Mechanical Ventilation:

A review of the clinical efficacy, use cases, and changes following the COVID-19 pandemic.

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Section 1: Background

Mechanical ventilation is a life-saving therapy that forces air into the central airways—the trachea and bronchi. The resulting pressure gradient causes air to flow into the small airways and alveoli. The purpose of mechanical ventilation is dual: it performs the work of breathing and promotes pulmonary gas exchange in patients with respiratory failure.

Ventilators are most commonly used in acute care settings such as intensive care units (ICU) and emergency departments (ED). In fact, mechanical ventilators catalyzed the development of modern ICU's.[1] Patients in these settings may present under respiratory distress and imminent respiratory failure arising from various clinical conditions. In these patients, mechanical ventilation is initiated following specific guidelines. If these guidelines are not followed, mechanical ventilation can lead to serious clinical and physiological complications.[2] This phenomenon received widespread attention during the COVID-19 pandemic. This will be discussed in more detail in **Section 2.**

Another common use of mechanical ventilation is among patients who do not have respiratory distress but who must be sedated to undergo invasive procedures. The typical use case in this category is patients undergoing surgery under general anesthesia. Besides the heavy sedation, muscle paralysis is also induced in these patients. Invasive mechanical ventilation may also be useful in those who require airway protection to reduce the risk of aspiration. This is the case among patients with a depressed mental status from a drug overdose and those with certain types of gastrointestinal hemorrhages, e.g., variceal bleeding.

In acute care settings, mechanical ventilation is an invasive therapy. The delivery of positive air pressure to the lungs is via an endotracheal or tracheostomy tube. These procedures require a high level of technical expertise and carry a significant risk of complications. However, there is an option for non-invasive mechanical ventilation (NIV) at home for a select group of patients.[3] Additionally, even in the acute care setting, there are new devices and modes of ventilation that increase patient safety and reduce the time that ventilation is needed. This will be discussed in more detail in **Section 3.**

History of Mechanical Ventilation

Mechanical ventilation has its origins in the mid-16th century with the work of Flemish physician Andreas Vesalius. His seminal treatise *De Humani Corporis Fabrica* published in 1543 contains

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Section 2: Clinical Uses and Complications

Definition

Mechanical ventilation is the use of a machine to assist with the work of breathing.[13] The goal of ventilation is to provide oxygen and to remove carbon dioxide from the lungs. Mechanical ventilation can be either **invasive or noninvasive.**

Invasive mechanical ventilation can be defined as the delivery of positive pressure to the lungs via an "advanced airway"—an endotracheal or tracheostomy tube and it is most commonly used in the acute care setting. It is considered an invasive intervention because the insertion of an endotracheal or tracheostomy tube requires a high level of technical expertise and carries a significant risk of complications. Endotracheal tubes are used more commonly and they are the first-line option for most patients presenting with acute conditions. Tracheostomies are generally used for long-term management of the airway. However, they may be the primary option in emergency cases where intubation through the oral cavity or nose is not feasible (e.g., gunshot wounds to the face).

Mechanical ventilation forces a predetermined mixture of air—oxygen and other gases—into the central airways and then flows into the most distal respiratory unit, the alveoli. This creates a pressure gradient in the airways. As air flows through the lungs, intra-alveolar pressure increases. This pressure build-up generates a **termination signal** (flow or pressure) that causes the ventilator to stop forcing air into the central airways. As pressure in the central airways decreases, expiration follows passively **(Figure 2).**

Figure 2. Process of mechanical ventilation showing the pressure gradient driving each ventilatory cycle.

While mechanical ventilation is considered invasive if intubation is required, an alternative method of delivery is **noninvasive ventilation (NIV).** NIV uses an external interface, usually a face mask, to deliver air to the lungs. This and other less invasive delivery methods will be discussed in more detail in **Section 3.**

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Section 4: Market Considerations

The Impact of COVID-19: A Resilient Market

COVID-19 was an unprecedented event not only from a public health perspective, but also from an economic one. The pandemic affected multiple domains of the respiratory care and ventilator market:

Market

- Supply
- Demand

Political & Economic

- Regulatory framework
- Macroeconomic factors

Stakeholders

- Providers & hospitals
- Patients
- Governments

For the North American market of mechanical ventilation, 2020 meant a **record revenue of $4.35B.**[51] This stemmed primarily from increased demand during the surge of COVID-19 cases in different regions of the world. To maintain supply, governments eased regulatory barriers and expedited the approval process, for example, through Emergency Use Authorization (EUA) in the U.S. Funding also increased through public-private partnerships and increased government funding for prevention, diagnostics, therapeutics, and long-term care of COVID-19 patients.

Manufacturers increased supply, but this was constrained by severe supply chain limitations. This led to innovation among manufacturers to shift production from less essential equipment to ventilators. Additionally, some companies took advantage of more relaxed regulation to venture into the ventilator market. Such was the case for **Fitbit,** a key player in the wearables market. During COVID-19, Fitbit pivoted some resources to meet this market by creating the Fitbit Flow. Fitbit Flow was easier to operate than the commonly available ventilators and thus reduced the burden on medical staff.[52,53]

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Section 5: Methodology

This literature review on mechanical ventilation was conducted in April 2023 using the following biomedical databases: 1) the National Library of Medicine's PubMed, 2) Medline, 3) CINAHL Plus, 4) Embase, and 5) Cochrane. For clinical decision-making guidelines, we consulted tools such as UpToDate and StatPearls. Additionally, we queried market data using ProQuest.

Where appropriate, we also consulted relevant textbooks, news articles, official communications from regulatory agencies (e.g., FDA), and national and international society guidelines. Certain reports from private research institutions such as and Gartner and Grand View Research were also used.

Terms included in the search were "mechanical ventilation" OR "ventilators" OR "modes of ventilation" OR "respiratory support" OR "invasive ventilation" OR "noninvasive ventilation". To look for associations, these terms were combined with others relevant to this review such as "COVID-19" OR "complications" OR "lung injury" OR "advances" OR "new technologies" OR "home therapy". For articles in these databases, the criteria for inclusion included 1) written in English, 2) published in peer-reviewed journals, 3) published between 2010 and 2023. We assessed each article for relevance to the questions of interest based on title or abstract review. Ultimately, we cited 45 peer-reviewed papers to create this report in addition to the other sources listed above. Therefore, Juniper Life Sciences is confident in the quality of the insights provided.

Limitations

We acknowledge certain limitations such as the relatively few data from randomized clinical trials and systematic reviews on the topic of new ventilation modes. While advantageous in some ways, these remain largely investigational and data are inconclusive regarding clinical outcomes compared to conventional modes of ventilation. Regarding mechanical ventilation and COVID-19, the decision to intubate still depends on physicians' clinical judgment and there are no societal guideless with firm criteria.

In producing this report, we have considered the best available evidence. However, because there are certain gaps in knowledge until more information is available, certain recommendations are based on societal guidelines or expert opinions. Expert recommendations do not replace high-level evidence, particularly randomized controlled trials and systematic reviews and metanalyses.[58] Given this limitation, the reader should exercise caution when using the information contained in this report to make clinical or business decisions.

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