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The Evolution of Medical Oxygen as an Essential Life-Saving Medicine in Modern Healthcare – A Narrative Review

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ABSTRACT

Oxygen has become an inevitable life-saving component in modern medicine. Oxygen is supplied to all the areas of the hospital such as emergency departments, Intensive care units, wards, and even Outpatient departments. The Covid-19 pandemic has highlighted the significance of medical oxygen. The history began with the laboratory separation of oxygen in the 18th century by Scheele and Priestley, then continued with the inventions of oxygen delivery devices, storage instruments, oxygen generators, concentrators, and finally the implementation of safety regulations; all these made medical oxygen a vital medicine in modern health care. The contributions of scientists such as Thomas Beddoes, "father of respiratory therapy," and Haldane, "father of oxygen therapy," was a great milestone in history. Their contribution has helped to develop oxygen generation, storage, supply, and administration. Such historical turning points of medical oxygen were explored in this viewpoint. Future discoveries and advancements in the field of medical oxygen will be a breakthrough. This narrative review discusses the historical, technological and future advancements in medical gas pipeline systems that will make the process of oxygen storage, supply, and administration efficient along with safety assurance.

Keywords: *History of oxygen, medical oxygen, evolution of oxygen, essential life saving medicine, oxygen*

1. INTRODUCTION

Medical oxygen is an essential medicine that is crucial for various medical conditions. Oxygen provides lifeline support in emergencies and becomes the "sign of survival". oxygen is important for the management of hypoxemia, respiratory disorders, and emergencies. The significance of medical oxygen was realized during the COVID-19 pandemic. The practices of oxygen therapy followed in current clinical practice were not made overnight, they are the output of trials, failures, faults, and achievements by inventors, engineers, scientists, and healthcare workers. Various inventors laid the pillars for the advancement and innovations in medical gas pipeline systems, which revolutionized healthcare. oxygen was accidentally discovered in the laboratory, later through experiments it was recognized as oxygen. Later, the role of oxygen in inspiration and expiration was discovered. When a person undergoes difficulty in breathing, they understand that oxygen might be the contributing factor. Here comes the use of oxygen for medicinal purposes to the individuals who were sick. An attempt was made to separate the oxygen from the atmosphere and store it. Later cylinders were invented. Gradually, the inventions in the field of medical oxygen began. This viewpoint was written to mark the milestones of oxygen discovery, inventions of devices, and technical advancements in medical oxygen as well as medical gas pipeline systems.

2. DISCOVERIES – KEY MILESTONES

Oxygen Discovery (1771-1774)

The discovery began with Carl Wilhelm Scheele, who was influenced by a comment from Torbern Olof Bergman, the Uppsala University professor, regarding the product (saltpeter- potassium nitrate) that Scheele's employer supplied produced red vapors (now known as nitrogen dioxide) when heated. Scheele hypothesized that the saltpeter transformed into nitrite when coupled with an acid, which also emitted a new gas known as "phlogisticated air".[1] In 1771, Scheele's experiments led him to identify a new gas, called "fire air," later recognized as oxygen.[2] Scheele's work was not published until 1777.[3] He continued to have bad luck and passed away too soon from mercury poisoning while generating oxygen. In 1774, Joseph Priestley heated red mercuric oxide isolated oxygen and observed its effect on candle flame. He gave oxygen the name "dephlogisticated gas" because he had faith in the phlogiston concept. His early publication bought him the credit for being the first to announce the discovery.[4] Later in 1775, Antoine Lavoisier, after communicating with both Priestley and Scheele, repeated the experiment and named the gas "oxygen" derived from the Greek, "Oxys" which means "sharp" referring to the sour taste of acids, and "Genes" means "begetter".[5]

Liquid Oxygen

Raoul Pictet and Louis Paul Cailletet both succeeded in turning oxygen into liquid in 1877, Unfortunately, it wasn't stable.[7] Stable liquid oxygen was successfully produced in 1883 by Karol Olszewski and Zygmunt Wroblewski, who were employed at the Jagiellonian University in Cracow.[8]

Oxygen as Medicine

Oxygen was first introduced in medicine by Thomas Beddoes, known as the "father of respiratory therapy". In 1798, he established the Pneumatic Institute in Bristol, England where he administered oxygen for Heart Failure, asthma, and other conditions.[5]

3. THE JOURNEY FROM SIMPLE FACE MASKS TO MODERN VENTILATORS

Nasal catheters

Then, in 1907, Arbuthnot Lane introduced a simple yet effective tool: a rubber tubing designed to serve as a nasal catheter for delivering oxygen directly to the patient.[9] The early 20th century brought about another breakthrough in invention. In 1949, nasal prongs or cannula were invented and patented by Wilfred Jones, a more comfortable and efficient oxygen delivery method that soon became widespread

Face masks

The prototype for the modern N95 and surgical mask was designed by Dr. Wu Lien-teh in 1910, to prevent the Manchurian plague outbreak he made a surgical facemask with multiple layers.[10] His design was the precursor to modern surgical masks and even N95 masks used today. Further, the invention was continued by John Scott Haldane in 1917, he designed the complete oxygen delivery set with a facemask, flowmeters up to 10 Liters per minute, oxygen cylinder along pressure gauge, this invention made the oxygen delivery more efficient.[11] This invention has brought an advancement in providing supplemental oxygen to patients in need, he gained the title "Father of Oxygen Therapy".[12]

Venturi Mask

A decade later, in 1960, the Venturi mask was invented by Dr. Moran Campbell at McMaster University Medical School.[16] This occurred when he applied the Venturi effect stated by Giovanni Battista Venturi 1000 years back, this mask allowed for high oxygen concentrations without the risk of carbon dioxide retention, providing a new level of precision and control in oxygen therapy.[17]

High-Frequency Nasal Cannula (HFNC)

In 1988, Transpirator Technologies, Inc. took another major step by patenting the High-Flow Nasal Cannula (HFNC), which delivered high levels of oxygen while ensuring comfort and effectiveness for patients.[23]

Ventilators

John Hunter, a Scottish surgeon, proposed the use of bellows to insufflate air in 1776, a method first proposed by Paracelsus in 1530. His proposed idea made the future inventors to design and develop the modern ventilators used in current practices. In 1832, John Dalziel built this concept by creating one of the earliest negative-pressure mechanical ventilators.[6] In 1952, Roger Manley from Westminster Hospital, London made a revolutionary advancement by developing an entirely gas-driven ventilator.[14] Shortly after in 1955, a ventilator using positive pressure was designed by Forrest Bird.[15]

4. OXYGEN STORAGE AND SUPPLY

In 1868, the development of the first oxygen storage cylinders made it possible to utilize oxygen in general anaesthesia. In the 1950s, Ambulatory patients with dyspnoea were treated by Barach using trans-filled oxygen bottles which were portable. Hospitals were forced to purchase a large number of costly oxygen cylinders due to a growing need for oxygen in all areas of the hospital. Hence the decision to supply oxygen using a pipeline was made. The medical gas pipeline system was implemented and adopted by many hospitals worldwide. using large tanks as a primary source and manifold cylinders as secondary sources were made into practice during the 1930s.[13]

Oxygen concentrators

To increase the purity of oxygen as it is supplied to patients, oxygen was concentrated from the atmospheric air using the Pressure Swing Adsorption (PSA) technique by Charles W. Skarstrom in 1960. It was the first patent application for PSA technology. [18] Medical oxygen concentrators were invented in 1970.

5. SAFETY STANDARDS AND GUIDELINES ESTABLISHMENT

In 1973, Sudbury General Hospital, Canada reported deaths due to medical gas cross connection.[19]

During this period, medico-legal cases drove clinicians to prioritize the safety of medical gas pipeline systems (MGPS). Maintaining strict safety standards from the source (manifold room) to the delivery point became crucial. The global guidelines were standardized by the National Fire Protection Association, NFPA 99 (US) and Health Technical Memorandum, HTM 02-01 (UK), International Standards Organization (ISO), and others.[20] In 1977, the color-coding system was fully standardized internationally with the creation of the ISO 32 standard, which provided guidelines for medical gas cylinder identification.[22]

6. WORLD HEALTH ORGANIZATION AND MEDICAL OXYGEN

In 1979, Oxygen was included in the World Health Organization's (WHO) Model Listing of Essential Medicines.[21] On 25 February 2021, WHO announced that the COVID-19 pandemic had increased global oxygen demand, making its delivery more urgent, especially in vulnerable countries.[24] The World Health Organization supports countries in improving access to medical oxygen through a variety of efforts by providing technical and logistical support, technical guidance, education, training on the use, maintenance, procurement, and selection of medical devices, Research support, Development tools to help with forecasting and decision-making related to oxygen systems. WHO has provided oxygen concentrators for many countries during COVID-19 to alleviate oxygen shortage.

Webinars were conducted on official World Health Organization websites regarding medical oxygen. The WHO website also has training videos for biomedical regarding oxygen-delivery devices.

7. LATE 20TH AND 21ST CENTURY – ADVANCEMENTS

Many incidents occurred due to human errors which compromised the patient safety and quality of patient care. Following the invention of instruments and devices, many technological advancements and developments were made in medical oxygen. To reduce errors, improve efficiency and accuracy many modifications were made to the inventions. All these improved global respiratory care, improved patient outcomes, and decreased healthcare worker's burden. Even though COVID-19 has demanded a real need for advancement in medical oxygen.

8. ARTIFICIAL INTELLIGENCE AND MEDICAL OXYGEN

Artificial Intelligence (AI) has the ability to improve safety, control, and monitoring, which completely modifies the medical gas pipeline system. With the help of AI, real-time oxygen storage tank level monitoring can be done, which ensures the early refills and uninterrupted oxygen supply. In certain circumstances, the primary liquid oxygen supply should be changed to a secondary manifold supply, AI can be embedded in the automatic change-over panels. AI helps to reduce oxygen wastage by promoting better oxygen utilization and improving patient safety. Pressure monitoring and leak identification can be done with the help of AI. AI can be embedded with alarms that provide timely information about the medical gas pipeline system In unforeseen circumstances, it can provide alerts for abnormalities such as system failures, leakage, and pressure variation. Additionally, AI can measure the oxygen consumption for a particular ward, saves cost and resources as well as reduce manpower. Automated or AI-controlled shut-off valves help in remote access to specific wards in the hospital. AI establishment can upgrade the medical gas pipeline systems. Ethical considerations for incorporating AI in health care may be challenging.

9. FUTURE DIRECTIONS (CONCLUSIONS)

Oxygen is an invaluable diamond in the field of medicine. The transformation of medical oxygen from a laboratory discovery to an essential medicine underscores the scientific advancement of the health care system. The discovery gradually shifted to distribution, from the invention of oxygen cylinders to the implementation of medical gas pipeline systems. However, oxygen was not recognized until the COVID-19 pandemic, until the limitations of current systems were fully exposed. Shortages in oxygen supply during the pandemic were not solely due to production constraints but reflected systemic inefficiencies in storage and delivery. This made the healthcare systems to provide attention towards oxygen infrastructure. Future research and trials are required for better oxygen utilization in healthcare systems. Integrating automation will upgrade the current medical gas pipeline system technologies, bringing a revolution to future healthcare. By embedding automation and artificial intelligence into oxygen monitoring and management systems, hospitals can significantly reduce wastage and enhance safety. However, the implementation of AI has challenges and concerns regarding ethical use, data security, cost, and difficulty in embedding with the existing hospital systems. Equity remains another central issue, while high-resource settings rapidly integrate intelligent delivery systems, many low- and middle-income countries still struggle to ensure uninterrupted oxygen availability. World Health Organization efforts to bridge the gap, sustained investment, political commitment, and capacity building are essential for long-term progress. This review emphasizes that medical oxygen is no longer just a therapeutic adjuvant; it is integral to patient safety, surgical outcomes, critical care, and public health preparedness. Its management should be treated as seriously as the administration of any pharmaceutical agent, with standardization, safety protocols, and innovations in the future. As the health care system becomes increasingly digital and interconnected, smart oxygen delivery systems have the potential to revolutionize respiratory care. To realize this vision, interdisciplinary efforts including clinicians, engineers, policy makers, funding agencies, and public health experts are essential

Figures and Tables

Figure 1: Sources of oxygen supply to the hospital

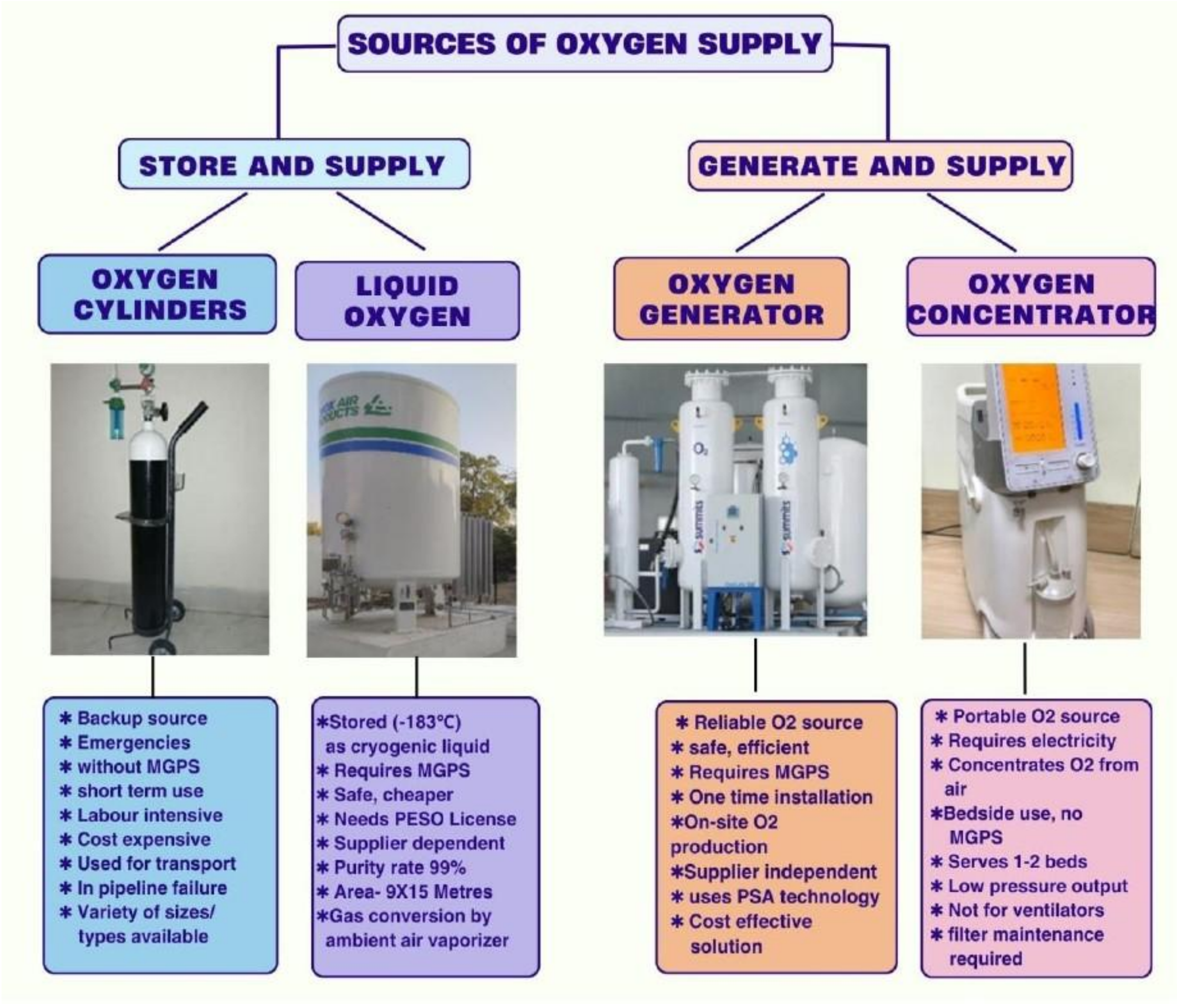


Figure 2: Timeline history of Oxygen

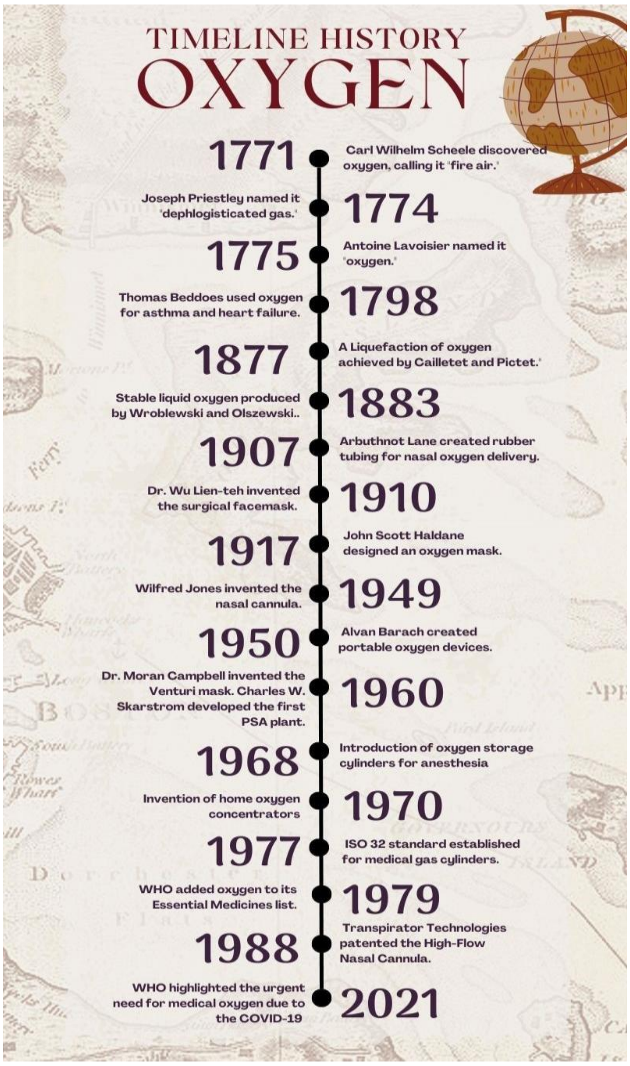
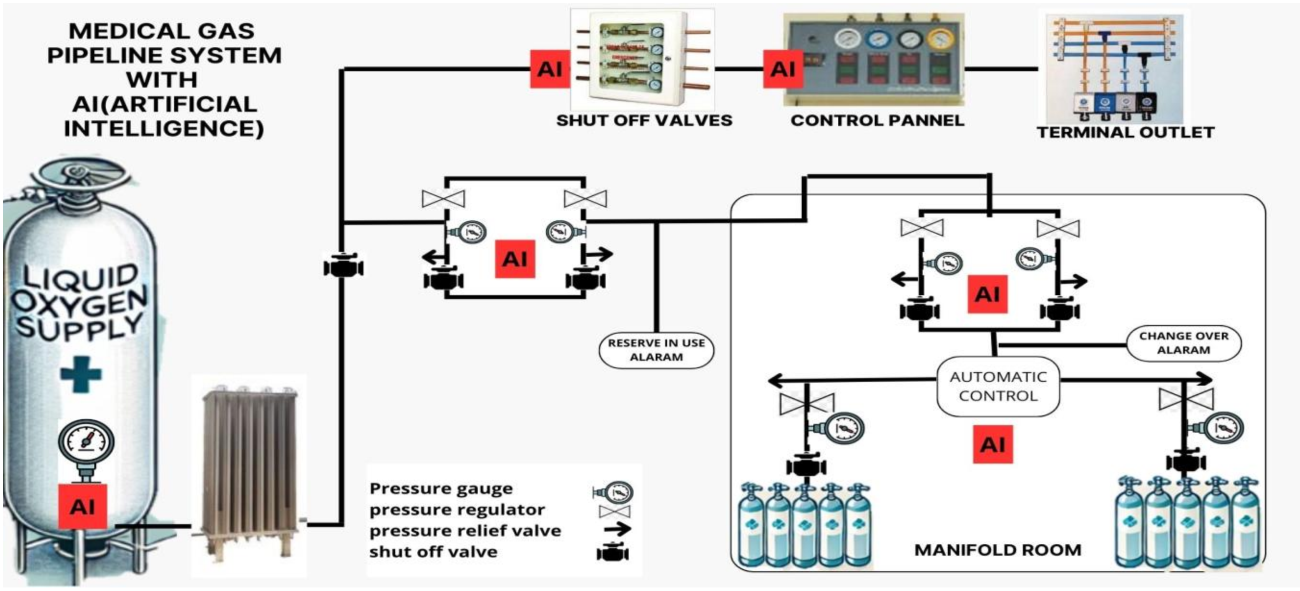


Figure 3: Medical gas pipeline system with Artificail Intelligence (AI)



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Conflict of Interest

We declare no conflict of interest

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Not applicable

Ethics statement

This study did not involve human participants, animal subjects, or any material that requires ethical approval

Informed consent

This study did not involve human participants, and therefore, informed consent was not required

Clinical trial registry

This study does not involve clinical trials

Authors contribution

Rupika E: writing, review, editing; Rani P: writing, review, visualization, and supervision; Hemanth Kumar V R: Visualization and supervision; Prakash Raju K N J: review and visualization; Kishore M F: review and visualization

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