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Multiple Mechanical Ventilation: historical review and cost analysis

Ventilación mecánica simultánea: revisión histórica y análisis de costos

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Abstract

In times of crisis in public health where the resources available in the hospital network are scarce and these must be used to the fullest, innovative ideas arise, which allow multiplying the use of existing resources, as artificial mechanical ventilators can be. These can be used in more than one patient, by attaching a device to distribute the mixture of air and oxygen from the ventilator being used simultaneously (multiple mechanical ventilation). This idea, although innovative, has generated controversy among the medical community, as many fear for the safety of their patients, because attaching such devices to the ventilator loses control over the mechanical ventilation variables of each patient and can only maintain general vigilance over the ventilator. These misgivings about the device have led several researchers to take on the task of verifying the reliability of this flow splitter connector. It is for this reason that this article presents a thorough review of the studies carried out on the subject and additionally shows an analysis of comparative costs between the acquisition of a mechanical ventilator and the flow division system.

Keywords: Flow Division System; Mechanical Ventilation; Cost Analysis; public health; COVID-19.

Resumen

En tiempos de crisis de salud pública donde los recursos disponibles en la red hospitalaria son escasos y estos deben ser aprovechados al máximo, surgen ideas innovadoras, que permiten multiplicar el uso de los recursos existentes, como pueden ser los ventiladores mecánicos artificiales. Estos se pueden utilizar en más de un paciente, mediante la conexión de un dispositivo para distribuir la mezcla de aire y oxígeno del ventilador que se utiliza simultáneamente (ventilación mecánica simultánea). Esta idea, aunque innovadora, ha generado polémica entre la comunidad médica, ya que muchos temen por la seguridad de sus pacientes, pues al acoplar dichos dispositivos al ventilador se pierde el control sobre las variables de ventilación mecánica de cada paciente y solo se puede mantener la vigilancia general sobre el ventilador. Estos recelos sobre el dispositivo han llevado a varios investigadores a asumir la tarea de verificar la fiabilidad de este conector divisor de flujo. Por ello que este artículo presenta una revisión exhaustiva de los estudios realizados sobre el tema y adicionalmente muestra un análisis de costos comparativos entre la adquisición de un ventilador mecánico y el sistema de división de flujo.

Palabras clave: sistema de división de flujo; ventilación mecánica; análisis de costos; salud pública; COVID-19.

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1. Introduction

The breathing process, essential for human life, has four main periods. 1) Pulmonary ventilation: where air enters and leaves the lungs, 2) diffusion: characterized by the passage of oxygen and carbon dioxide (C_O2) from the lung to the pulmonary capillaries, 3) oxygen transport to different cells, and 4) regulation of the whole process, controlled primarily by the brain. When there are failures in the breathing process, cells, especially in the brain, begin to die after 4-6 minutes, much earlier if we compare it with the failure of blood circulation [1].

Breathing is usually rhythmic, slow, and often stable. Physiologically, it varies with age and physical condition. The normal breathing rate of an adult at rest ranges from 12 to 20 breaths per minute. Figures above normal (Adult > 20 x min.) are called polypnea and values below (Adult < 10 x min.) bradypnea.

SARS Cov2 (COVID19) is a virus that has spread around the world at high speed since the end of 2019 due to its high contagion rate. It mainly affects the respiratory system, as shown by its first cases in the municipality of Wuhan in Hubei province in China, which had symptoms of pneumonia [2].

This new Coronavirus has put public health systems in many countries on alert because, despite its low mortality rate of approximately 3.7%, its rapid spread has led to the activation of protocols to stop its spread [3]. In many cases, these protocols have been insufficient, leading to the collapse of the health system due to the lack of resources, both in supplies and medical equipment to detect, contain, and medically treat the virus.

In this context, since the beginning of the pandemic, the main public and private laboratories have entered a race to find an effective vaccine against the virus, leading to the global development of more than 200 vaccines in different research states [4]; six of which were already tested on healthy volunteers [5], to March 2021 the vaccines of Pfizer/BioNTech, Janssen, Moderna, Sinopharm and the two versions of AstraZeneca/Oxford - (SKBio-Serum Institute of India) have been approved by the World Health Organization (WHO) and are being distributed around the world [6]. These WHO-approved vaccines represent approximately 64% of the doses purchased by Latin American countries, the remaining 36% are from 8 other laboratories [7]. Of the 1,398 million doses purchased for the region, 70% belong to Brazil and Mexico, which are also the two most populous countries in Latin America with more than 50% of the region's population [8].

Figure 1 shows that only six countries in the region have prepared for this pandemic by acquiring the necessary doses to protect 100 percent of their population.

Figure 1. Percentage of both insured and optional doses from some countries in the region. Source: [8].

The percentage of vaccines expected to be procured by each country in the region is significant because, according to WHO, the proportion of the population that must be vaccinated to achieve a collective immunization is still unknown [9] and some researchers present more in-depth analysis on this topic, such as the article published by science journalist Christie Aschwanden in the journal Nature on March 31, where there are five reasons why herd immunity cannot be trusted against COVID-19 [10].

Another problem with vaccine-only pandemic control plans is the effectiveness of vaccines since WHO recommends that vaccines must be 70 percent effective, although they set a minimum critical value of 50 percent, this means that none of the vaccines will control the pandemic in the entire vaccinated population [11]. Some of the effectiveness values for the most commercially available vaccines are presented in Figure 2, considering that three of these vaccines are below the WHO recommended value and represent approximately 23 percent of the doses purchased in the region, is an element that will affect the development of the pandemic when other alternatives are not analyzed to control the over-quota of the Intensive Care Units (ICU).

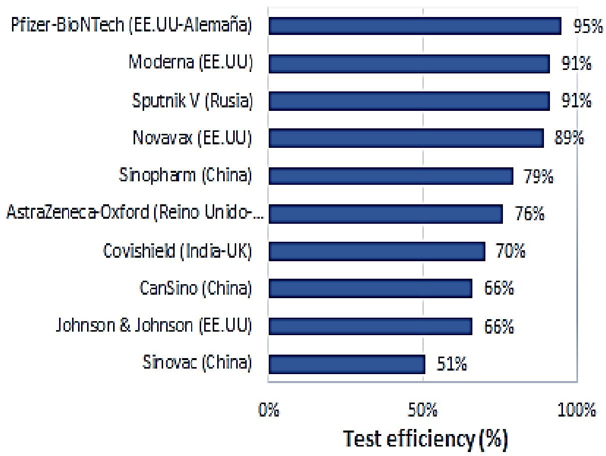


Figure 2. Effectiveness of the most commercialized vaccines. Source: [7].

The last element that is influencing the progressive development of the pandemic (third and fourth peaks) is the timing of vaccination plans, since, as of May 5, 2021, only Chile has reached 80% of the vaccination population with at least one dose. While the other countries of South America are far from these values, Uruguay and Brazil reach 55% and 21% respectively of their population while Argentina and Colombia are between 10% and 20% of their population vaccinated with at least one dose, the other countries of South America are below 10%. Vaccination time can be extended much longer since these vaccination processes have been in progress for 3 to 5 months [12].

When assessing the state of the pandemic in Colombia as of May 5, 2021, it can be seen that the main cities of the country such as Bogotá, Medellín, Cali, and Barranquilla exceed 90% of the occupation of intensive-care rooms[13], while some others such as Tunja reach 100% occupation [14]. It is necessary to implement strategies that allow new procedures to be applied to address this current problem that the country and the Latin American region are experiencing.

One of the fundamental pieces of equipment for this fight against the COVID19 is the assisted mechanical respirators used in the intensive-care rooms of the medical centers, which are currently very busy in our country (Colombia). In this context, an innovative idea has emerged, which allows multiplying the use of artificial mechanical ventilators, by attaching to them a device to distribute the mixture of air and oxygen coming from the ventilator to several patients simultaneously (multiple mechanical ventilation) [15].

This peculiar technique was applied during the Las Vegas (U.S. shootings). However, this solution has created debate among the medical community, as many fears for the safety of their patients, because when coupling the device (flow divider) the ventilator loses control over the variables of the mechanical ventilation of each of the patients and could only be kept a general watch on the ventilator.

Intending to contribute diminishing the controversy surrounding the safety of the mechanical respiration methodology for multiple patients, this article presents a thorough review of the studies carried out on the subject, which provides an objective view of the risks and benefits of the method, in addition to carrying out a comparative cost analysis between the acquisition of a mechanical ventilator and the flow division system.

2. Methods

2.1. Information Flow divider connector

Mechanical ventilation is an essential component in intensive-care units as it is responsible for generating the cycles of inspiration and expiration in people with respiratory system failures. There are different modes in which a mechanical ventilator can operate between which two of them can be highlighted, 1) volume control (VCV) where a certain pre-adjusted inspiratory flow is kept constant uncontrollably varying lung pressure conditions; and 2) pressure control (VCP), where airway pressure is adjusted and remains constant, regardless of changes in lung tissue resistance and diaphragm [16].

The flow splitting device (see Figure 3) is an accessory, usually plastic; it can be coupled to the mechanical ventilator (see Figure 4), to generate multiple pulmonary ventilation for patients, which is an alternative to address the possible shortage of hospital pulmonary ventilation devices.

The methodology applied for the selection of articles follows the recommendations given for an article, where it is recommended to evaluate the validity of the study, the results obtained, and the relevance or applicability of the same [17]. Thus, the methodology of the review focuses on those studies that help to reduce the controversy over the use of these systems, in the first place the criteria that contribute to the discussion are established, understanding and identification of the effects they may have on patients; the methodology used is then sought, prioritizing the most up-to-date and experimental studies with systems incorporating instruments to measure and control variables; finally, studies that show results that pro or against the use of these multiple patient systems are identified. Concerning comparative cost analyses, quotes from specialized marketers, online sources, and medical staff are sought, to have a comprehensive overview of equipment costs, the average values of the equipment and accessories required to determine the suitability of these mechanical respiration systems for multiple patients will then be taken.

3. Results and discussion

The idea of using a flow-splitting device has been approached experimentally by several research groups, where using simulators of lungs, animals, or in short intervals of time in humans, aim to determine the reliability of the method and the parameters to be configured in the ventilator for multiple pulmonary ventilation. In Table 1 are shown the studies carried out regarding the subject, including, configuration and main results:

(a) (b)

Figure 3. Flow divider devices for multiple patient lung ventilation. (a) VESper ™ device licensed for emergency use (UAE) by the FDA during times of acute equipment shortages [18]. (b) Different shapes of Flow Splitter Devices for 3D printing manufacturing [19].

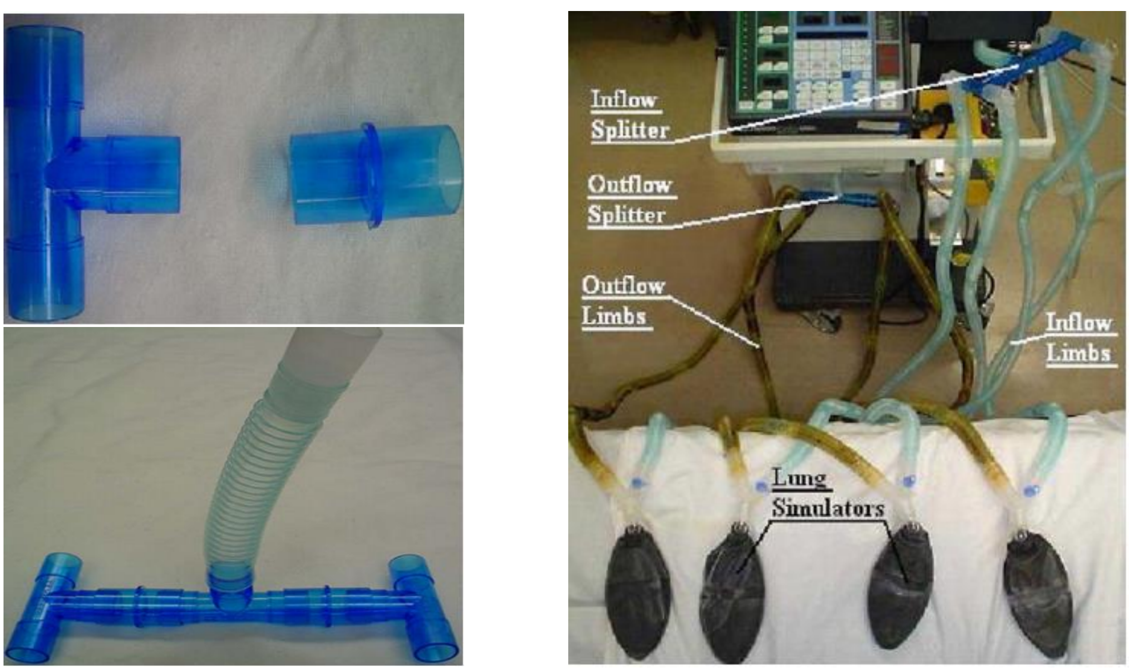


Figure 4. Circuit assembled to provide simultaneous ventilation to four adults in the study "A Single Ventilator for Multiple Simulated Patients to Meet Disaster Surge" [20].

Table 1. Consolidated research on multiple mechanical ventilation (1 of 4)

Title	Year	Configurations	Conclusion
A Single Ventilator for Multiple Simulated Patients to Meet Disaster Surge [20].	2006	A ventilator to provide simultaneous ventilation to four adults of 70 Kg each. Equipment: Ventilator, breathing circuits, splitting devices, lung simulators. Time: 12 consecutive hours. 5:33 h/VCP and 6:11 h/VCV VCP: Pressure 25 mm H_2O→ 471 ml/pulmonary simulator. VCV: Volume 2 L→ Average maximum pressure 28 cm H_2O	A single ventilator can be quickly modified to ventilate four 70 kg adults, with the same respiratory requirements, for a limited time. However, the authors suggest further studying.
Increasing ventilator surge capacity in disasters: Ventilation of four adult-human-sized heep on a single ventilator with a modified circuit [21].	2008	A ventilator to provide simultaneous ventilation four adult sheep. Equipment: Ventilator, breathing circuits, dividing devices, adult sedated sheep of 70 kg each. Time: 12 consecutive hours Control: Compulsory intermittent ventilation synchronized with 100% oxygen at 16 breaths/min and current volume of 6 ml/kg combined weight of sheep.	The ventilator and modified circuit successfully oxygenated and ventilated the four sheep for 12 h (the sheep remained sedated and have the same respiratory requirements). All the sheep remained hemodynamically stable.
Use of a single ventilator to support 4 patients: laboratory evaluation of a limited concept [22].	2012	A ventilator to provide simultaneous ventilation to four patients. Equipment: Ventilator, breathing circuits, splitting devices, lung simulators. Control: 2L volume, breathing rate of 10 breaths/min and PEEP of 5 cm H_2O. Performed combinations of resistance and compliance of the lung simulators	The authors conclude that multiple pulmonary ventilation is an attractive concept; however, it is not possible to control the current volume for each subject, and the disparity of it is proportional to the variability in compliance. Added to the practical limitations of its implementation, it is unable to support the use of this concept for the respiratory failure of mass victims.
Splitting one ventilator for multiple patients -- a technical assessment [15].	2020	A ventilator to provide simultaneous ventilation to two patients. Equipment: Ventilator, breathing circuits, splitting devices, lung simulators. Control: They used 2 ventilation control modes, one by pressure and one by volume. They used two test lungs connected to a ventilator, measured volumes and pressures in both lungs for different combinations of pulmonary dispensability, airway resistance, ventilation modes, Inspiratory and final expiratory pressure levels.	The authors found differences in the standard volumes delivered for matched test lungs proportional to compliance differences, plus little influence of differences in airway resistance, and that changes in compliance with a single test lung would also change the current volume delivered to the other test lung when controlled in volume mode.
One ventilator for two patients: feasibility and considerations of a last resort solution in case of equipment shortage [23].	2020	Simple and easy to build circuits to allow emergency ventilation of two patients with a single ventilator. Equipment: Ventilator, breathing circuits, splitting devices, lung simulators. Control: In pressure control mode. Different pulmonary fulfilments and airway resistance were evaluated.	The authors confirm the technical feasibility of ventilating two patients with a single ventilator but stress the difficulties and possible damage caused by this configuration. Which is why they suggest a flowchart with descriptions to start this type of ventilation. (Prerequisites, configurations, Start-up procedures, Monitoring and alarms)
Multiplex Ventilation: A Simulation-Based Study of Ventilating 2 Patients with a Single Ventilator [24].	2020	A ventilator to provide simultaneous ventilation to two patients with imbalance of resistance and pulmonary compliance. Equipment: Ventilator, breathing circuits, splitting devices, lung simulators Control: VCP and VCV were used. Six pairs of patients with different resistance and compliance ranges were simulated. Finding that depending on differences in strength and compliance, differences in volume vary from 1% (with equal strength and compliance) to 79%. Differences in lung volume at the end of expiration varied from 2-109%, while differences in pH varied from 0-5%.	The authors practically corroborated considerable differences in the ventilation and oxygenation potential of patients with unequal impedances of the respiratory system during multiple ventilation. Three critical problems must be solved to minimize the risk: (1) individual division of the inspiratory flow from the ventilator for the 2 patients (2) measurements of the volume delivered to each patient and (3) control of PEEP individually.

Table 1. Consolidated research on multiple mechanical ventilation (2 of 4)

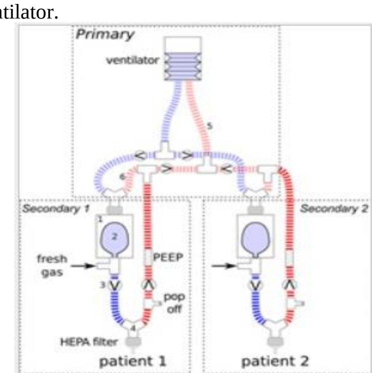
Title	Year	Configurations	Conclusion
Ventilating two patients with one ventilator: technical setup and laboratory testing [25].	2020	Improved configuration to ventilate two patients with a ventilator and to evaluate the distribution of volume in different pulmonary fulfilments. Individualizing the volume by adding inspiratory resistors in the circuit. Equipment: Ventilator, breathing circuits, splitting devices, pneumotachographs, unidirectional valves, filters, lung simulators. Control: VCP. Different pulmonary fulfilments were evaluated. Variables were measured every minute.	The authors assure that, with a modified circuit, it is feasible to ventilate two patients with a ventilator in a relevant range of fulfilments. Adding inspiratory resistance allows individual assessment of current volume, and the incorporation of unidirectional valves prevents pendelluft.
Differential Ventilation Using Flow Control Valves as a Potential Bridge to Full Ventilatory Support during the COVID-19 Crisis: From Bench to Bedside [26].	2020	Simultaneous ventilation to two patients with different pulmonary strains.	Differential Ventilation Using Flow Control Valves as a Potential Bridge to Full Ventilatory Support during the COVID-19 Crisis: From Bench to Bedside.
Shared Ventilation in the Era of COVID-19: A Theoretical Consideration of the Dangers and Potential Solutions [27].	2020	It initially highlights the potentially disastrous sequels of shared ventilation, where patients simply connect in parallel to a ventilator without regard to their individual ventilation requirements. They then examine possible approaches to the individualization of mechanical ventilation, using modifications in the breathing circuit that may allow the tuning of individual volumes and pressures during ventilation.	Shared Ventilation in the Era of COVID-19: A Theoretical Consideration of the Dangers and Potential Solutions
Personalized Ventilation to Multiple Patients Using a Single Ventilator: Description and Proof of Concept [18].	2020	Simultaneous ventilation to two or more patients with a single ventilator, while allowing the individualization of the current volume, the fractional concentration of oxygen and the positive pressure at the end of expiration for each patient, independent of the respiratory system of the other patients.	The authors describe that secondary circuit systems "bag-in-the-box" allow individualized ventilation of two lungs, overcoming many of the concerns of ventilating more than one patient with a single ventilator.  bag-in-the-box
A rapidly deployable individualized system for augmenting ventilator capacity [28].	2020	They designed a system to individualize the ventilation of each patient, using a series of valves and flow regulators in parallel to effectively maintain the desired current volume and PEEP for each patient. In a ventilator configuration to simultaneously and more safely support 2 people. Equipment: Ventilator, splitting devices, filters, flow control valves, unidirectional flow valves, pressure release valve and standard sensors (pressure, flow and capostato), lung simulators, two pigs. Control: VCV. In addition, the rebalancing of ventilation in response to the improvement or deterioration of an individual's respiratory status, and incorporates mechanisms to measure lung mechanics, mitigate cross-contamination and return flow, and accommodate sudden changes in flow.	The authors cite that the system designed allows the individualized handling of the ventilation through valves, sensors and alarms. Through bench and in vivo testing, they demonstrated that not only can current volume and PEEP be individualized, but also rebalance ventilation to accommodate changes in respiratory mechanics in a channel, that otherwise could endanger the flow to a second connected channel. It can be used with closed and open circuit ventilators.

Table 1. Consolidated research on multiple mechanical ventilation (3 of 4)

Title	Year	Configurations	Conclusion
Coping with COVID-19: ventilator splitting with differential driving pressures using standard hospital equipment [29].	2020	This study investigated the effect of ventilator flow splitting on system variables (inspiratory pressure, flow, and volume) and the possibility of operating different ventilation targets for each limb using a single standard hospital equipment. Equipment: Ventilator, dividing devices, breathing circuits, heat and moisture exchangers (HME), flow and pressure meters, lung simulators, Hoffman clamp and tracheal tube. Control: The ventilator was used in pressure and volume control modes. It was configured to ventilate the low compliance lungs at end-expiratory volumes of 500 ± 20 ml. A Hoffman clamp and tracheal tube were used on the inspiratory limb of the lungs to limit flow. The restriction apparatus was successfully modified for inspiratory pressure, minute ventilation, and volume delivered to the high compliance test lungs in both pressure control (27.3–17.8 cmH2O, 15.2–8, 0 l.min -1 and 980-499 ml, respectively) as in the control volume (21.0-16.7 cmH2O, 10.7-7.9 l.min -1 and 659-498 ml, respectively)	The authors have shown in a landmark study that it is possible to achieve ventilation of two test lungs with differential conduction pressures using standard medical equipment. Pressure control and volume control ventilation modes were feasible. The use of this method in the clinical setting has not been validated, and therefore the authors do not recommend its use until further clinical studies have been completed.
Cloud Computing for COVID-19: Lessons Learned from Massively Parallel Models of Ventilator Splitting [30].	2020	A simulation of airflow to the patient was developed to help address the urgent need for an expansion of ventilator capacity in response to the COVID-19 pandemic. The computational model provides guidance on how to divide a ventilator between two or more patients with different respiratory physiology. Equipment: Numerical simulation performed in MATLAB Sims cape software, with input data: PIP, PEEP, I: E, RR), endotracheal tube diameter, Resistance and compliance. And the mobile app connected to a cloud-based API to receive the input values and return the corresponding results. Control: From the initial simulation, they found that the pressure-controlled ventilation mode was inherently safer for flow division than volume-controlled ventilation.	The numerical model to support the clinical use of the ventilator flow and resistance division system (VSRS) in case of ventilator shortages was performed using Matlab Sims cape, with input data: PIP, PEEP, I: E, RR), Endotracheal tube diameter, Strength and compliance. This model was validated by the authors with laboratory data, subsequently they implemented the scale model and compiled the simulation results in an easy-to-run mobile application, both on low-end mobile phones and high-end tablets, to maximize VSRS portability to global health scenarios, as well as high-tech ICUs.
Development of a multi-patient ventilator circuit with validation in an ARDS porcine model [31].	2021	The authors performed a mathematical model to simulate a multi-patient ventilation circuit (MPVC), which they validated with four animal studies. Each study had two human-sized pigs: one healthy and one with lipopolysaccharide-induced ARDS (LPS). LPS was chosen because it reduces lung compliance like COVID-19 Equipment: ventilator, flow divider, endotracheal tube, breathing circuit, flow restrictions, filters, exhalation valves, star connector, flow valves, monitor. Control: Pressure controlled ventilation mode.	The authors showed as a result that a multi-patient ventilation circuit (MPVC) where precision flow resistance could be adjusted to restrict flow to the healthiest patient (PH) to avoid over ventilation The animal study demonstrated that it is possible to ventilate multiple subjects on a single ventilator for a short period using simple flow restrictions and minor modifications to the tubing set. The authors consider that the presented method should only be considered during ventilator shortages. Additionally, to practically implement MPV in a medical facility, ventilator alarms must be set to alert healthcare personnel to ventilation problems. Finally, they show a table where they describe the impact of ventilator settings on the effects on the healthiest and least healthy patients.

Table 1. Consolidated research on multiple mechanical ventilation (4 of 4)

Title	Year	Configurations	Conclusion
Exhalatory dynamic interactions between patients connected to a shared ventilation device [32].	2021	In this study, the researchers performed experimental tests to validate a simplified linear numerical model of grouped elements based on the Hydraulics and Mechanics libraries of the Matlab Simulink program, where two patients with different respiratory requirements are connected to evaluate their expiratory dynamics. The experimental studies were performed with precision test lungs. Equipment: Enhanced Capacity of Mechanical Ventilators (ACRA), two ACCU LUNG (Fluke Biomedical) precision test lungs, two Smarting 2000 lungs (IMT analysis), orifice plate differential pressure sensors, and a Fluxed monitor (MBMed). Control: Pressure controlled ventilation mode.	The researchers showed that patients connected to shared ventilation had time delays during exhalation, where the size of this effect depends on different parameters associated with the patients, the circuit and the ventilator, as well as they can experience auto-PEEP (expiratory pressure positive ending). Adverse effects on exhalations became less noticeable when patients had similar respiratory requirements. The results of the numerical model were validated thanks to the remarkable agreement with the experimental results. As a final recommendation, they ask that the data should be validated with clinical tests so that the medical personnel consider the results of the model as accurate.
Sharing Mechanical Ventilator: In Vitro Evaluation of Circuit Crossflows and Patient Interactions [33].	2021	In this study, two lung simulators ventilated by an anesthesia machine connected via two breathing circuits and T-pieces were evaluated. Five different combinations of compliance and airway resistance were tested, one of which has similar respiratory requirements. For each combination, 4 pressures and 8 flows were measured Equipment: Mindray WATO EX-65 ventilator, two adult lung simulators (Dual Adult Lung Simulator), two adult breathing circuits for anesthesia (22mm smoothbore breathing system, 2m), two T-pieces, filters HME on Y-connectors. One-way valves were not used. Control: Pressure controlled ventilation mode.	The authors conclude that the simultaneous ventilation of two or more patients with a ventilator is a complex procedure that could result in large ventilation discrepancies for patients. Likewise, the use of a ventilation circuit without unidirectional valves generates cross flows between simulated patients in all the combinations tested, both during the inspiratory and expiratory phases.
Ventilator output splitting interface 'ACRA': Description and evaluation in lung simulators and in an experimental ARDS animal model [34].	2021	The researchers conducted three experimental studies to evaluate the behavior of two patients connected to a single ventilator. All studies are based on a circuit known as Capacity Enhanced Mechanical Fans (ACRA), which has specific components and a specific assembly, connection and use process. The first study evaluates two lung units with similar respiratory requirements, the second uses two respiration simulators under heterogeneous conditions, and the third study evaluated the behavior of two live pigs with heterogeneous lung conditions. Equipment: standard ICU mechanical ventilator (Nellcor Puritan Bennet 760 Ventilator), lung units (ACCU LUNG Precision Test Lung), breathing simulators (ASL 5000, InGMAR Medical), a piping circuit called ACRA consisting of two standard breathing systems, four one-way valves, one adjustable PEEP valve, two pinch valves, two analog pressure gauges, and HMEF and HEPA filters. Control: Pressure controlled ventilation mode.	After evaluating the three experimental studies, the researchers obtained the following results: Using an ACRA type circuit, in all three cases it was possible to independently provide the volume and pressure conditions required for each patient. There were statistically significant differences between the data provided by the ventilator and the pressure gauges incorporated into the interface downstream of each pinch valve, which must be carefully analyzed to control each patient. In conclusion, dual ventilation limits the capabilities of single ventilation, however, it was shown that it is possible to independently control the pressure and total volume delivered to each of the paired units. Likewise, it was possible to establish that the ACRA is a preformed circuit that minimizes the risk of accidental incorrect assembly, which adds a potential safety quality to this practice.

Source: authors.

Some other authors, through letters to journal editors, expressed their concerns about the results of these experimental studies [35], [36], giving their opinions on the significant risks to patient safety (inability to individualize the ventilation of each patient, insufficient monitoring, cross-contamination, rebalancing of the airflow when a patient improves or deteriorates), which is shared by some medical associations that discourage the use of this methodology [37] and add that there would be logistical challenges to implement them and ethical problems.

The first published article analyzed the feasibility of using a ventilator for mechanical ventilation for up to four patients (with the same respiratory requirements) without delving into the medical implications of each one. From the crisis generated by the lack of medical equipment (mechanical ventilators) due to the COVID-19 pandemic, research on this topic was increased, analyzing the connection of patients with different respiratory requirements.

From previous studies, it can be noted that the initial idea, although innovative, carries dangers for patients. These risks were subsequently addressed by other researchers, who tried to solve them through the inclusion of accessories to the respiratory circuits that connect the ventilator to patients, to individualize the ventilation and monitoring system, for everyone connected to the ventilator.

For example, in the work of "A rapidly deployable individualized system for augmenting ventilator capacity" [28] the accessories are shown and where they were located to install the pulmonary ventilation of multiple patients more safely (See Figure 5).

The design of the assembly proposed by Srinivasan contains several extra accessories that are not included in the conventional respiratory circuits, which will allow dividing the ventilation with certain safety parameters. A cost analysis of the inclusion of these accessories is shown in Table 2.

The conventional mechanical ventilation, as shown in Figure 6, includes a mechanical ventilator that has a front panel that allows to monitor and control the parameters of the patient to be ventilated, and includes a respiratory circuit and filters. A cost analysis of a conventional system is shown in Table 3.

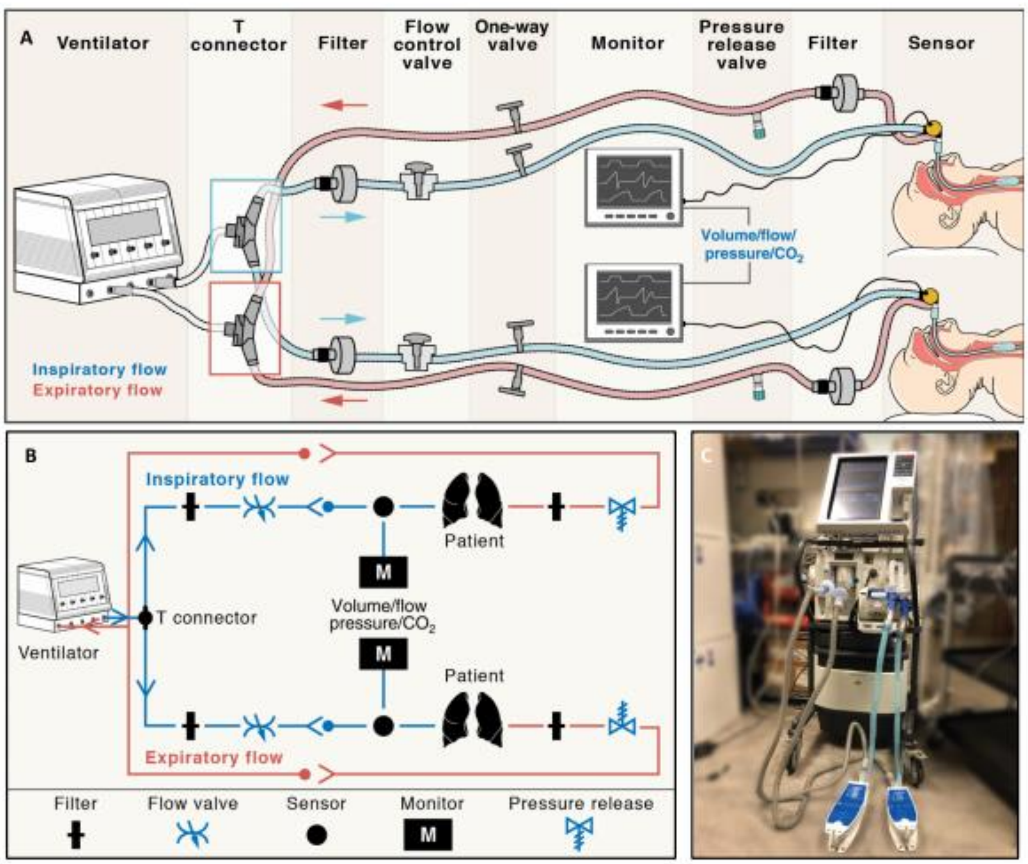


Figure 5. Individualized system design to provide patient simultaneous ventilation more safely "A rapidly deployable individualized system for augmenting ventilator capacity" [28].

Table 2. Cost analysis of multiple mechanical ventilation system for two patients

Circuit Diagram with Flow Divider Connector					
			Quantity	**Unit cost**	**Total cost**
Respiratory machine			1	$ 65.000.000	$ 65.000.000
Monitor + standard sensors volume/flow/pressure/CO_2			2	$ 4.000.000	$ 8.000.000
				Total Cost Main Elements	**$ 73.000.000**
	Inspiratory circuit	**Expiratory circuit**	**Total x accessory**	**Unit cost**	**Total cost**
Duplicator (T or Y connector)	1	1	2	$ 90.000	$ 180.000
Filters	2	2	4	$ 10.000	$ 40.000
Flow control valves	2	0	2	$ 230.000	$ 460.000
Unidirectional valves	2	2	4	$ 30.000	$ 120.000
Pressure release valve	0	2	2	$ 170.000	$ 340.000
Hoses ventilation circuit	1	1	2	$ 20.000	$ 40.000
				Total Cost of Accessories	**$ 1.180.000**
				Total Cost	**$ 74.180.000**

Source: authors.

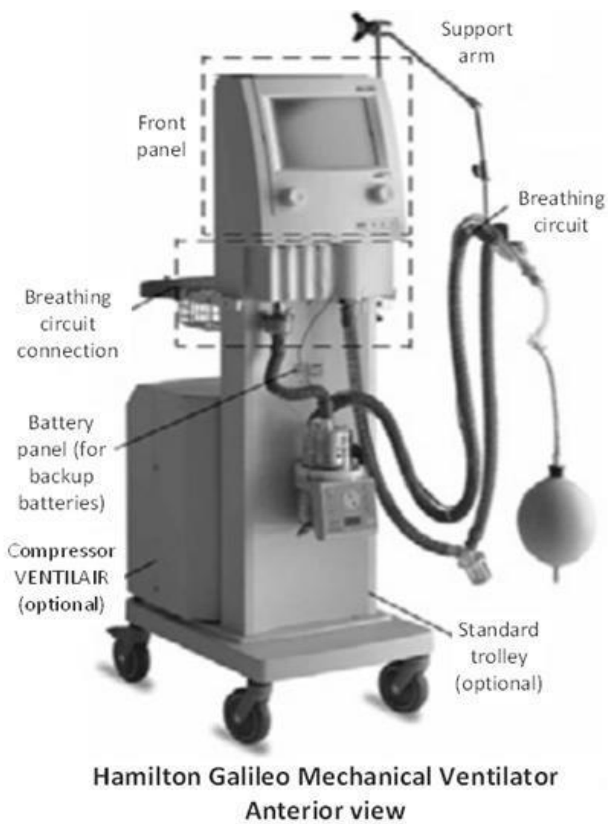


Figure 6. Conventional mechanical ventilation "Mechanical ventilation". Source: [38].

Table 3. Cost analysis of conventional mechanical ventilation system for each patient

Conventional Circuit					
			Quantity	**Unit cost**	**Total cost**
Respiratory machine			1	$ 65.000.000	$ 65.000.000
Monitor + standard sensors volume/flow/pressure/CO_2			0	$ 4.000.000	$ 0
				Total Cost Main Elements	**$ 65.000.000**
	Inspiratory circuit	**Expiratory circuit**	**Total x accessory**	**Unit cost**	**Total cost**
Duplicator (T or Y connector)	0		0	$ 90.000	$ 0
Filters	1		1	$ 10.000	$ 10.000
Flow control valves	0		0	$ 230.000	$ 0
Unidirectional valves	0		0	$ 30.000	$ 0
Pressure release valve	0		0	$ 170.000	$ 0
Hoses ventilation circuit	1		1	$ 20.000	$ 20.000
				Total Cost of Accessories	**$ 30.000**

Source: authors.

4. Conclusions

Analyzing the values of Table 2 and 3, corresponding to the cost analysis of each of the systems, it can be asserted that it is more economical to use a circuit with a connector for flow division in two patients, which would entail a total cost of approximately $74,180,000, to connect each of them separately, which would lead to a total approximate cost of $130,060,000 ($65,030,000 purr patient). In addition, it can be concluded that the inclusion of additional accessories such as filters, unidirectional valves, limiting and pressure-releasing valves, together with monitors and flow-splitting devices, have allowed the division of ventilation with certain safety parameters, as was shown by some experimental studies, which were summarized in Table 1.

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