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Innovations in ICU Expansion Solutions: From Tents to Modified Shipping Container Mobile Pods

This article discusses the 2020 innovations in ICU surge capacity, their benefits and challenges and how they may prevent or delay the need to enact triage criteria /decision-making in pandemic and mass casualty situations.

Introduction

Even though governments in many countries have taken unprecedented steps to shut down their economies and impose massive self-isolation, social distancing and masking policies to help their healthcare resources meet the demands for care, COVID-19 has caused intensive care units (ICUs) globally to develop, revise or expand their surge planning as the virus has ravaged communities around the world (Carenzo et al. 2020; Junyang et al. 2020; Litton et al. 2020; Shadman et al. 2020). Such surge plans are key to maintaining essential services and to providing care for large amounts of people affected by the pandemic. Surge plans have traditionally involved expansion into spaces that can readily accommodate critically ill patients (e.g. post anaesthesia care units, emergency departments, operating rooms) and exploring other more "hostile" spaces that can however be adapted (with minimal alterations/construction) to meet the air, oxygen and suction needs required to provide ICU care (Einav et al. 2016; Sprung et al. 2010; Kersten et al. 2020). Redistributing patients within regions to optimise resource availability is also a key strategy in meeting needs (Michaelson et al. 2020). Once these options are exhausted though, currently difficult triage decisions must be faced. Triage generally combines a utilitarian (greatest good for greatest number) approach with a scientific evidence-based assessment of the ability of critical care to help the patient; including such evidence as exists for those affected with the novel pathogen (Christian et al. 2006; Baumrucker et al. 2020; Dougherty et al. 2014). After the SARS outbreak in Toronto, and in the face of a subsequent potential influenza pandemic, triage criteria combining utilitarianism with scientific evidence and military colour coding to allocate ICU resources were created and formed the foundations of triage planning worldwide (Christian et al. 2006). The proposed triage plan was not perfect: it lacked details for particular categories of illnesses; was not stringent enough nor flexible enough to adapt as resources become increasingly consumed. In the face of dire prediction modelling forecasted ICU surge capacity being overrun (Joebges and Biller-Andorno 2020; Lamblin and de Montgolfier 2020; Litton et al. 2020), COVID-19 resulted in the rapid development and adoption of triage criteria globally building on these past experiences (Baumrucker et al. 2020; Leclerc et al. 2020; Maves et al. 2020; Singh and Moodley 2020; Vincent and Creteur 2020).

As in the past, triage criteria in 2020 have also proposed giving weight not only to scientific evidence for likelihood of ICU survival but also to other societal "values", with some arguing for the incorporation of social utilitarianism, fair innings provisions, lotteries, and more resources to disadvantaged members of societies (White and Lo 2020; White and Angus 2020). Such considerations have given rise to internal tensions and contradictions within COVID-19 triage policies, ethical tensions among and within healthcare teams, and ethical dilemmas in their proposed application (Vincent and Creteur 2020). COVID-19 triage planning has however also brought new scientific evidence into criteria development: outcome based evidence from neurocritical care, more sophisticated illness specific prognosticating scales, the concept of physical and cognitive frailty, decreased silos in healthcare as seen by concepts of expansion into different less affected regions of countries and criteria by which the allocation of resources becomes more stringent and harsh as scarcity progresses (Baumrucker et al. 2020; Leclerc et al. 2020; Maves et al. 2020; Singh and Moodley 2020; Vincent and Creteur 2020).

Most intensivists have fortunately never had to face triage decisions such as those that occur in the final stages of critical care resource availability and most dread making tough decisions and apply policies about the allocation of the last ICU bed. What if there was a way to not have to face difficult triage decisions in a pandemic at all? What if there was another way to quickly expand ICU capacity and bring this capacity to places in need? This paper will explore the innovative ICU expansion solutions of 2020 that are at the forefront of what could be a new reality for critical care medicine.

ICU Expansion Solutions: Importance and 2020 Innovations

ICU tents and repurposed spaces

To delay, for as long as and as much as possible, triaging of critical care resources, for the first time, ICUs have, on a massive, global scale, explored expansion options outside their usual bricks and mortar hospital boundaries. In the first COVID wave, societies bore witness to the deployment of hospital tents including ICU beds, hospital naval ships, and the conversion of large hotels, auditoriums and conference centres into field hospitals. The provision of hospital and critical care in tents and naval ships is not new and has been successful in other natural disaster and war trauma situations (Brosh-Nissimov et al. 2015; Nam et al. 2018; Fisher et al. 2018; Wenfang et al. 2009;Wu et al. 2008). Hospital naval ships which also include some ICU beds are limited national military resources, require a port to be able to accept patients and thus are not a viable solution for many countries. Tents are rapid to deploy, adaptable yet require variable set up time once on site. Most hospitals that have used tents, have deployed them as external screening facilities, though some have used them as treatment facilities for patients requiring hospital ward level care. A few hospitals have also used tents to expand their ICU capacity (e.g. New York City). Tents require generators, oxygen and water supply and equipment including personal protective equipment (PPE) and HEPA filters have to be shipped and then installed. Information is lacking on infection control practices and environmental disinfection requirements that arise when providing pandemic care in tents-in particular during aerosol generating procedures. The use of tent-based solutions may also pose additional challenges depending on the climates in which they are being deployed and the resulting impact on the working environment. Most tent hospitals and tent ICUs are not negative pressure environments. The innovation arising from the COVID-19 pandemic is that more companies around the world are now developing negative pressure tents making these more available and accessible as an ICU resource.

The creative conversion of hotels, auditoriums and conference centres into hospitals has not been previously done on such a global scale. The set-ups used have varied with commonalities being the division of space into rows upon rows of beds, with construction to create some sort of privacy barriers between patients. While they can host large numbers of patients, they also inherently lack negative pressure capability, oxygen, gas and suction lines and equipment required for ICU care and pose significant infection control challenges in HEPA filtering, in disinfecting and cleaning the environment around and between patients. Though they provide significant ICU expansion solutions by their very pre-existing structural nature, and are climate controlled, these infection control challenges in disinfecting the walls and spaces of either tents or converted auditoriums and large conference rooms in particular after the aerosol generating procedures may create situations where breaches in IPAC procedures are unavoidable, posing as yet unknown safety risks for healthcare workers.

Once no longer needed, the storage of tents is relatively simple though requires some additional costs to properly store and maintain. Auditoriums and conference centres will engage additional "de-construction" costs. Once again attention must be paid to decontamination of the tents and materials of the makeshift hospital spaces to prevent spread of illness to disassembly teams and workers.

Modified shipping containers: Mobile ICUs

By far, the most innovative development in ICU surge capacity to arise from this pandemic, is the transformation of shipping containers into mobile ICU units. The first of these was designed and created in four weeks by the open-source, not-for-profit

CURA group in Italy with an international task force including designers at Carlo Ratti Associati with Italo Rota, engineers at Jacobs, and health technology company Philips for medical equipment supply (curapods.org). The concept of a mobile pod solution is a game changer for ICU care allowing the rapid expansion of surge capacity, and of negative pressure rooms, an increasingly valuable, yet currently limited, commodity in most hospitals, within a slightly smaller footprint. These mobile units can be quickly constructed, maintain the ability to offer speedy deployment and flexibility in both size and configuration of inter-unit connections as seen with tent based solutions. The units are negative pressure units and already pre-set up as ICUs with all the required equipment, PPE and HEPA filters prior to deployment and shipping, significantly decreasing the time from deployment to readiness to use. They are climate controlled and can be deployed in a wide range of global settings without problem by truck, rail, plane or ship. They can be connected to a hospital as an extension or, like tent-based solutions, can function independently with generators, oxygen and water supplies. Unlike most tent based solutions, these units have windows to decrease the incidence and severity of delirium - a frequent complication in COVID-19 patients (Kotfis et al. 2020). Each CURA mobile ICU pod can care for two critically ill patients per 20 foot container. The first prototype, sponsored by UniCredit Bank was installed in Turin Italy and the World Economic Forum has extended support to the project (curapods.org/).

In Canada, FERO International (ferointl.com) has taken the concept even further and designed and developed larger units that unite two 40 foot containers which can provide care to two ICU patients (1 patient per 20 feet), with their larger size providing the added features of an anteroom to house supplies, maintain donning and doffing of PPE practices and an added bedside nursing station/workspace for each ICU nurse). The FERO International ICU/OR and hospital units are constructed with hospital grade walls and flooring, include Drager technology that decreases the inter-professional ICU team's frequency of need to enter the COVID patient's rooms while maintaining high standards of observation, monitoring and ability to respond to changing care

needs. In an additional innovation, FERO International units can be switched from negative to neutral to positive pressure units while they are deployed providing the added advantage of conversion from operating rooms (positive pressure), to ICU units (neutral or negative pressure) in mass casualty situations. The units have wireless connectivity to maintain family contact and enable the timely provisions of situational updates from healthcare workers, important considerations when caring for COVID-19 patients whose families are typically not allowed to visit. The design includes remote monitoring capabilities at a centralised nursing stations (ferointl.com/).

Each mobile unit is designed to either function independently or can be joined together (using different techniques depending on the manufacturer) to form a larger ICU and/or hospitals with hallways, remote nursing stations and common areas in configurations that fit the space designated for their deployment. Once they are no longer needed, complex disassembly is not required, the units can just be picked up and transported to storage facilities. Cleaning to meet IPAC specifications is generally more straightforward depending on the materials used for walls and floors, decreasing the risk to healthcare workers and disassembly crews. Long-term storage of such units does however require more planning and a proper facility. Regular maintenance checks while in storage are also required to ensure the units are functional and ready to be deployed at any time. While these logistics should not be overly complicated, they do engage additional costs and expertise as compared to tent-based solutions.

While the modified shipping container mobile ICU units present many attractive advantages, the key question is are they functional? Can patients be provided with high quality inter-professional care in these spaces? Will people and equipment actually fit? Are there biomedical concerns that would prohibit certain kinds of care? Infection control precautions and environmental services concerns that would jeopardise either patient or staff safety? The answers to these questions were recently addressed by FERO International in a rigorous, week-long, multi-pronged evaluation of their modified shipping container mobile negative pressure ICU units with anterooms and bedside nursing stations conducted by University Health Network (UHN), a tertiary academic centre associated with the University of Toronto. The goal was for the multi-pronged teams to identify potential areas of concern and to propose solutions. UHN's Biomedical, IPAC, Environmental Services each conducted their own independent evaluations of the units. UHN's Human Factors team facilitated workflow and functionality testing with two days of inter-professional ICU team simulations. The simulated scenarios ranged from activities of usual daily care and escalated to crisis/resuscitation situations. Each stage of the inter-professional crisis simulations required the rapid entry of multiple team members, resuscitation activities, including/followed by the entry of supplies and equipment such as a portable x-ray machine, portable ultrasound machines, defibrillators and resuscitation medications in order to evaluate changes to workflow patterns, issues in communication in particular in crisis situations and to discuss potential ways to mitigate any perceived or real disruptions to usual components of patient care. Each inter-professional team member provided feedback as an individual and as a member of the simulated patient's care team. The results of these evaluations were overall very positive with suggestions from the teams to further maximise floor space, to ensure greater patient visibility from the beside nursing stations without compromising the sturdiness required for deployment and facilitating improved intra-team communication even beyond what exists in many traditional brick and mortar ICUs. Further adaptations of these units will permit the provision of haemodialysis which, since in this pandemic 20% of critically ill patients with COVID-19 develop acute kidney injury (Hansrivijit et al. 2020), is not an insignificant consideration and means dialysis needs can be addressed without moving the patients back into the main hospital setting. From the testing results, the answer to the most fundamental question—can high quality ICU care be provided in these mobile units? – is an unequivocal yes.

Other Considerations: Implications for Healthcare Workers

The ability to increase physical surge capacity is crucial in global pandemics. Yet physical space is not the only need: the space is nothing without healthcare workers, the medications and equipment they need to provide care. COVID-19 has led to a broader understanding of the role of telemedicine in providing ICU support to healthcare teams such as what has been used by MSF Canada for decades to support its field teams around the world (www.telemedhub.org/about-telemedicine; Lilly and Mullen 2020). COVID-19 has also led to the concept of broad re-deployment and role expansion, whereby physicians, nurses and inter-professional healthcare workers are asked to stretch their skills and practice outside their usual area of expertise. Quick online ICU training courses have proliferated (Brickman et al. 2020; Coughlan et al. 2020; Fraher et al. 2020; Nunez-Villaveiran et al. 2020; Price and Campbell 2020) yet the required speed of their development has meant little input by or real appreciation of the educational needs of the wide range of end-users of the material occurred. As such, an interesting future research topic will be to assess how well ICU faculty anticipated the needs of those who were being "trained" to treat critically ill patients independently or under the supervision of an actual intensivist or ICU nurse. Additional challenges for learners in critical care, have subsequently been the stressful global shortages of key medications to provide such care such as narcotics, sedatives and neuromuscular blockers, as global demand has outstripped production requiring further adaptation of clinical education and practice (Haina 2020). Yet even more challenging to anticipate and understand is the interplay between the role expansion/re-deployment and working in new innovative ICU environments such as tents, conference centers or mobile modified shipping container ICUs. Data on healthcare workers and support staff experiences, patient care and outcomes is lacking though it will hopefully soon be forthcoming as healthcare teams publish their experiences in providing care in such settings to enable us to understand the challenges and practical solutions in order to provide safe, consistent, effective patient care in such environments and not compromise patient outcomes.

Conclusions

Fundamentally critical care medicine is about helping more than it hurts, saving those lives that can be saved, easing pain and suffering, and not continuing to treat to achieve a life that the person would not want to live and not prolonging their death when death is the only possible outcome. Central to all these critical care goals is the concept of trying intensively every day to help people in need. Triage is a challenging concept: in usual practice, ICU teams do not stop before they even begin, when there is an ability to help and the person wants to be helped, such as what is seen in triage decision-making. Nor do teams identify people on whom life support is to be withdrawn because they no longer meet allocation criteria yet in other times could survive their critical illness. For a field that is trained to respond, trained to try, standing down in the face of need, is deeply heart wrenching and haunting.

For these reasons, innovative ICU expansion solutions are a vital component of this and of future pandemics and need to be considered in any mass casualty situation in order to help the greatest number of people possible, maintain essential healthcare services for those unaffected by the situation and achieve the best possible outcomes without invoking increasingly harsh triage decisions. Though all expansion solutions have a role to play in these situations, a fundamental future consideration for such solutions is as follows: when everything is new, when everyone is exhausted, worried and even scared, the more a mobile expandable solution can resemble a "traditional" ICU, the more readily healthcare workers can adapt to the new environment and provide the care needed to give patients with life-threatening illnesses the best chances at survival.

Conflict of Interest

Laura Hawryluck volunteered her time to assist FERO International understand requirements to care for critically ill patients and to develop and participate in the inter-professional simulation scenarios for University Health Network's Human Factor's evaluation of the FERO International mobile ICU. Rebecca Repa led the recruitment of the UHN multi-pronged evaluation teams of the FERO units to assess the provision of care, patient and staff safety in such spaces. ■

Abbreviations

IPAC: Infection Prevention and Control

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