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Sailing Through Choppy Waters: Management of Medical Oxygen Emergencies During the Second Wave of the COVID-19 Pandemic in India

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Abstract

During the second wave of COVID-19 pandemic, an increasing number of patients experienced breathlessness, which progressed to acute respiratory distress syndrome, leading to the need for supplemental oxygen therapy and mechanical ventilation. With each passing day, the need for medical oxygen increased and simultaneously medical oxygen reserves in the country were getting depleted. Government agencies deployed multipronged strategies to ensure that the hospitals had an adequate supply of medical oxygen. Mechanisms and formulae were devised for the rational allocation of medical oxygen to various regions in the country; the production of medical oxygen was boosted along with the curtailment of oxygen usage in industries; and efficient supply chain management, which included "Oxygen Express"— special trains for transporting oxygen, aircrafts for transporting medical oxygen, creating green corridors and real-time monitoring of oxygen levels using information technology. The usage and promotion of indigenous PSA oxygen technology augmented the medical oxygen generation capacity at the health care facility level. This emergency situation demonstrated a need for strengthening established intersectoral coordination mechanisms for swift and effective responses to similar situations in future. Various strategies adopted by the Central Government and other government agencies to a large extent helped in addressing the medical oxygen emergencies.

Like other countries, including developed nations, India witnessed a deluge of patients during the second wave of pandemic of the COronaVIrus Disease of 2019 (COVID -19). Resurgence of COVID-19 was caused by the delta variant of SARS-CoV-2, which was highly virulent, transmitted rapidly (with a high R_0 value), and affected the lower respiratory tract, causing pneumonia. In comparison to the number of patients during the first wave of the COVID-19 pandemic, a larger proportion of patients experienced breathlessness during the second wave of pandemic, which progressed to acute respiratory distress syndrome (ARDS), leading to an increased need for supplemental oxygen therapy and mechanical ventilation.[1]

An exponential increase in the number of patients requiring admission and oxygen support led to overwhelming of patient care services (emergency, inpatient, and critical care services) in health care facilities across the country, which foreshadowed the movement of the COVID-19 pandemic; not all the health care facilities were geared to provide medical oxygen on all hospital beds. To meet this sudden surge of COVID-19 patients requiring admission, temporary hospitals and COVID-19 treatment facilities were set up. The availability of various medical equipment and supplies including hospital beds, ventilators, breathing masks, personal protective equipment, etc. were also augmented. The government reinvigorated its push to increase vaccination rates throughout the nation. Public awareness programs were ramped up to provide information about COVID-19-appropriate behavior, the importance of vaccination, and ways to prevent/contain transmission.

The Second wave of COVID-19 pandemic tested resilience of the health care delivery system in the entire country, especially in Maharashtra, followed by the capital city of Delhi, the second largest metropolitan city in the world.[2] This health care emergency situation forced the central government to implement various containment measures across the country, and a Nationwide lockdown was announced on March 24, 2020 to contain the transmission of COVID-19 in the country. It was supplemented with the policy of the "3Ts," i.e., testing, treating, and tracing the residents to contain the COVID-19 transmission. Travel advisories and guidelines on surveillance, contact tracing, sample collection and transportation, clinical management, discharge policy, infection prevention and control, and home quarantine were also issued. Media reports of oxygen shortages in health care facilities created an environment of uncertainty. The need for medical oxygen increased each day as medical oxygen reserves in the country were decreasing.[3]

The government authorities moved swiftly to ensure that the hospitals had an adequate supply of medical oxygen for patient care services. The production of medical oxygen was boosted, and mechanisms/provisions aimed at efficient supply chain management of medical oxygen were put in place. Various measures/strategies adopted by the government agencies to manage medical oxygen emergencies and to ensure an adequate supply of medical oxygen are discussed in this brief report.

The Supreme Court of India recommended the constitution of a National Task Force, an expert body of renowned national experts with diverse experience in health care who could help in identifying strategies for a concerted public health response to the COVID-19 pandemic inter-alia, formulating a methodology for the scientific allocation of oxygen to the States and Union Territories (UTs), facilitating Oxygen Audit, etc. The aim of conducting oxygen audits was to ensure the accountability and transparency with respect to the allocation of medical oxygen to various State/ UTs. It was also ensured that the allocated medical oxygen reached the intended destination in time and was being made available to the health care facilities through a transparent distribution network.

Mechanism for LMO Allocation

The medical oxygen supply industry before the pandemic operated in a free-market, and each hospital was permitted to enter into an agreement with the vendor identified or selected by the respective hospital. However, owing to liquid medical oxygen (LMO) shortages, the central and state governments assumed the responsibility of allocating and distributing LMO as needed by various regions/ states/health care facilities. A formula was devised by an Empowered Group 2 (EG2) consisting of national experts, constituted by the Government of India, for the allocation of LMO to various States and Union Territories (UTs). In this formula, medical oxygen consumption for a non-Intensive Care Unit (ICU) bed was taken as 10 litres per min (administered through a face mask or nonrebreathing mask [NRBM]), while for ICU beds, the average oxygen requirement was taken to be 24 litres per min (administered through invasive/noninvasive ventilation [NIV]/high-flow nasal cannula [HFNO] using up to 60 litres per min).

Formula 1: *Calculating the LMO (in Metric Tonnes [MTs]) Requirement for a Health Care Facility*

$$\begin{aligned} \textit{For non ICU beds}^{\#} &= (\textit{Hospital beds} * 10 * 24 * 60/2)/(1000 * 770) \\ &= \textit{MTs of LMO} \end{aligned}$$

$$\textit{For ICU beds} = (\textit{No. of beds} * 24 * 24 * 60)/(1000 * 770) = \textit{MTs of LMO}$$

#Based on the assumption that only 50% of the hospital beds have oxygen supply and not all the admitted patients requires medical oxygen.

However, the validity of the formula had been debated according to various media reports on different grounds.[4] In our opinion, in metropolitan areas such as Delhi and Mumbai, and bigger cities, many health care facilities could have a piped oxygen supply on each inpatient bed; therefore, theoretically, the percentage of patients being administered medical oxygen can be more than 50%. Hence, the formulae for non-ICU beds might underestimate the LMO requirement in such setting. In contrast, not all ICU beds in a hospital are equipped with ventilators/NIV/HFNO; hence, the oxygen requirement for ICU beds may be an overestimation of the actual requirement. However, the abovementioned formula provides a much-needed reasonable estimate of the LMO requirement for hospitals in a region that could be used for equitable allocation of medical oxygen.

LMO-generating plants were also ear-marked with fixed quota of LMO for allocating medical oxygen to various states and UTs. Daily quotas for LMO allocation were also determined for each hospital within each respective state and UT. The distribution of LMO for various hospitals and authorized medical oxygen cylinder refillers in a state/UT was centralized and brought under the control of the State/UT Drug Regulatory Authority.

Supply Chain Management

Empirically, it was known that the supply chain management of medical oxygen was a bottleneck, as not even a single LMO manufacturing/generation plant was located within National Capital Territory of Delhi (NCT Delhi). Medical oxygen requirement in hospitals of Delhi was being met by a single vendor, whose LMO generation plants were located in neighboring states. The additional required LMO was transported from the far-off states by road, which took significant time to reach NCT Delhi.

In order to meet the increased demand of LMO, central government through executive orders instructed the industrial producers (petrochemical industries) to divert their LMO for usage in the health care sector and prohibited its usage in other industrial sectors. Further, because the major oxygen production units/plants were based in Eastern part of the country, large volumes of LMO were transported from the eastern regions to the northern parts of the country. Similarly, large volumes of LMO had to be sent to the states of Maharashtra and Gujarat in the western region from the eastern part of the country. It was a logistic challenge to transport millions of high-pressure steel cylinders, regulators, nonsparking valves, connectors, etc. across the country.

Additionally, the manufacturing and supply of cryogenic containers, which can transport compressed liquid oxygen, was limited. To obviate the increased transportation time, the Government of India used the rail transport “Oxygen Express” and defense aircraft for transporting LMO tankers under the roll on, roll off (RO-RO) scheme, with the endeavour to deliver as much LMO as possible in the shortest possible time. Oxygen Express was started by Indian Railways on April 24, 2021 to provide respite to Indian states requiring medical oxygen, and more than 35 000 MTs of LMO was transported to 15 states. Approximately, 480 Oxygen Express trains were operationalized and the intrastate distribution of the LMO tankers was being handled by the state transport corporation, which had limited experience in such situations.[5] The giant C-17 and IL-76 aircraft of the Indian Air Force airlifted large empty oxygen tankers from their place of use to the filling stations across the country to increase the distribution of required medical oxygen.[6]

The increased requirement of LMO tankers for efficiently managing the supply chain was met by utilising industrial oxygen-supplying tankers in addition to hiring available LMO tankers from the market. These tankers were faced with the challenge of not having matching outlets or couplings for the LMO Tank installed in hospitals, which was resolved by arranging the couplings at the local level. It sometime led to delayed offloading process, thereby increasing the turnover time.

Round-the-clock Oxygen Control Room

The central government had set up a control room for nodal officers from various state governments to coordinate the management of medical oxygen supply. It was done to ensure speedier coordination between respective ministries and health care institutions. The Government of Delhi started a 24x7 oxygen control room with

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hunting lines for the management and monitoring of medical oxygen supplies. Constitution of Oxygen Cells and Nodal Officer were identified for each hospital for managing medical oxygen supplies. The Oxygen Cell allocated the supply and had the authority, in crisis situations, to divert LMO supplies (1-2 MTs) to the needed hospital after assessing the veracity of the situation. It was also ensured that, concurrently, the normal medical oxygen supplies of these hospitals were not altered.

Green corridors were created for the unhindered, traffic-free movement of the vehicles carrying LMO tankers on the road to ensure the safe, secure, and timely delivery of medical oxygen for inter- and intrastate transport. It was the responsibility of the concerned state/UT to provide a designated police control room vehicle to escort the vehicle carrying the LMO tanker. This approach not only ensured the safe passage of LMO tankers but also allowed them to be diverted to a hospital requiring medical oxygen on an urgent basis.

Real-time Monitoring of LMO

The Government of Delhi developed a and various other state governments COVID portal and dashboard for real-time monitoring of LMO supplies.[7,8] Information pertaining to medical oxygen consumption was collected and collated, which was linked to the supply end for better supply chain management. Real-time monitoring of consumption patterns of medical oxygen in each district and each hospital was performed to forecast the requirements for enabling equitable medical oxygen supply. Data analytics was employed for monitoring trends, hence leading to evidence-based decision making.

Internet of Things (IoT) was leveraged for monitoring oxygen installations and managing oxygen supply systems. IoT devices were deployed in oxygen generation units, transport vehicles, and liquid oxygen tanks in hospitals. These devices collected the level of LMO and other needed data from LMO storage tanks, transmited the same to centralized servers, and analyzed the collected data to guide prompt decision-making. IoT systems included GPS or location-tracking capabilities, allowing authorities to monitor the movement of LMO tankers. It ensured timely delivery to areas with high demand.

Usage of Industrial Oxygen in Health Care Facilities

In India, mobile industrial oxygen (used in the steel industry and oil refineries) was used for patient care in health care facilities. In addition, the use of industrial oxygen in industries other than for health care was temporarily banned by the Executive Order of the Central Government to ensure maximum oxygen availability to hospitals. Industrial oxygen contains no harmful contaminants, as oxygen is separated from air by a process in which air, collected in its gaseous form, is liquefied at very cold temperatures. The different constituent gases boil off at different temperatures, making it possible to capture pure oxygen. In addition, quality reports of oxygen generated by various industrial units can also be obtained while supplying oxygen to various medical facilities. According to an article by Claiborne Ray and deliberations of the committee of leading subject experts of the country consisting of critical care, pulmonary medicine, internal medicine, etc., there is practically no difference between industrial and medical oxygen.[9,10] Both come from the same source and are produced in the same way; however, to sell oxygen as medical gas, as it is with any prescription drug, regulations must be complied with to ensure that it is being properly dispensed and that it is traceable, with a lot number in the event of a recall.

Scaling Up Indigenous PSA Technolog[11]

In principle, pressure swing absorption (PSA) oxygen-generating plants are used to generate medical-grade oxygen by separating it from the surrounding air. The advantage of PSA plants is that they can be installed at the health care facility itself, thereby allowing onsite generation of medical oxygen. It was important in emergency situations where transporting liquid oxygen could be challenging due to lockdowns and geographical constraints.

Medical Oxygen Plant (MOP) technology in India was developed by the Defense Research and Development Organisation (DRDO) from the On-Board Oxygen Generation for Light Combat Aircraft (LCA) — Tejas by Defence Bioengineering and Electro Medical Laboratory (DEBEL). It was leveraged for developing PSA Oxygen Plants for health care facilities and was exponentially scaled up in within a very short time for tackling medical oxygen emergencies. These plants were designed to have a oxygen generation capacity of 1000 litres per minute (LPM) to meet the medical oxygen requirements for 190 patients (with a flow rate of 5 LPM), and to refill 195 D-type oxygen cylinders per day. The Government of India sanctioned, procured, installed, and commissioned 1563 PSA plants under the Prime Minister's Citizen Assistance and Relief in Emergency Situations (PMCARES) Fund. Additionally, 338 PSA plants were established by the Public Sector Undertakings of the Ministry of Petroleum & Natural Gas, the Ministry of Power, the Ministry of Coal, the Ministry of Railways, etc. The states were also advised to install PSA plants in public health facilities, and to the facilitation, in private health facilities.

Conclusion

Various strategies adopted by the Central Government and other government agencies, to a large extent, helped in addressing the medical oxygen emergencies. An LMO allocation formula helped in reducing intertstate/interdepartmental conflicts in times of crisis and promoting transparency in dsitribution. Creation of the National Task Force by the Supreme Court of India helped in identifying strategies for tackling the medical oxygen crisis. This can also serve as a model for managing future health care emergencies of similar nature and magnitude. Health care facilities, especially in remote areas, have become self-reliant for generating medical oxygen since the installation of PSA plants. The establishment of PSA plants across the country under the PMCARES Fund has augmented and strengthened the medical oxygen supply equally. However, there is a need to ensure the equitable distribution of industrial medical oxygen generation plants and create regional buffer stocks to reduce supply chain pressure in case of an emergency situation. The established intersectoral coordination mechanism must be optimally strengthened to generate an immediate and effective response to such emergency situations. COVID-19 prompted the need for long-term reforms in health care infrastructure and supply chain management and for health care facilities to be made disaster resilient. Innovative strategies and concerted efforts adopted by various government institutions and agencies have played crucial roles not only in managing medical oxygen emergencies but also in enhancing the capacity to produce medical oxygen at the health care-facility level.

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References

1. **Srivastava S.** The Oxygen Express: How Regional Cooperation Can Help Prepare for Future Pandemics. Economic and Social Commission for Asia and the Pacific. Published on 17th May 2021. Last accessed on 14th Nov 2023 https://www.unescap.org/blog/oxygen-express-how-regional-cooperation-can-help-prepare-future-pandemics
2. **Kumar G**, **Mukherjee A**, **Sharma R**, et al. Clinical profile of hospitalised COVID-19 patients in first & second wave of the pandemic: insights from an Indian registry based observational study. *Indian J Med Res.* 2021;**153**(5):619.
3. **Faruqui N**, **Raman V**, **Shiv J**, et al. Informal collectives and access to healthcare during India's COVID-19 second wave crisis. *BMJ Glob Health.* 2021;**6**(7):e006731.
4. **Ismail J**, **Bansal A.** Medical oxygen: a lifesaving drug during the COVID-19 pandemic—source and distribution. *Indian J Pediatr.* 2022;**89**(6):607–615.
5. **The First Oxygen Express arrives in Mumbai**. Press Information Bureau. Published April 26, 2021. Last accessed on 14th Nov 2023. https://pib.gov.in/PressReleasePage.aspx?PRID=1714162.
6. **IAF Airlifting Oxygen Containers, Essential Medicines & Other Medical Equipment in Fight Against Fresh Surge in COVID-19 Cases**. Press Information Bureau. Published April 23, 2021. Last accessed on 14th Nov 2023. https://www.pib.gov.in/PressReleasePage.aspx?PRID=1713580.
7. **Gowda NR**, **Siddharth V**, **Kumar P**, et al. Constrained Medical Oxygen Supply Chain in India During COVID-19: Red-tapism, the Elephant in the Room?" *Disaster Med Public Health Prep.* 2023;**17**:e296.
8. **Hasan I**, **Dhawan P**, **Rizvi SAM**, et al. Data analytics and knowledge management approach for COVID-19 prediction and control. *Int J Law Inf Technol.* 2023;**15**(2):937–954.
9. **K.E.K. V**, **Nadeem SP**, **Meledathu Sunil S**, **Suresh G**, **Sanjeev N**, **Kandasamy J.** Modelling the strategies for improving maturity and resilience in medical oxygen supply chain through digital technologies. *J Glob Oper Strateg Sourc.* 2022;**15**(4):566–595.
10. **Two Kinds of Oxygen**. Claiborne RC. Published May 15, 2007. Last accessed on 14th Nov 2023. https://www.nytimes.com/2007/05/15/science/15qna.html.
11. **Update on Oxygen for COVID-19 Patients in Delhi**. Press Information Bureau. Published May 4, 2021. Last accessed on 14th Nov 2023. https://pib.gov.in/PressReleasePage.aspx?PRID=1715993.