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Facility Preparedness for Biological Emergencies: Lessons from AUBMC's Oxygen System Overhaul

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Abstract

Biological emergencies strain health care facilities that are typically designed to accommodate routine surges. The SARS-CoV-2 pandemic exposed vulnerabilities in hospital oxygen delivery systems worldwide, resulting in ventilator failures and disruptions in patient care. At the American University of Beirut Medical Center (AUBMC), the Emergency Department experienced significant challenges in maintaining the oxygen delivery system due to the unprecedented oxygen demand, over-frosting of pipelines, and system-wide depressurization. In response, the AUBMC established the Emergency Engineering Response Team (EERT) to rapidly develop and implement innovative, engineering-based strategies. This report shares the challenges faced by the AUBMC during the SARS-CoV-2 pandemic, details the solutions implemented, and provides recommendations to strengthen health care facility preparedness for future biological emergencies.

Introduction

Biological emergencies critically strain health care systems, overwhelming infrastructure designed for routine surge capacity. The SARS-CoV-2 pandemic exposed vulnerabilities in hospital preparedness, particularly in oxygen delivery systems.[1,2] Globally, standard safety margins proved inadequate under pandemic conditions,[3] with low-resource settings disproportionately affected.[1,4] These systemic failures call for a paradigm shift: implementing adaptive hospital engineering systems that dynamically adjust to surge demands in real-time and revising facility oxygen delivery standards. The Emergency Engineering Response Team (EERT) model addresses oxygen system failures and offers a transformational approach to facility readiness.

Prior to the SARS-CoV-2 pandemic, the oxygen pipeline system in the Emergency Department (ED) at the American University of Beirut Medical Center (AUBMC) was designed to support high flow delivery (15 liters/min) to 25% of beds, simultaneously. This calibration was based on local historical demand and international health care facility building codes.[5] At the peak of the pandemic, the system failed to meet daily demand, leading to frequent manual reservoir refills, over-frosting of pipelines, and inadequate flow and pressure. These failures resulted in oxygen flow instability and ventilator malfunctions,[6] disrupting patient care. This crisis highlighted the limitations of static infrastructure and facility standards and emphasized the need for adaptable and dynamic engineering solutions.[7-10]

In response, AUBMC leadership established an Emergency Engineering Response Team (EERT)—multidisciplinary task force that evaluates infrastructural gaps and develops resilient strategies. Between 2020 and 2021, the EERT implemented rapid infrastructure interventions to meet clinical demand during the SARS-CoV-2 pandemic. Today, its role extends beyond oxygen supply management, becoming fully embedded in the hospital's preparedness, mitigation, and response to biological, radiological, and high-yield explosive (CBRNE) emergencies. The oxygen delivery crisis served as a catalyst, emphasizing the importance of system adaptability to ensure health care resilience.

Narrative

Between January and May 2021, the AUBMC treated 10,742 patients, including 1815 SARS-CoV-2 positive patients. The ED experienced its peak in January 2021, with 2,208 patient visits, 673 of whom were SARS-CoV-2 positive and 183 requiring admission for oxygen treatment, representing 30% of total admitted patients. Among admitted patients, 123 patients required non-invasive ventilation (bilevel positive airway pressure or high-flow nasal canula) and 57 required

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invasive ventilation. The ED is divided into low (8 beds), intermediate (13 beds), and high acuity (22 beds) zones, with each bed space equipped with 2 oxygen outlets, allowing bed-spaces to double, if needed. At peak use, there were 71 admitted patients in the ED, and the average length of stay for admitted and discharged patients was 60.8 hours and 20.7 hours, respectively. Admitted patients required mechanical ventilation in the ED, exceeding the oxygen system's maximal capacity (25% of simultaneous oxygen outlet use). The unprecedented surge inevitably caused ventilatory machines to fail as oxygen pressure and flow dropped below operational thresholds. With the pipeline system overwhelmed by demand and mechanical ventilators failing, clinicians had to manually intervene, troubleshooting issues in real time to ensure patient safety. Figure 1 illustrates the burden on the ED by looking at patient volumes (total visits and number of active patients treated in the ED), disease burden, and resource utilization (oxygen consumption in liters).

The Oxygen Pipeline System

The AUBMC facility relies on a large liquid oxygen (LOX) system consisting of 2 main holding tanks that supply oxygen to the main hospital building and the Emergency Department. During the SARS-CoV-2 pandemic, a new hospital area was designated as the COVID unit and it was supplied oxygen from the same source. Liquid oxygen is stored in these tanks and converted into gas via an ambient air vaporizer.[11] The original blueprint of the ED's oxygen pipeline system was built to standard[5] and was supported by ⅝-inch pipes connected to all oxygen outlets.

The Failure of Oxygen Delivery

During the pandemic, AUBMC faced 3 major challenges: a sudden surge in oxygen demand, over-frosting of the pipeline system, and depressurization. Facility managers struggled to meet the increased oxygen needs with the original infrastructure and worked tirelessly to prevent ventilator failures. Before the pandemic (January 2020), oxygen tanks were monitored weekly and refilled every 5-to-8 days, with an average daily consumption of 1,045 liters. By October 2020, the daily consumption nearly doubled (approximately 1,980 liters/day), requiring a refill every 2-to-3 days. In January 2021, daily oxygen consumption reached 3,520 liters, requiring daily refills and continuous quality checks, as usage far exceeded pre-pandemic levels.

The oxygen vaporization process occurs at low temperatures, resulting in frost formation. Ambient air vaporizers are designed to tolerate some frosting under usual operating conditions; however, sustained high demand led to excessive frost accumulation. This interfered with pressure regulation and disrupted oxygen flow to patient rooms. AUBMC facility managers were forced to manually defrost the oxygen pipelines around the clock using warm water to prevent system-wide failure. In addition, the existing pipeline system, with a single pipe sourcing all COVID sections of the ED, was unable to deliver the requisite pressure and flow for continuous ventilator use, further causing system-wide depressurization.

Development of the Emergency Engineering Response Team

During the SARS-CoV-2 pandemic, the oxygen infrastructure could not handle the unprecedented surge in demand. In response, the hospital leadership swiftly established the Emergency Engineering Response Team (EERT), tasked with ensuring a continuous and safe oxygen supply for uninterrupted patient care. The EERT liaised between AUBMC administration and the ED's clinical team and rapidly designed and implemented a parallel oxygen pipeline system to meet patient needs. The EERT developed new oxygen pipeline pathways with an increased pipeline diameter and added an additional liquid oxygen source to supply the new pipeline system to prevent excessive frost formation and the drops in pressure related to a singular pipeline source.

Given the high-risk nature of the transition, the team meticulously assessed the oxygen requirements of each ED patient and coordinated transitions onto oxygen cylinders. During the installation of the new pipelines. The project was executed in 2 phases over a course of one week. Phase 1 focused on repiping the low-acuity zone (26 oxygen outlets) in a single day. After testing and monitoring, phase 2 was initiated which involved repiping the high-acuity zone (44 oxygen outlets).

The success of the EERT crisis response during the SARS-CoV-2 pandemic identified a gap in institutional planning and operations: the lack of dedicated engineering expertise capable of swiftly responding to evolving demands of a biological emergency. The AUBMC leadership institutionalized the EERT, a permanent unit within its administrative network that is tasked with emergency response and emergency planning and mitigation. Since the pandemic, the EERT has played a pivotal role in institutional readiness and response to biological emergencies. They have become a core component of AUBMC's broader strategy for managing biological emergencies, adapting the facility infrastructure to meet evolving health care demands.

Discussion

Biological emergencies strain health care infrastructure beyond their capacity to withstand surges.[12] The SARS-CoV-2 pandemic posed global challenges in managing and maintaining hospital oxygen infrastructure,[13,14] which led the WHO to recommend the development of an "oxygen surge plan."[13] Indeed, facility building code must be revised to exceed current standards, which typically accommodate only 25-50% of simultaneous oxygen outlet use in the ED,[5] and mandate the capacity to supply 100% of ED beds at 15 liters/min, with careful assessment of pipeline infrastructure to support ventilator pressure requirements during surges. The pandemic also underscored the need for engineering and policy-driven innovation that can swiftly respond to the crisis and ensure facility resilience and sustainability.

At the AUBMC, the creation of the EERT led to the immediate assessment, planning, and implementation of a collateral oxygen piping system capable of delivering oxygen safely and meeting clinical requirements. This system ensured adequate oxygen flow and pressure for an unprecedented number of patients requiring mechanical ventilation. The EERT's success led to its integration into facility management, solidifying its role in disaster preparedness and response.

The EERT evolved over time to evaluate facility infrastructure on a continuous basis and anticipate potential challenges that may be encountered. Beyond crisis management, the EERT meets regularly to review historical surges, assess local patterns, and ensure operational readiness. The establishment of EERTs must be adopted across all institutions, worldwide, particularly in low-resource and low-income settings, to enable swift adaptation and implementation of engineering solutions during CBRNE emergencies.

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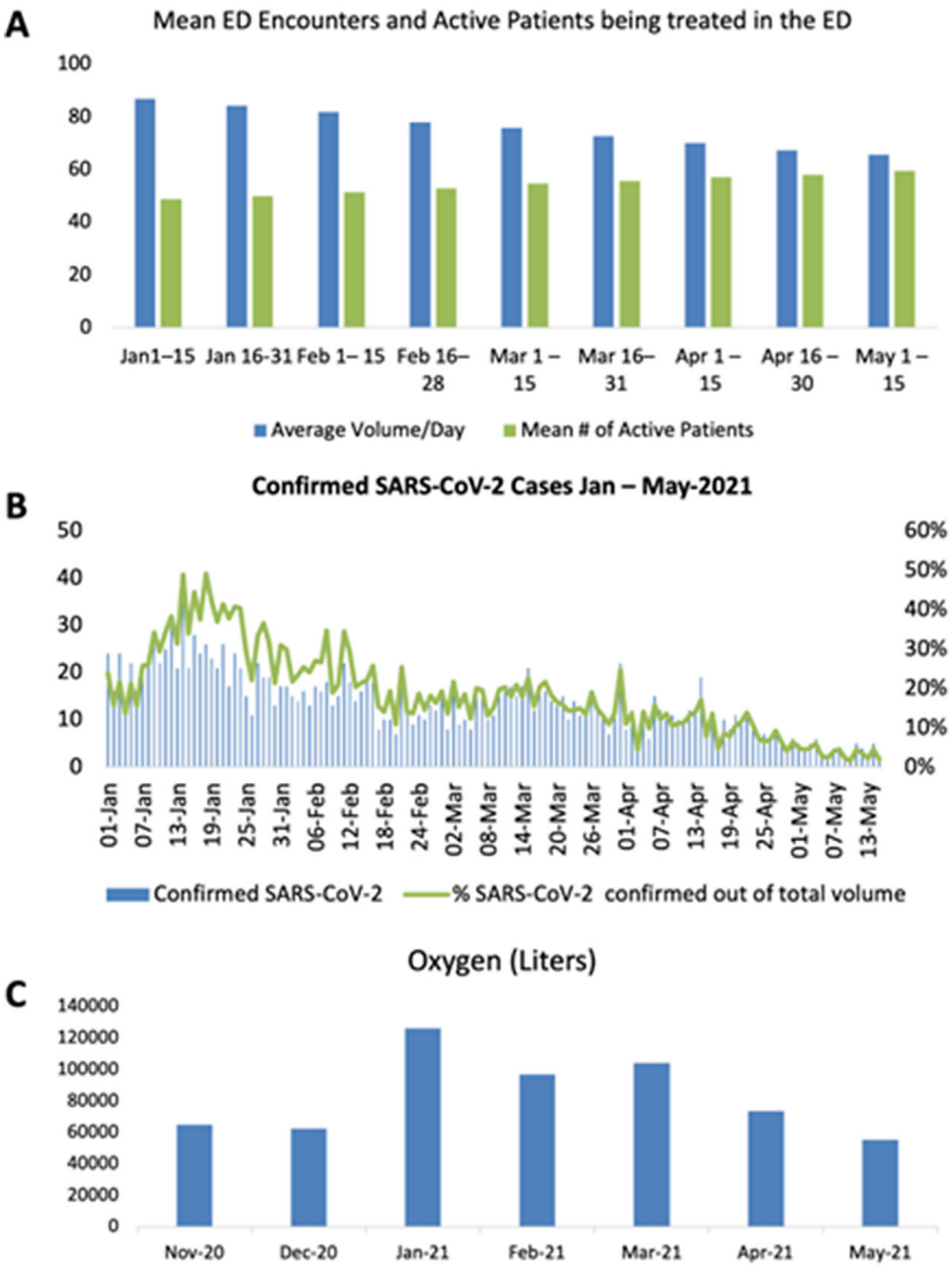


Figure 1. (A) Mean number of Emergency Department (ED) encounters during peak of the COVID-19 pandemic (January-May 2021) shown alongside the average number of active patients being treated in the ED. (B) Number of confirmed SARS-CoV-2 cases in the ED and the percentage of these cases representing the total volume of ED patient volume. (C) Oxygen utilization during pandemic peak, including the average oxygen use in the 2 preceding the peak and the total consumption during the peak months.

At the AUBMC, the EERT plays a crucial role in all aspects of disaster management, preparation, mitigation, response, and recovery. In preparedness, the EERT participates in institutional disaster exercises, training, and facility planning. In the mitigation phase, the team evaluates infrastructure and forecasts risks based on local epidemiological patterns. In the response phase, it collaborates

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with hospital leadership and clinicians to rapidly adaptations. In recovery, the EERT leads to facility restoration and long-term improvement to resume routine operations.

The EERT has transformed collaboration between administrators, facility managers, and clinicians. Their role now extends beyond crisis response, ensuring accountability, continuous infrastructural improvements, and expert presence during a disaster response. The SARS-CoV-2 pandemic underscored the necessity of institutionalizing an engineering response team and the implementation of policies that ensure the continuous infrastructure evaluation and updates.[15] Biological emergencies transcend borders and the development of EERTs can foster cross-regional collaboration, innovation, and resilience. To achieve true facility preparedness in the face of biological emergencies, EERTs must become a standard component of emergency response, worldwide.

Competing interests. Authors RS, GK, RJ are employed at AUBMC. Authors MEB, AM, WS, and EAH declare none.

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