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Artificial Intelligence and Medical Oxygen

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ABSTRACT

Producing medical-grade Oxygen to improve the availability of oxygen therapy and other treatments, especially in developing countries, remote areas strained during the COVID-19 pandemic, and beyond. It argues on the technical challenges, ethical concerns, and other issues of medical oxygen production with Medical Oxygen Concentrators (MOC) for specialized treatments. The article looks into how to integrate proper usage of either ML or DL considering the optimization models, data collection, technical considerations, and bias. It explains how pressure-swing adsorption (PSA) based MOC can be a source of medical-quality Oxygen that can serve different healthcare system levels. It also highlights the advantages and disadvantages of locally generated PSA oxygen, such as its independence from commercial gas producers, ease of use, potential malfunctioning of the sieve, and excess water vapors. While describing how PSA oxygen works by concentrating Oxygen from the ambient air, it highlights the difference in applying Deep Learning or Machine Learning for AI-assist optimization and operation of MOC. The authors address several promising research avenues for novel medical oxygen treatments and production with AI-assisted capabilities, including non-bias data sources, unconventional problem formulations, and human–AI collaboration. Finally, we consider meaningful technical and ethical challenges in issues spanning from data scarcity to racial bias. It concludes that optimizing PSA oxygen devices is essential for improving oxygen therapy and saving lives, notably in Low-Resource Settings.

Keywords: Oxygen Generator; Pressure-Swing Adsorption; Medical Oxygen; Covid-19; PSA

Abbreviations: AI: Artificial Intelligence; DL: Deep Learning, LRS: Low-Resource Settings; ML: Machine Learning; MOC: Medical Oxygen Concentrator; PSA: Pressure-Swing Adsorption

Introduction

The importance of the Medical Oxygen Concentrator (MOC) will increase in the coming years. The need and challenges of producing medical-grade Oxygen are crucial, especially in developing countries, remote areas, or during the COVID-19 pandemic. Based on our research and the ongoing work in many regions around the world, Artificial Intelligence (AI), Deep Learning, and Machine Learning (ML) can help address some of the challenges faced by healthcare systems or even revolutionize healthcare. AI can improve the practinionesrs day-to-day work. Letting healthcare staff spend more time caring for patients, ML and DL can allow for better care outcomes and improve the productivity of care delivery, and, in so doing, raise staff morale, and improve efficiency and retention [1-3]. Pressure-swing adsorption (PSA) Oxygen generating plants can be a source of medical-quality Oxygen that can serve different healthcare system levels. PSA oxygen works by concentrating Oxygen from the ambient air by removing nitrogen through a molecular sieve, such as ion transport membranes or zeolite. But it's a complex thermodynamic mechanism that is substantially influenced by the context and operating conditions. That is where AI can help.

The advantages of PSA oxygen include its independence from industrial or commercial gas producers, ease of use, potential malfunctioning of the sieve, and excess water vapors. MOC based on the PSA process can generate medical-quality Oxygen has an oxygen concentration between 90% and 96%, and most PSA oxygen devices can produce 90 to 93% oxygen at a rate of less than 10 liters per minute. The use and optimization of portable medical oxygen concentrators (MOCs) based on pressure-swing adsorption (PSA) to generate and deliver medical-grade Oxygen in low-resource settings (LRS) is even more critical [3,4]. Many authors have reviewed the evidence of the effectiveness, reliability, and low cost of MOCs compared to other oxygen sources, as well as the challenges of maintenance and power supply. It also considers the factors that affect the performance and design of MOCs, such as maximum flow output, oxygen concentration output at higher altitudes, and humidification. It concludes that MOCs are versatile and beneficial devices for oxygen therapy, especially for patients with serious lung diseases or COVID-19. The current article will discuss the possible extensions and applications of flexible PSA processes for MOCs using Machine Learning and, more generally, Artificial Intelligence. It suggests that a microcontroller can be used to monitor the oxygen level in patients' blood and adjust the operation of the MOC to meet their Oxygen needs in real-time. It also mentions that artificial intelligence can be used to simulate and optimize the complex PSA process and its outcomes. It also points out the potential for improving the exergy efficiency of the process by reducing the exergy losses at different stages.

AI in Healthcare

The healthcare provider struggles to keep up with the most recent advancements in his area and lacks appropriate time to dedicate to each patient due to our rising expectations for the best quality healthcare and the rapid rise of more precise medical knowledge. Due to time constraints, most medical choices must be made quickly, using the doctor's unaided judgment [5-7]. Both Machine learning and Deep learning are types of AI. While ML is AI that can automatically adapt with minimal human interference, DL is a subcategory of ML that uses artificial neural networks to mimic the human brain's learning process. ML and DL tools can assist in retrieving, organizing, and restoring medical knowledge required by a doctor's ability to make decisions and giving a better, quicker, and more accurate prognosis. The Mayo Clinic, Massachusetts General Hospital, Memorial Sloan Kettering Cancer Center, and National Health Service have developed AI algorithms for their diagnosis process, monitoring, therapy, and patient care [8,9]. Although artificial intelligence is still in its infancy, it cannot yet equal a doctor's level of intelligence and most definitely cannot replace a doctor who is physically there. Electronic medical records may be fully utilized with the help of AI, going from electronic filing cabinets to full-fledged doctors' assistants that can give clinically pertinent, high-quality data in real time. How could this benefit doctors? Doctors can cross-reference the data with the most recent clinical studies using Watson, IBM's artificially intelligent supercomputer. AI has come a long way, it still can't fully function on its own or think as a person would, but artificial intelligence has much to offer medical professionals and facilities worldwide. To name a few, AI incorporates virtual presence, decreases cost, eliminates human mistakes, and offers quick and precise diagnoses. Many infections spread quickly, necessitating prompt treatment to prevent them from worsening. Systems equipped with artificial intelligence can retrieve the knowledge that has been stored anywhere in the globe and learn from prior cases. Artificial intelligence, which is rapidly expanding in many areas directly related to health, is used in so many applications [10-12].

PSA-Based Oxygen Production

In the Pressure swing adsorption (PSA), ambient air passes through an internal filtration system (e.g., a molecular sieve [zeolite granules or membranes]), which has a large enough total surface area to separate nitrogen (N_2) from the air, concentrating the remaining Oxygen (O_2) to a known purity. It typically consists of an air compressor, dryer, filters, dual separation chambers, a reservoir, and controls [13,14]. PSA is an economical and reliable method to separate mixed gas into individual gases while achieving a high purity level. PSA is a non-cryogenic air separation process which essentially means it is a process that uses near ambient temperatures for the production of Oxygen in contrast to the cryogenic distillation techniques of gas separation, which take place are very low temperatures and is a process commonly employed in chemical and petrochemical processes in commercial practices [15-17].

Medical Oxygen with AI-Assistance

There is not much development in the context of AI-assisted Medical Oxygen. But for a few articles, such as Ref. [18], it isn't easy to find much essential medicine from the WHO guidelines [19,20]. But the potential for support is high, especially in regions where this resource MO is limited or has an intermittent supply chain (such as in many developing countries). We already have some examples of AI-assisted oxygen treatments. Notably, AI Compass: A device that uses AI to monitor and adjust the oxygen flow for patients with COPD (chronic obstructive pulmonary disease) based on their activity level, blood oxygen saturation, and heart rate. OxyGEN: A device that uses AI to convert manual ventilators into automatic ones, by controlling the oxygen flow and pressure for patients with respiratory failure, especially those with COVID-19, or Oxynov: A device that uses AI to provide adaptive oxygen therapy for patients with hypoxemia, by adjusting the oxygen flow according to the patient's breathing pattern and oxygen saturation. But we might go even further than assisting treatments. It can also provide the optimum quality of Oxygen produced locally, independent from supply chain struggle and for a lower cost [21]. Properly implemented Machine Learning or Deep Learning can improve medical oxygen production with PSA-based MOC. The outcomes of such integration can allow for further improvement of Medical Oxygen Treatments and Production with MOC in several ways presented in (Table 1). Further along, the patient's journey with oxygen therapy or other O_2-based treatments, having access to patient information and being able to adjust Oxygen Quality from any location is now more critical than ever (Table 2). Distributed ways of working have quickly become the norm in the wake of COVID-19, with remote reading and even diagnosis creating opportunities to balance workload and leverage specialists across enterprise networks [22-24].

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Table 1: AI-Assisted Improvement of Medical Oxygen Treatments and Production with MOC.

	AI (ML or DL) can assist to:
Monitoring oxygen levels:	Measure and track patients' oxygen saturation, especially those with chronic respiratory conditions or COVID-19, using wearable devices or smartphone apps.
Optimizing oxygen delivery:	Adjust the flow and concentration of Oxygen delivered to patients using smart oxygen concentrators or ventilators based on their individual needs and treatment preferences.
Reducing oxygen waste:	Detect and prevent leaks, overflows, or misuse of oxygen supplies using sensors and algorithms that monitor the pressure, temperature, and flow of Oxygen in cylinders or pipelines.
Reducing resources usage:	Optimizing the MOC process and treatment would allow for better quality with small resource usage and improve energy efficiency; this would greatly help to stabilize Medical Oxygen Supply in developing countries during power outage periods and other LRS.
Improving oxygen access:	Forecast the demand and supply of Oxygen in different regions or facilities using data from health records, epidemiological models, and logistics systems, and provide recommendations for optimal allocation and distribution of oxygen resources.

Table 2: AI applications in healthcare.

	Applications in Healthcare	AI is already used, or in deployment, to:
1	Imaging analysis	Identify abnormalities, reduce radiation dose, and improve image quality in CT, MR, and ultrasound modalities.
2	AI-assisted robotic surgery	Guide surgical robots and provide real-time feedback to surgeons, resulting in more precise and less invasive procedures.
3	Preliminary diagnosis	Analyze symptoms, medical history, and test results, and provide a possible diagnosis or a list of differential diagnoses for patients.
4	Virtual nursing assistants	Monitor patients' conditions, answer their queries, remind them of their medications, and alert medical staff if needed.
5	Connected medical devices	Collect and analyze data from wearable devices like smartwatches that track vital signs, activity levels, and other health indicators.
6	Prescription error recognition	Detect and prevent errors in prescribing or dispensing medications, such as drug interactions, allergies, or dosage mistakes.
7	Drug discovery	Accelerate the process of finding new drugs or repurposing existing ones by screening large databases of chemical compounds and predicting their effects and interactions.
8	Forecasting kidney disease	Predict the risk of developing chronic kidney failure or kidney disease based on factors (e.g., blood pressure, glucose levels, and demographics).
9	Researching and treating cancer	Analyze genomic data, identify mutations, classify tumors, recommend personalized treatments, and monitor responses for cancer patients.

As shown in (Figure 1), while distributed working methods take hold, central coordination is critical. This might mean that we will see a substantial rise of clinical and operational command centers – either virtual or physical – that allow for the dynamic orchestration of people, data, treatment, and, notably, medical Oxygen across the healthcare setting. These command centers will be instrumental in managing complexity and unpredictability, and better managing Medical O_2 will be essential in an already overburdened system. In cardiac care, cloud-based AI already helps quickly detect atrial fibrillation or heart rhythm disturbances based on an analysis of remote electrocardiogram (ECG) recordings. Atrial fibrillation affects millions each year. However, the condition is often unrecognized and untreated (Figure 2). By flagging readings that may require the most urgent attention, clinicians are empowered to deliver cardiac care faster and more efficiently. [25] The same approach could be used with Oxygen Therapy. But research still needs to continue to allow for proper and ethical integration of machine learning in healthcare, especially in the medical oxygen supply. Further along, the patient's journey with oxygen therapy or other O_2-based treatments, having access to patient information and being able to adjust Oxygen Quality from any location is now more critical than ever. Distributed ways of working have quickly become the norm in the wake of COVID-19, with remote reading and even diagnosis creating opportunities to balance workload and leverage specialists across enterprise networks [22-24]. As shown in (Figure 1), while distributed working methods take hold, central coordination is critical. This might mean that we will see a substantial rise of clinical and operational command centers – either virtual or physical – that allow for the dynamic orchestration of people, data, treatment, and, notably, medical Oxygen across the healthcare setting (Figure 3). These command centers will be instrumental in managing complexity and unpredictability, and better managing Medical O_2 will be essential in an already overburdened system.

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Figure 1: Process diagram of the PSA Medical Oxygen Production.

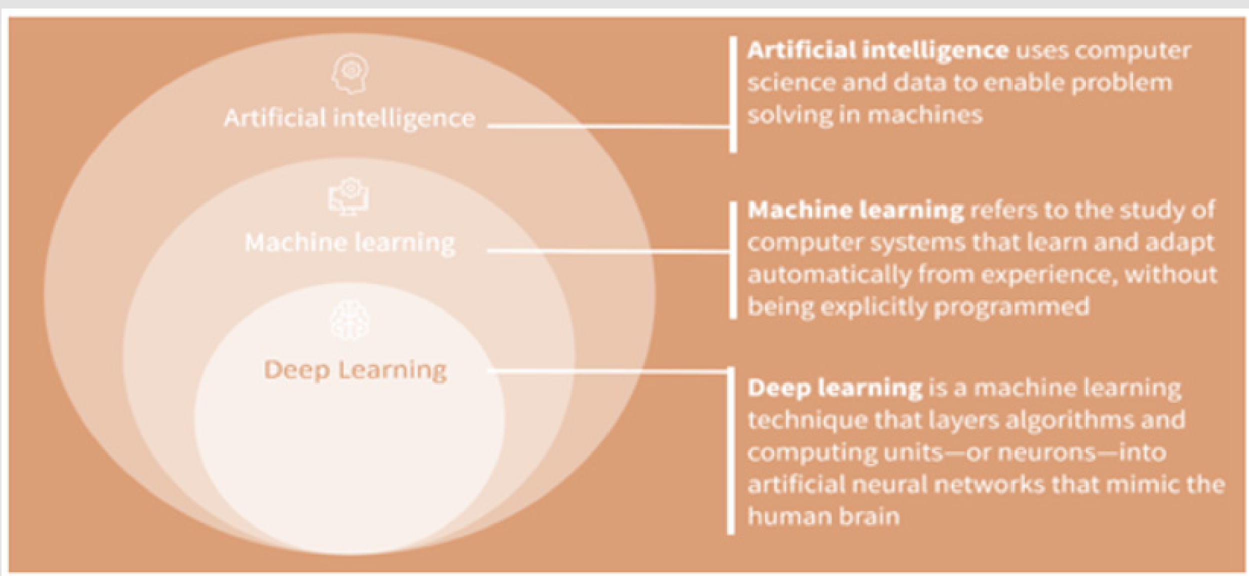

Figure 2: Deep learning vs. machine learning.

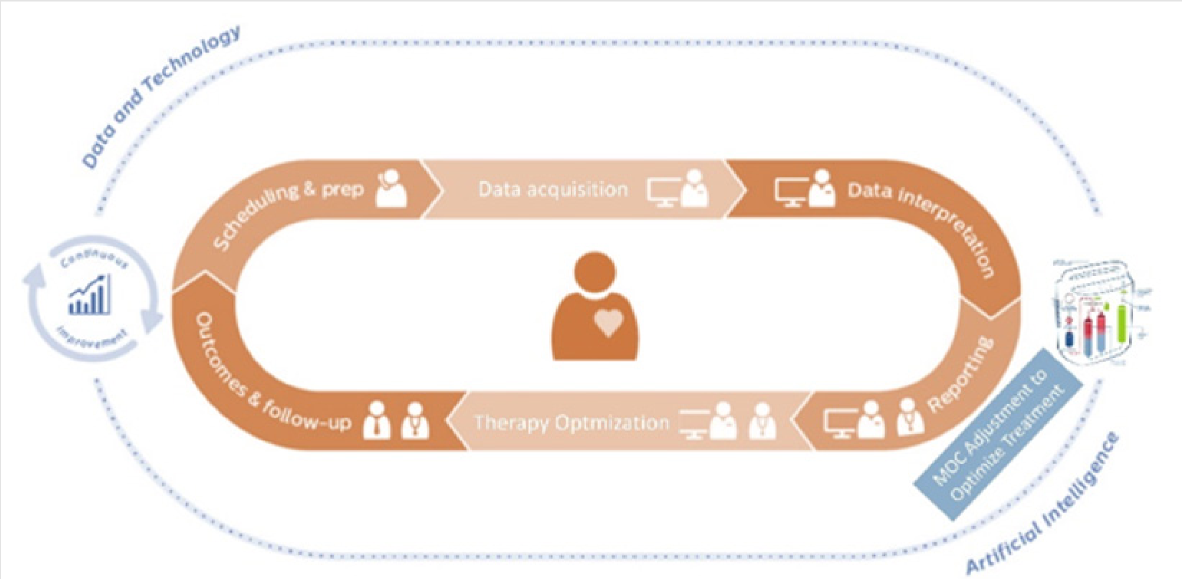

Figure 3: Framework for using AI-assisted process for Medical Oxygen Treatment with MOC.

Figure 4: Overview of the progress, challenges, and opportunities for AI in health. CMS, Centers for Medicare & Medicaid Services.

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In cardiac care, cloud-based AI already helps quickly detect atrial fibrillation or heart rhythm disturbances based on an analysis of remote electrocardiogram (ECG) recordings. Atrial fibrillation affects millions each year. However, the condition is often unrecognized and untreated. By flagging readings that may require the most urgent attention, clinicians are empowered to deliver cardiac care faster and more efficiently [25]. The same approach could be used with Oxygen Therapy (Figure 4). But research still needs to continue to allow for proper and ethical integration of machine learning in healthcare, especially in the medical oxygen supply. Minimizing equipment downtime through predictive maintenance is also an advantage of AI-powered units. Next to augmenting the skills of physicians and staff, AI can also help improve continuity of care by predicting when medical equipment requires maintenance. For example, through continuous sensing (with remote supervision of staff), a unit can monitor and analyze over 500 parameters on a MOC, allowing it to identify proactively when certain hardware parts may need maintenance or replacement. For MR machines, results have illustrated preventing avoidable interruptions (up to 30% of service cases can be resolved before downtime is caused) to clinical practice and unnecessary patient delays [25]. In the future, having a full digital twin, or virtual representation of an entire imaging fleet, could allow for even more comprehensive predictive maintenance and continuous operational optimization. In a nutshell, the AI-assisted framework asks for better human–AI collaboration.

In some cases, AI-assisted oxygen treatments can be more effective than traditional methods, depending on the type and severity of the condition, the availability and quality of Oxygen, and the patient's preferences and compliance. Some possible benefits of AI-assisted oxygen treatments and products have been identified:

A. Reducing mortality rate: A study using a reinforcement learning algorithm to manage oxygen flow rate for COVID-19 patients under intensive care [26,27] showed that the algorithm could potentially lower the mortality rate by 2.57% compared to the standard of care.

B. Enhancing photodynamic therapy: Photodynamic therapy (PDT) is a technique that uses light and photosensitizers to generate ROS and kill tumor cells, but it requires Oxygen to work. Some studies have shown that using AI to regulate oxygen delivery or supply can improve the efficacy and safety of PDT for cancer treatment.

C. Improving patient comfort: AI can help to provide personalized and adaptive oxygen therapy for patients with different conditions, such as COPD, hypoxemia, or respiratory failure, by adjusting the oxygen flow according to their activity level, blood oxygen saturation, heart rate, or breathing pattern. This can reduce the risk of oxygen toxicity, hypercapnia, or hypoxemia and improve patient comfort and quality of life.

D. Improving oxygen availability or usage: In a case of stretched resources (Oxygen, energy, staff), a healthcare facility is sometimes or more often (see [22-29]) unable to appropriately respond to the demand for medical Oxygen. AI can help minimize usage for the same or even better level of treatment quality.

Discussion

While Deep Learning appears to be less adapted to MOC optimization because it requires a much more significant amount of data than ML, Machine Learning can be used faster to improve oxygen delivery systems. But Deep Learning appears to be the natural next step into optimization, such as advanced thermodynamic models [2,13,22,28] since DL is an advanced ML technique that layers algorithms and neurons (the computing units) into an artificial neural network. Nevertheless, DL learns independently from the environment and past mistakes using a specialized GPU (graphics processing unit) to train. On the other hand, ML requires more human intervention to correct and learn but can be trained on a more accessible CPU (central processing unit). In any case, ML and DL AI assistance can help optimize the design, fabrication, and performance of oxygen delivery systems, such as oxygen carriers, oxygen generators, or oxygen sensors. This can improve oxygen therapy's efficiency, safety, and accuracy for various conditions. ML allows for shorter training and can be implemented quickly, offering lower precision. DL comes with more extended training, but higher accuracy is possible with proper models since it can make non-linear, complex correlations. This is getting more important when supply chains are stretched or the healthcare facility is in difficult context or severe conditions, including very low, very high humidity, temperature, or high altitudes. Notably, Oxygen is scarcer at higher altitudes (e.g., oxygen levels from sea level at 20.9% O_2, 2,000 m 19.4% or even 18.6% at 3,000 m). Patients in the installations of these higher altitudes may require higher volumetric flow rates for acceptable medical-oxygen quality than patients at sea level, especially true for longer-duration therapy because temperature and humidity tend to decrease at higher altitudes [22]. Since two parameters play opposite directions, deep learning modeling might be the only way to define the best or optimum outcome.

While we focused on optimizing the MOC process performance and quality of treatments, the analysis quickly shows the possibilities, including innovative approaches for Medical O_2, an essential medicine [30]. One example is to use ML or DL to make the most of the flexible nature of PSA-based MOC in the monitored environment (illustrated in Figure 1) to determine MOC optimal control to meet the patient's oxygen requirement in real-time. The effects of design and operating conditions shall be mapped to help the designers and engineers map outlet product specifications and production effectiveness [31]. To make it practical and accurate, the way forwards would be an efficient translation into machine learning models or even the deep learning networks that might be better suited to simulate the complex PSA process. Continuing research is needed, and additional steps might include getting faster and more accurate real-time modeling and integrating artificial intelligence into the mix. But there are still some limitations of AI-assisted oxygen treatments and O_2 production, such as:

a. Technical challenges: AI algorithms may face difficulties in dealing with complex, noisy, or incomplete data or in generalizing to new or diverse settings. They may also require high computational power, a reliable internet connection, and frequent updates.

b. Ethical concerns: ML or DL based systems may raise issues of privacy, consent, accountability, transparency, and fairness, especially when handling sensitive health data or making life-or-death decisions. They may also pose risks of bias, discrimination, or error.

c. Human factors: AI systems may encounter resistance or mistrust from patients or clinicians, who may not understand how they work or what benefits they offer. They may also require training, education, and collaboration to ensure proper use and integration.

Rajpurkar, et al. [25] discussed these challenges and referred to the US CMS (Center for Medicare and Medicaid Services) Overview of the progress, challenges, and opportunities for AI in health. This applies to medical Oxygen as well. Their article argues that collecting medical data for AI can be difficult for various reasons. One reason is the cost of the devices needed to capture the data, such as scanners or cameras. These devices can be expensive and inaccessible in many healthcare settings, which limits both the availability and diversity of data. Another reason is the data size, especially images, which can be too large to fit into standard neural networks.

There are several ways to deal with this problem, such as resizing or changing the design, splitting them into smaller units, or using human experts to identify solutions of interest. However, these methods can also introduce drawbacks, such as losing fine details, breaking thermodynamics/optimal relationships, or adding manual steps. While this “data limitation” can be limiting for other applications of AI in healthcare, in the case of Medical Oxygen, there is much better control of the data as soon as we get a good model well based on the laws of physics. Also, probing data can be obtained from non-expert sources, such as crowdsourcing platforms or other AI models. However, these sources can also introduce noise or inaccuracies into the labels, and raise privacy concerns, as the data have to be shared with multiple parties.

We can also identify how bias can affect medical datasets and AI models related to MOC. We might assume that they are influenced by genre, age, race, etc. One type of bias is single-source bias, which occurs when a dataset is generated by a single system with fixed settings, such as a single camera with a specific resolution or angle. This type of bias can limit the generalization ability of AI models, as they may not perform well on data from different sources or settings. But how significant is it on the results? That would orient the way forward using the approach. Some possible solutions to mitigate single-source bias include performing site-specific training and validating models on datasets from multiple sources, and adapting models to each region or age group or where Ai-assisted MOC are deployed. Medical AI raises ethical concerns in many areas or treatments, such as regulating AI in medicine, allocating responsibilities among researchers, physicians, and patients, and the equity and fairness of data use and access. They should also be raised for medical oxygen treatment and production with AI assistance. The text implies that these concerns must be addressed carefully and responsibly to ensure the safety and quality of medical AI. The following figure outlines the challenges and the opportunities associated with AI-assisted technologies and treatment illustrated by the Centers for Medicare & Medicaid Services. As a folding remark, PSA plants can be turn-key units when adequately optimized, e.g., using Machine Learning or Deep Learning tools discussed in this article but in conjunction with good modeling and thermodynamic tools. However, optimization is not the only required item in implementing a PSA Oxygen plant. For example, the staff operating and maintaining these MOCs requires specialized training and support. In addition, while they can be monitored through the AI-assisted framework, strict maintenance schedules and resources are needed to prevent malfunctions, while a reliable supply chain is required to meet any additional needs.

Conclusion

In this article, we discussed some of the technical challenges and ethical concerns of medical oxygen production with MOC and treatments (such as Oxygen Therapy) using ML or DL, focusing on the issues related to optimization models, data collection, and other technical considerations. We cover prospective studies and advances in MOC, which have reduced the disparity between research and deployment. The flexibility of MOC makes it so that PSA oxygen devices’ operation can be optimized for improving oxygen therapy and saving lives. ML and DL are both types of AI that can be used to optimize the PSA process. While machine learning can automatically adapt with minimal human interference, deep learning uses artificial neural networks and more resources to mimic the human brain’s learning process and generates more accurate outcomes. It explains how medical AI data for medical Oxygen are less limited than other applications of AI in healthcare by the cost of equipment, the size of inputs, and the availability of labels. It also describes how labels can be obtained from different sources, such as experts, crowdsourcing, or other AI models, but with varying degrees of accuracy and privacy. We also address several promising research avenues for novel medical Oxygen with AI-assisted capabilities, including non-image/non-bias data sources, unconventional problem formulations and human–AI collaboration. Finally, we consider meaningful technical and ethical challenges in issues spanning from data scarcity to racial bias. Notably, datasets can suffer from single-source bias, which can affect the generalization ability of AI models. It suggests some possible solutions for the medical oxygen case, such as integrating proper thermodynamic models and performing site-specific training. Resolving these challenges would free AI's potential, making healthcare more accurate, efficient, and accessible for patients worldwide. That AI-optimization PSA oxygen device has a substantial potential for improving oxygen therapy and medical oxygen availability and quality and, in terms, of saving lives, particularly in LRS. But human–AI collaboration will be critical to long-term solutions, especially in LRS and remote locations.

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