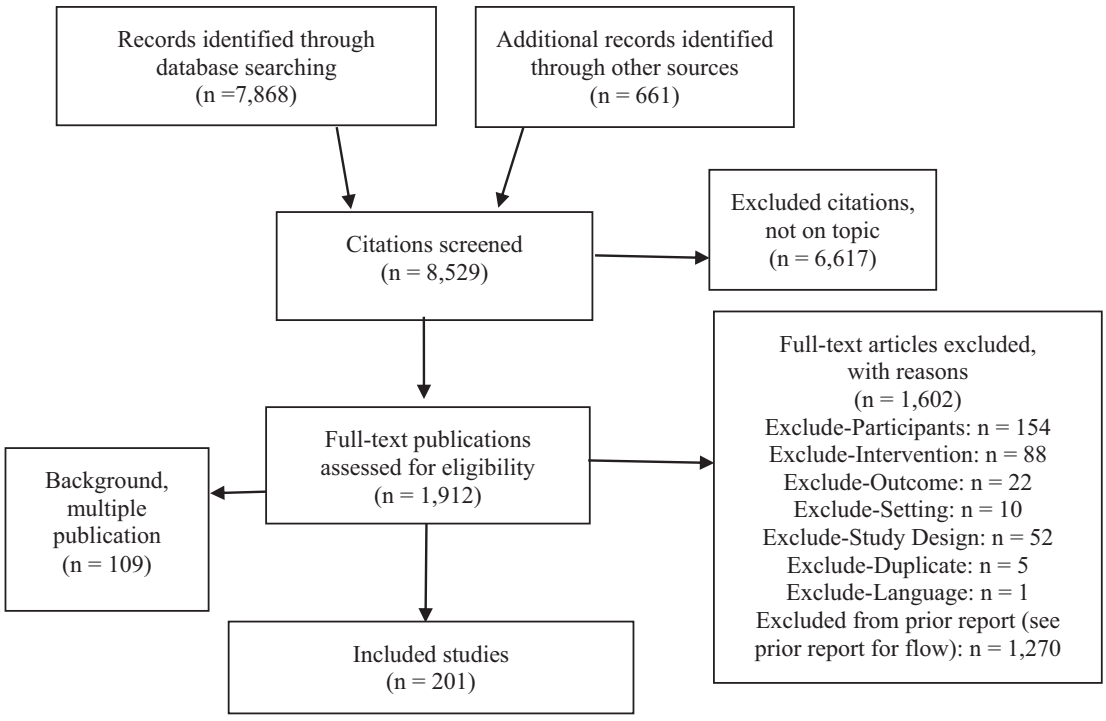

Fig. 1. Literature flow Note: Details on the prior AHRQ report can be found here: https://effectivehealthcare.ahrq.gov/products/mass-casualty-events-scarce-resources/research

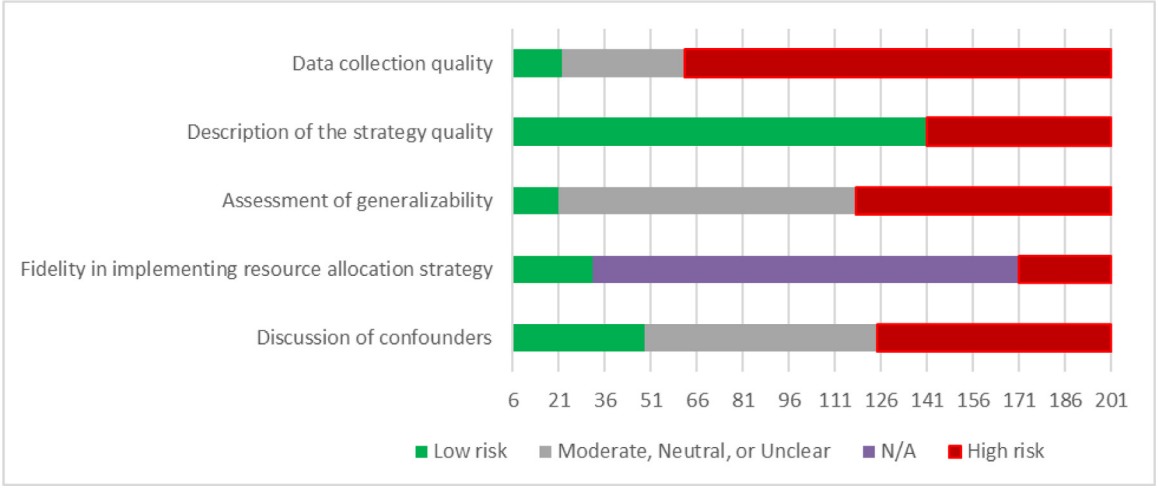

Fig. 2. Critical appraisal scores for all studies by domain.

existing resources (n = 28); optimizing use of existing resources (n = 23); and one publication addressed implementing crisis standards of care relevant to policymakers. The summary of findings table (Table 1) shows the identified research supporting the strategies. Studies are documented in the evidence table (Appendix C).

Identified studies addressed infectious disease threats (anthrax disease, chikungunya disease, COVID-19, Dengue fever, Ebola virus disease, pandemic influenza, smallpox, SARS, Zika virus disease, and bioterrorism and pandemics in general), natural disasters (Hurricane Sandy, Katrina, and Rita; earthquakes), terrorism (September 11 attacks, truck attack in Nice, France), or general mass casualty events not further specified. Half were conducted in the US. Each addressed unique questions and scenarios.

3.1. Strategies to reduce or manage less urgent demand for healthcare services

The largest group of studies (n = 149) assessed strategies aiming to reduce demand for healthcare services, primarily through preventive measures. Studies evaluated medical and nonpharmaceutical countermeasures and many

Table 1. Summary of findings: general strategies and identified evidence informing the strategies

Strategy category	*Strategy and evidence base*
Reduce or manage demand for healthcare services n = 149	*Nonpharmaceutical interventions (*83 studies) • Mass screening, testing • Contact tracing • Quarantine, isolation • Social distancing, contact reducing, • Protective behavior education and recommendations • Canceling public events, closing entertainment venues • Face mask wearing, distribution of protective kits • School closure, work restrictions • Movement restriction, travel restrictions • Point of entry screening • Vector control • Deploying self-diagnosis tools • Restricting nonurgent hospital care (e.g., elective surgery) • Training for public health officials *Medical countermeasures* (33 studies) • National and state stockpiles • Vaccine uptake promotion • Mass vaccination campaigns • Allocating vaccines (ring vaccination, community vaccination, push vs. pull-based) • Point of dispensing strategies for preventive measures • Drive-through vaccination clinics, ad hoc clinics *Combined medical and nonpharmaceutical countermeasures (*33 studies)
Optimize use of existing resources N = 23	*Load and information sharing* (15 studies) • Central command structure • Site emergency management centers • Statewide coordination of medical countermeasure distribution • Collaboration of laboratories • Using local health work force and agencies *Optimize equipment and supplies* (8 studies) • Strategies to optimally dispense antivirals • Installation of local extraction fans to achieve ventilator performance
Augment resources N = 28	*Temporary facilities or workforce* (14 studies) • Alternate site surge capacity facilities • Medical Reserve Corps Volunteers • Emergency task force • Cross training and using non-hospital volunteers *Equipment and supplies* (11 studies) • Decision support • National ventilator stockpile • National antiviral stockpile • Disaster call center *Mutual aid agreements and community support* (3 studies) • Mutual aid agreements • Community partnerships
Implement crisis standards of care N = 1	*Consensus guideline* (1 study) • Decision support

studies assessed combinations or competing strategies for policymakers.

3.1.1. Nonpharmaceutical interventions

Countermeasures (N = 83) included stockpiling of personal protective equipment, restricting movement, raising awareness, deploying self-diagnosis tools, controlling vectors carrying diseases, contact tracing, social distancing, mass screening, and implementing restrictions on elective medical procedures. Of these, the 21 with higher critical appraisal scores are described below.

One study tested mass screening and reported varying implementation success [5]. An interactive, web-based tool deployed during the 2009 H1N1 pandemic to help adults with influenza-like illness self-assess the need for emergency department visits reported 800,000 site visits [6]. A Ebola simulation suggested that contact tracing is useful in containing epidemics but required five to ten contacts per index patient influence the epidemic's behavior [7]. An H1N1 simulation also indicated that contact tracing could have considerable impact in overcoming limited antiviral efficacy. Several studies addressing social distancing sug-

gested that the adherence is likely a key factor. One study used a survey to assess protective behavior recommendations to stop the spread of influenza during a large gathering; 77% of respondents reported some protective behavior [8]. Another assessed school closure, voluntary home quarantine of patients and their contacts, and an information campaign, and concluded that compliance was associated with the level of understanding of the directions [9].

Evaluations of school dismissal policies suggested that school closure could be highly effective in mitigating influenza spread [10,11]. A simulation indicated that school closures could decrease the number of infected students at peak but are less effective in decreasing total number of infected students. Two simulations indicated the complex interplay between disease characteristics and effects of school closure, particularly when addressing health outcomes, cost-effectiveness, and productivity impacts due to parents' work absenteeism.

Seven studies addressed travel restrictions and point of entry screening. The success of interventions varied by disease and intervention. In Japanese districts, the total number of influenza cases was negatively correlated with the percentage of districts with airport quarantine inspection [12]. An H1N1 simulation concluded that early on in the Mexican pandemic, screening at eight airports could have reduced spread by 90%. Two studies found that airport health screenings based on passenger's self-identification was not successful in identifying influenza; non-symptomatic passengers overreported and sick passengers underreported symptoms [13,14]. An airport fever screening program concluded that the approach is promising to detect Dengue fever [15]. Two studies indicated that fever screening is insufficient for detecting influenza; during a seasonal epidemic of influenza type B, the proportion of infected travelers who were febrile was low and the system was not much better than chance at identifying travelers likely to be infected with influenza [16,17].

One study reported that training sessions for public health officials increased confidence to take specific actions such as imposing quarantine [18]. Imposing restrictions on ambulatory and inpatient medical and surgical care for nonurgent cases across all hospitals in Toronto during the 2003 SARS epidemic produced unintended consequences [19]. While nonurgent admissions decreased significantly, high acuity emergency department visits and transfers also decreased, suggesting that some patients did not receive needed care.

3.1.2. Medical countermeasures

The countermeasure research (n = 33) included a large number of simulations. Of these, 14 were higher quality. One modeling inventory visibility concluded that information on vaccine inventory would decrease not only the amount of leftover inventory but also decrease influenza infection rate. Models typically assumed that supply is limited and that policymakers need to distribute resources strategically. One simulation documented a threshold at which a one-dose influenza vaccine to many individuals would be superior to a two-dose approach for half as many individuals. A simulation addressing Ebola virus disease documented conditions for which a ring vaccination policy (immunizing close contacts of infected individuals) rather than a community vaccination policy (vaccination in the community independent of their connection to an infected person) would be appropriate.

Four simulations assessed strategies for populations. One concluded that vaccinating children aged five to19 and their parents would be particularly effective, since children are often vectors of transmission to others. Another simulation reported that prioritizing prophylaxis in healthcare workers would be an effective use of a national antiviral stockpile without a deleterious effect on disease control in the population. A further simulation indicated that the most effective targeting strategy may depend on a policymaker's objective: to minimize population morbidity, children, adolescents, and young adults should be targeted; in contrast, to minimize mortality, infants, young adults, and older adults should be targeted. One simulation outlined the interdependency of parameters, for example, surveillance strategies to enhance anthrax bioterrorism attack detection would not result in reduced mortality when dispensing capacity is low.

Other studies addressed whether a "pull" or "push" strategy is better for dispensing medical countermeasures. One study reported a centralized pull system (where people come to a fixed site) provided slightly faster and more accurate processing than a hybrid model that combined the centralized pull approach and a push approach (in which supplies were delivered to some persons at their work site) [20]. Another study using U.S. Postal Service mail carriers to deliver prophylactic antibiotics in an anthrax attack exercise reported the push approach served more people per hour than the fixed "pull" dispensing sites [21].

Five studies assessed the throughput in mass vaccination exercises. A study determined that drive-through clinics can vaccinate 200 to 361 children and adults per hour [22]. Another reported that a drive-through clinic was able to provide prophylactic medication in a timely manner with minimal human-to-human contact [23]. Three studies evaluated equity; i.e., one H1N1 vaccination study found disparities in vaccination rates and one concluded community efforts are needed to reach economically disadvantaged people [24,25]. Others reported challenges in influencing uptake, for example through a telephone intervention to enhance vaccination uptake in neighborhoods with lower coverage rates [26].

3.1.3. Combined medical and nonpharmaceutical countermeasures

The majority of the identified studies (n = 33) were computer simulations; four higher quality studies addressed combinations. One simulation concluded that preferentially

vaccinating urban locations was the single most effective strategy but travel restrictions delayed the peak of the epidemic. An influenza simulation concluded that for severe pandemics, the combination of antiviral use for treatment or prophylaxis, school closure for an extended duration, and social distancing to reduce contacts in the community would reduce the total costs of the influenza pandemic the most. A smallpox simulation suggested that it is advisable to carry out mass vaccination, or both traced vaccination and mass vaccination, simultaneously with school closures. An influenza simulation tested seven countermeasures and concluded that implementing all policies, the disease attack impact would be around 8% compared to 54% with no intervention.

3.1.3.1. Strategies to optimize use of existing resources. The identified 23 studies evaluated load sharing and information sharing between agencies and counties as well as optimizing the use of existing equipment and supplies; six were higher quality.

One study described a successful partnership between CDC and community laboratories to test low risk patient samples for Zika virus in commercial laboratories [27]. A study reported successful medication distribution by enlisting agencies to assist people with functional needs [28]. An evaluation of pediatric disaster services after a tornado concluded that no preventable adverse events were identified but highlighted that established communication channels between hospitals in the region facilitated integration of services [29]. An evaluation reported a reduction in patient transfer times once a coordinated regional trauma system was introduced for routine, small-scale trauma events following Hurricane Katrina [30]. One study evaluating the response to the September 11 attacks concluded that the absence of an enforced patient distribution system led to uneven load in trauma centers [31].

Other studies addressed optimizing strategies to contain infectious diseases: one higher quality simulation found that two-drugs (one for prophylaxis and a different drug for treatment) would be more effective in delaying the propagation of disease during an influenza pandemic than a single drug for both prophylaxis and treatment, but the strategy would be more likely to increase multi-drug resistance. The results of the remaining studies, predominantly simulations and evaluations of responses to earthquakes, are documented in the appendix.

3.1.3.2. Strategies to augment existing resources. The 28 included studies addressed augmentation of existing resources through temporary facilities and temporary workforce, additional resources through mutual aid agreements or community collaboration, or adding supplies and equipment such as software that supports decision making. Twelve were higher quality and described below.

Seven studies assessed temporary workforce and temporary facilities. One study evaluating Hurricane Sandy concluded that volunteers helped fill gaps in reaching vulnerable populations [32]. An exercise using Medical Reserve Corps volunteers in a response to an influenza outbreak reported high satisfaction with the work of the volunteers [33]. One study reported that an alternate care site provided so much medical surge capacity following Hurricane Katrina that emergency departments and trauma centers in the region saw no significant rise in patient visits [34]. An anthrax simulation that examined expanding hospital surge capacity (e.g., by cross training and using volunteers to extend trained personnel and mobile servers from other federal agencies) concluded that deaths would dramatically decrease (10-fold or more) with sufficient personnel. An evaluation of training personnel for mass medication distribution indicated increased throughput rates [35]. Testing rapid dispensing of medication through a school-based approach showed medication dispensed in 50 minutes to 10% of the local population [36]. A simulation concluded that using a Japanese shopping street for food distribution and evacuation shelters would provide many advantages after an earthquake.

Three studies assessed the use of decision support tools. An evaluation of the use of a computer simulation model that allocates resources for a point of distribution site reported a more efficient use of time for a group responding to a bioterrorism threat when supported by the model [37]. Using decision support software to determine staffing for point of dispensing medical supplies following a hypothetical anthrax release helped to achieve the highest throughput [38]. An evaluation of disaster call centers concluded that this additional service was highly used, indicating need that was not met by other services [39].

One study reported good results for community partnerships that resulted in a high vaccination rate compared to other jurisdictions [40]. A computer simulation highlighted the importance of establishing mutual aid agreements between counties and the need for a greater understanding of the logistics and supply chain aspects of pandemic planning and management. The remaining studies addressed a range of healthcare entry points and services (see Appendix).

3.1.3.3. Implementing crisis standards of care. Crisis standards of care approaches are the last resort in the continuum of care ranging from conventional, through contingency, to crisis standards. One higher quality study evaluating resource allocation under crisis standards of care described how a multidisciplinary healthcare ethics committee enabled ethical decision making during the Haiti earthquake [41].

3.1.3.4. COVID-19 studies. Fifteen studies evaluated strategies to specifically address COVID-19. All were published in the last few months; five had higher critical appraisal evaluations. Four addressed nonbiologic countermeasures: One study reported positive experiences

with "internet hospitals" in China that provided patients with online medical advice and likely reduced social panic. A Chinese study modeled the best timing for physical distancing policies using data from the Wuhan community to maximize impact. A contact tracing study highlighted the high transmissibility of COVID-19 before and immediately after symptom onset and concluded that finding and isolating symptomatic patients alone may not suffice to contain the epidemic. An international analysis reported that incidence of COVID-19 was lower in countries that had implemented community-wide mask policies compared to countries without. The fifth study concluded that combinations of countermeasures aiming to reduce the demand for healthcare (e.g., travel restrictions) that had been implemented in China had improved control of the coronavirus outbreak.

4. Conclusions

The current COVID-19 pandemic has dramatically identified the need for best practices and evidence-based approaches to optimally allocate healthcare resources when demands outpace supply. We conducted a rapid partial update of our comprehensive 2012 report on the allocation of scarce resources in mass casualty events [2] and focused on research applicable to policymakers. Of particular interest were responses to the current COVID-19 pandemic.

We identified over 200 research studies relevant to policymakers, a 7-fold increase from the 27 studies found in 2012. We grouped the existing evidence into four approaches, ranging from strategies to decrease healthcare demand, to optimize and augment resources, and adopting crisis standards of care when standard care or contingency standards cannot be maintained. Despite this research volume, evidence synthesis is limited by the quality of the studies and the wide variety of mass casualty scenarios, interventions, and outcomes.

Despite this limitation, our evidence table documents the variety of models for resource allocation, and provides a quick reference for policymakers to make informed decisions. In addition, our critical appraisal can help navigate the literature and highlights the best available evidence. Most of the higher quality research is available for strategies aiming to reduce the demand for healthcare. Of the biologic countermeasures, mass vaccination to contain pandemics was often found to be one of the most effective strategies. However, vaccines are not immediately available after an outbreak of a novel strain and the suggested strategies to best distribute a vaccine can only be executed once it is developed and available en mass. Simulations and exercises can inform, for example, when push or pull models or ring or random vaccination strategies are most effective [20,21].

Of the nonpharmaceutical countermeasures, contact tracing appears to be a useful tool, but a substantial number of contacts need to be traced to maximize effectiveness. Social distancing, particularly achieved through school closures, effectively delayed peaks of pandemics, often providing valuable time that can be used to care for infected patients and to develop vaccines. School closure is increasing receiving research attention, but policymakers need to carefully weigh potential costs of lost productivity and childcare [42–44]. The literature on travel restrictions shows that the success varies considerably by method and by disease (e.g., temperature scanning in airports is successful only for selected applications). Imposing restrictions on ambulatory and inpatient medical and surgical care for nonurgent procedures can result in some patients not receiving needed care.

Strategies to augment existing resources consistently reported positive results for the use of temporary facilities and using community systems for medication and information distribution. Studies testing the use of volunteers also reported positive experiences; however, research is based on one-time exercises and the duration of a pandemics may outlast volunteers' enthusiasm. Positive results were also reported for adding decision tools, albeit also in training exercises rather than real events. Strategies to optimize resources described positive effects of expanding the scope of work, for example involving community laboratories to achieve widespread testing. Other studies reported positive results after sudden mass casualty events but noted that success was made possible due to prior established collaboration efforts [29].

The evidence base is growing for COVID-19 policy interventions, and existing but limited literature supports contact tracing, social distancing, and community-wide mask policies.

Our review has limitations. The update used abbreviated methods to ensure a rapid turnaround and there may have been studies, in particular outside of journal articles, that are missing from this review. We used a targeted search strategy and did not review the clinical trial literature as we were focused on responses to disasters rather than disaster preparedness and it should be noted that this update is not a full systematic review. In addition, the evidence base for COVID-19 is rapidly evolving and the review covered only research to May 2020. We applied relevant critical appraisal criteria for all included studies and focused the narrative synthesis on studies meeting a methodological threshold. However, the evidence base does not include robust study designs such as randomized controlled trials that allow strong evidence statements, and no formal strength of evidence assessment was undertaken. The higher quality studies represent tested strategies that can inform policymakers rather than strong evidence suggesting clear evidence-based solutions. Furthermore, there are practical such as supply line issues [45] as well as ethical and legal questions that this review does not address [2].

policymakers need to carefully weigh alternatives to ensure that patients receive the best possible care under challenging circumstances. More information is needed about

the comparative effectiveness of the competing and sometimes mutually exclusive strategies that have been suggested to address scarce resources, and research should test promising strategies developed by simulation in practice.

As the current COVID-19 pandemic unfolds, health systems must be strategic to ensure equitable allocation of scarce resources. This unfortunate experience will provide opportunities to study implementation and effectiveness of resource allocation strategies. Armed with new information, future policymakers and healthcare delivery organizations will be able to incorporate research findings and lessons learned into their crisis of care standards and disaster plans.

Authors' contributions

Susanne Hempel: Conceptualization, methodology, analysis, writing-original draft preparation and editing, supervision, funding acquisition. Rita V. Burke, Michael Hochman, and Jeanne Ringel: Writing-review and editing. Gina Thompson, Annie Brothers, Ning Fu, and Jennifer Shin: Data abstraction, formal analysis, editing. Aneesa Motala: Project administration, data acquisition, editing. Maria Bolshakova: Writing-original draft, editing. Jody Larkin: Data acquisition, editing

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Supplementary material

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