History of Intermittent Mandatory Ventilation 1971 to present. Part two

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Abstract

Medical history is often overlooked as advances keep moving forward. Seldom is it that advances in medicine are truly new, unique ideas, but rather built on ideas that have been considered before. Even our latest developments will become history or forgotten as science and medicine advance.

This history of intermittent mandatory ventilation (IMV) is a two-part article in which the first part attempts to show that the concepts and apparatus that involve the now common mode of ventilation have been considered and described for nearly 200 years, if not earlier. This older history is not brought forward to diminish what has been done in the last 50 years, but to enhance awareness of how ideas and even mechanical ventilators change over time.

This second part will describe how those ideas and mechanics changed into what we now call IMV in its many forms.

Keywords: Intermittent Mandatory Ventilation, SIMV, History of mechanical ventilation

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Introduction

"Revolutions are the locomotives of history" Karl Marx

When people come together, reform can happen. These revolutions keep history moving like a locomotive, even small ones. Looking at IMV, from a historical perspective, we can see a progression and a new development being made. How techniques and the environment for innovation can change in such a short time!

The first author is a primary source of this history and was a player to a lesser degree in the development of intermittent mandatory ventilation (IMV), and its metamorphosis to synchronized intermittent mandatory ventilation (SIMV). The second author is an historian.

IMV as we know it today was developed, named, and popularized in the early 1970s. The first publication by Downs and collegues [1] put the name of the mode of ventilation in the medical literature and attracted a lot of attention. The group from the Shand's teaching hospital at the University of Florida was given the only scientific booth at the entrance of the exhibition hall at the American Association for Respiratory Therapy (AART) currently known as the AARC meeting in Fall of 1973, the year the inhalation therapy profession became respiratory therapy.

This National and worldwide attention changed mechanical ventilators and their use significantly. At the same time, it stimulated some research and much opinion as well as spawned well known detractors.

We will make every effort to be unbiased and point out information that may be speculative in this article.

IMV is the basis of most of the modes available on advanced mechanical ventilators today. [2] Of 76 modes of ventilation described, 47 (62%) are types of IMV mode.

The most succinct, simple definition of IMV among many may be: "Intermittent mandatory ventilation (IMV) and synchronized intermittent mandatory ventilation (SIMV) modes combine mechanical breaths with spontaneous breaths. SIMV differs from IMV by synchronizing the initiation of the mechanical breaths with the patient's spontaneous effort. The use of non-synchronized IMV has dramatically decreased because the lack of patient-ventilator synchrony results in patient discomfort and increased work of breathing. Improvements in technology have enabled most ventilators to be synchronized to the patient's respiratory effort." [3]

Currently the clearest definition of IMV/SIMV (IMV-Type1) appears in an IMV mode taxonomy put forth in 2021 by Chatburn (Figure 1). [4] This definition, if read carefully, is very clear, and precise (Figure 1).

Direct observations and experience

I joined the Inhalation Therapy/Anesthesia Department, in The Shand's Teaching Hospital at the University of Florida in the Fall of 1972. I was officially an evening/night shift supervisor and education coordinator even though the 12-hr. shift was covered by two respiratory therapists including myself, and a blood gas lab technician. Basically, it was a very busy intensive care inhalation therapy job.

This was not like the current era. We covered mechanical ventilator patients in Surgical ICU, MICU, PICU, NICU, Burn ICU and a busy emergency department. Our blood gas analyzer was a model before PCO_2 electrodes were common, so each blood gas sample had to be tonometered in a glass cuvette with gaseous carbon dioxide of two different concentrations to calculate $PaCO_2$.

The ventilators in use were a mixed of Emerson Pre-Op (3PV), Bennett MA-1, Bird MK6/14, and other ventilators that had volume control ventilation and sometimes assist-control mode.

How to Classify the IMV Types

Prof. Robert L. Chatburn

Definition of IMV

IMV stands for intermittent mandatory ventilation. It is defined as a breath sequence where spontaneous breaths are possible between mandatory breaths. Spontaneous breaths are those for which inspiration is both patient triggered AND patient cycled. Mandatory breaths are those for which inspiration is machine triggered OR machine cycled

IMV(1): Historically, Intermittent Mandatory Ventilation (IMV) started out as a patient circuit modification made by clinicians because ventilators (ie, adult ventilators) only provided Continuous Mandatory Ventilation (CMV). Note that infant ventilators at this time only provided PC-IMV and this was because in those days (early 1970s) the technology was not available to accurately trigger mandatory breaths for infants that often have erratic inspiratory efforts. Adult ventilators were modified by inserting anesthesia bags and one-way valves in the patient circuit and supplying the bags with a continuous flow of air/oxygen to support spontaneous breathing between the mandatory breaths. The idea was that to wean patients, all you had to do was gradually decrease the mandatory breath rate and the patient would maintain minute ventilation by increasing the spontaneous breath rate. It was not long before ventilator manufacturers started to build this feature into their modes. We call this IMV(1) where mandatory breaths are delivered at the set rate regardless of what the patient does. An example would be a mode called SIMV Pressure Control (PB 980 ventilator), However, there are data to suggest that, for most patients, IMV(1) prolongs the weaning process compared to daily spontaneous breathing trials followed by sudden discontinuation of ventilation.

IMV(2): Makers of home care ventilators, notably Respironics (now Philips), recognized that their patients' comfort was an important goal. Mandatory breaths are not as comfortable as spontaneous breaths because an arbitrary pre-set frequency and inspiratory time is imposed on the patient. Yet mandatory breaths provided the safety-net in the event of apnea. Hence, engineers invented a compromise; if the patient's spontaneous breath rate exceeds the set mandatory breath rate, mandatory breaths would be suppressed. This is called IMV(2). An example would be a mode called Spontaneous/Timed (V60 ventilator). If mandatory breaths are indeed suppressed, the ventilator waveforms look like continuous spontaneous ventilation (CSV).

IMV(3): There is a drawback of type 2 IMV; If the patient gets sick, often the breath pattern becomes rapid and shallow. Hence the patient may hypoventilate (due to a small V_T and hence large V_D/V_T) while the ventilator continues to suppress the larger mandatory breaths. IMV(3) attempts to avoid this problem by suppressing mandatory breaths only if the spontaneous minute ventilation is less than the minute ventilation created by the preset mandatory breath rate and tidal volume. An example would be a mode called Mandatory Minute Volume (V500 ventilator). Of course, this is only a partial solution because the settings for frequency and tidal volume are just a guess by the clinician about gross minute ventilation, not knowing the true alveolar minute ventilation requirement. More advanced modes, like IntelliVent, use volumetric capnography to automatically set an appropriate minute ventilation to maintain acceptable $PaCO_2$.

IMV(4): With this type of IMV, individual, scheduled mandatory breaths may be turned into spontaneous breaths. The simplest example of this is a mode called Pressure A/C on the Avea ventilator (Vyaire). In this mode, every breath for a passive patient is machine triggered (preset frequency) but flow cycled (as it is a pressure control mode). However, if there is a sufficiently large patient inspiratory effort in the trigger window, then the delivered inflation is patient triggered and patient cycled, and hence is a spontaneous breath. What this means is that this mode is not A/C as the manufacturer's name suggests, but rather IMV because spontaneous breaths may occur between mandatory breaths (ie, the definition of IMV).

There is another, slightly more complex example of IMV(4): The risk of synchrony during conventional volume control is high because the operator sets arbitrary values for tidal volume and inspiratory flow. For a patient making a large enough inspiratory effort, patient-ventilator synchrony will occur in the form of potentially dangerous work shifting. One engineering solution is for the ventilator to recognize this condition (as a drop in airway pressure below a preset threshold) and compensate. Recall from the equation of motion that in volume control, if P_{mus} (inspiratory effort) increases, then P_{vent} (airway pressure) must decrease an equal amount. Thus, the ventilator monitors P_{vent}, and if it drops by some default threshold (eg, 3 cm H_2O) the ventilator gives as much flow (and hence volume) as the patient wants. If the effort is large enough, inspiration may also change from volume/time cycling to flow cycling. This is a form of dual targeting, where volume control switches to pressure control and the tidal volume is larger than the preset value. In this case, if inspiration becomes both patient triggered and patient cycled, it is by definition a spontaneous breath that is obviously more synchronous with the patient's demand. This is called IMV(4), where individual mandatory breaths may be suppressed by spontaneous breaths if the inspiratory effort is high enough. An example would be a mode called Volume Control with Flow Adaptation (Servo-U ventilator).

Recognizing the type of IMV from the ventilator's graphical displays is often difficult. It may be possible if you spend enough time observing the patient. More practical is simply reading the description of the mode in the ventilator's operator manual or looking up the mode in a classification table.

Figure 1: Classification and description of IMV. With permission from Professor Robert L Chatburn

When I arrived IMV was being used for the first time on adult ventilator patients in its first mechanical configuration (Figure 2) of basically a T-piece (Briggs Adapter) connected via a Bird one-way valve through a hole bored in the top of the junction of the patient "Y" piece. This T-piece provided a flow of humidified oxygenated air from a venturi-jet aerosol nebulizer. The other side of the T-piece had a small reservoir tube to reduce entrainment of room air during the patient's spontaneous inspiration. Every attempt was made to match the oxygen percentage being provided by the ventilator and aerosol generator, but it was never perfect.

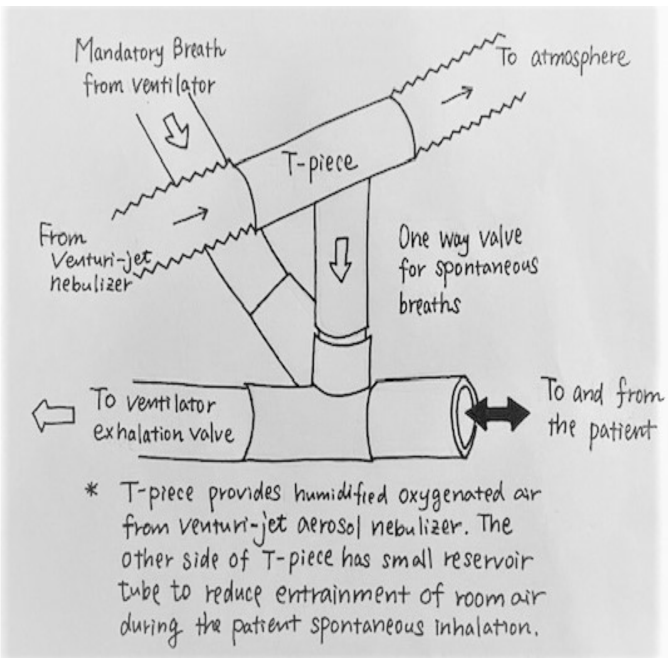

Figure 2

This arrangement was being used on most adult ventilator patients in this medical center and the VA hospital across the street. Prior to this, long forgotten attempts to let ventilator patients breathe spontaneously during volume-controlled ventilation had failed to become widespread or popular.

At the same time in 1972, our department was working with Dr. Forrest Bird of Bird Corporation to test and develop prototypes of the Baby Bird ventilator. Recall that the Baby Bird ventilator allowed the infant to breath spontaneously and interposed a mechanical breath at some pre-set breathing rate. This was what is now called IMV Type 1. This was prior to use of IMV in adults. The Baby Bird radically changed the survival outcomes of what was called "Infant Respiratory Distress Syndrome" (IRDS) and saved thousands of young lives.

So how did this come to pass?

In the recent past, the late 1960s, PEEP and CPAP had become widely used and people were thinking creatively about what other potential ventilators might have. According to a conversation I had with Dr. Robert de Lemos in 1995, he was working in an NICU and having bad outcomes trying to ventilate neonates with severe lung disease with control mechanical ventilation using machines that did not have precise control of tidal volume, sensitivity, and response time.

This was pretty much the experience across the country. As an aside, The Arp Infant Ventilator developed in 1969 was in limited use [5,6] showing somewhat better outcomes because of its increased sensitivity, better response time, precision of gas volume delivery, and ability to provide some assist-control ventilation. The Arp Infant Ventilator interestingly had a nasal mask patient interface. Also in 1969, Dr. DeLemos, who did not have an Arp Infant Ventilator, was told in a meeting with the NICU nurses that the neonates who "fought" the ventilator were the ones more likely to survive (DeLemos, Robert, personal communication, October 1995).

This led to the idea that it might be good if the IRDS ventilator neonates could somehow get some spontaneous breaths rather than fight the ventilator.

Together with Dr. Robert Kirby, Jimmy Schultz, an inhalation therapist, and Dr. Forrest Bird a prototype ventilator was made that was essentially a T-piece for spontaneous breathing with a mechanical thumb to periodically provide a mandatory breath. The sick babies started surviving at a much higher rate. [7,8]

Dr. Kirby then moved to the Shand's teaching hospital and continued his relationship with Bird Corporation. I had the opportunity to work with him as our medical director when I arrived in 1972.

During anesthesia rounds Dr. Modell and David Desautel wanted to make a safety valve for an infant struggling to breathe on an MA-1 adult ventilator. Desautel decided that a Babbit-Lee valve might work as a safety mechanism for neonates if placed at ventilator wye adapter (David A Desautel, personal communication, December 2021).

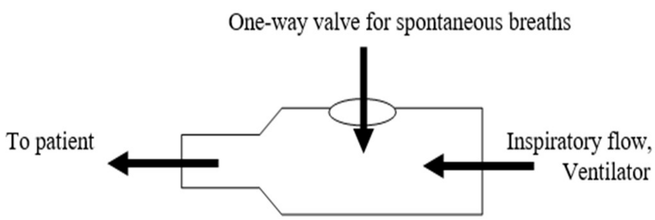

Figure 3 Babbit-Lee Valve

It worked! Unfortunately, the baby was inspiring room air during spontaneous breaths.

This was modified by replacing the Babbit-Lee valve with a Bird one-way valve and Briggs T-piece to heated nebulizer with oxygen at patient wye adapter (Figure 3). Now this was an adult ventilator modified for spontaneous breathing along with the mechanical breaths.

A resident Dr. John B. Downs wanted to try this modified MA-1 or similarly modified adult ventilator on adult patients as a weaning technique. It worked! This became the standard ventilator setup. Dr. Downs later was an innovator with non-invasive ventilation as well as inventing and patenting Airway Pressure Relief Ventilation (APRV). [9,10]

Dr. E.F. "Bud" Klein referred to it as "intermittent mandatory ventilation." This was the first time IMV was used as the term "intermittent mandatory ventilation" was coined by Dr. E. F Klein.

IMV becomes a worldwide phenomenon and was recognized as a new mode of ventilation, which spread across the country and around the world.

A flood of attention came to our department. Jack Emerson of J H Emerson Company, of the iron lung and volume ventilator manufacturing fame, visited wearing "work clothes" and carrying a toolbox. He immediately saw the sense in IMV and started making all his ventilators with IMV, the Emerson 1M Ventilator 3MV.

Dr. Forrest Bird was frequent visitor as the Baby Bird was in production and Bird Corporation was developing "second generation" IMV ventilators with names like, OmniBird, IMVBird, UrgencyBird.

We were a clinical testing site. Dr. Bird arrived piloting his private, dual engine propeller airplane that may have been a Consolidated PBY Catalina amphibious aircraft. He wore a business suit and was often accompanied by a very competent female co-pilot, engineer, personal assistant. They made a formidable pair when debating the fine details of prototype ventilator performance and possible changes. Especially intimidating was Dr. Bird flipping the reading lens of his dual eyeglasses up and down during the interaction.

Puritan Bennett Company sent an engineer and reported back that PB thought IMV was a dangerous idea, i.e., turning the ventilator rate below 6 bpm. Keeping safety in mind PB refused to modify their ventilator for IMV until some years later. I recall one day Jack Emerson, Forrest Bird and the chief engineer from Siemens were all in our small department at one time. Emerson asked Bird if he too was having supply problems getting gas regulators from some company. As a regular guy in my 20's I was shocked when Bird casually replied, "No, I own that company".

During this time, late 1972, staff therapist Eric Gjerde, now owner of Airon Medical, decided that the IMV setup on the patient wye piece was too bulky/heavy, and congested the area near the patient's airway. He moved the one-way valve/T-piece apparatus up stream on the ventilator inspiratory limb where it was typically supported by a manifold and the ventilator support arm. This was very helpful, and worked well; however, the patient still had to pull hard enough on inspiration to overcome PEEP and the aerosol nebulizer could not exactly match the ventilator FIO_2.

I saw this as an opportunity to move the IMV apparatus back to the ventilator humidifier, provide a constant humidified "IMV" flow from an oxygen blender that was also providing gas to the ventilator. This was placed on the ventilator side of the humidifier so the "IMV gas" would be humidified the same as the ventilator breaths (Figure 4).

This setup provided a constant flow of gas through the ventilator circuit via the patient wye, so the patient could easily get a humidified spontaneous breath at the same FIO_2 as the ventilator breath without having to overcome PEEP. The entire circuit was pressurized.

To allow for a patient taking a high flow rate spontaneous breath and to keep the constant IMV flow at a somewhat lower flow rate an anesthesia bag was attached at a T-piece on the oxygen blender side of the humidifier. This was initially used on the Bennett MA-1 ventilators but was quickly found to work on nearly any adult volume ventilator. It turned out when used on a Bennett Cascade Humidifier that it worked much better if a diffuser device called "the tower" was removed. This removal reduced the effectiveness of the Cascade Humidifier but was much easier for the patient's spontaneous breathing. In this endeavor I was surely helped by Eric Gjerde, Jim Booth and perhaps David Desautel.

This simple inexpensive "H" valve apparatus converted most any ventilator anywhere in the world to IMV capability. Dr. Jerome Modell, chair of the Anesthesiology department unbeknownst to me made a deal with Dr. Forrest Bird that we would not patent this device and that Bird Corporation would keep supplying us with ventilators.

I believe it was the Hudson Oxygen Company that began manufacturing these as disposable devices and selling them by the case. They sent us a couple cases for free. Not long thereafter Dr. Bird sold Bird Corporation to 3M and this verbal agreement came to an end. This was 1972 or early 1973.

Unbelievably, to this day, February 2022, fifty years later, this device is still available for purchase as a disposable item in cases of 15 - 50 each with prices ranging between $15 and $50 each as shown in Figure 5. These can be purchased as AirLife IMV (Intermittent Mandatory Ventilation) manifold from Carefusion, Vyaire, Angel Medical Supply, Rehab Mart and many others.

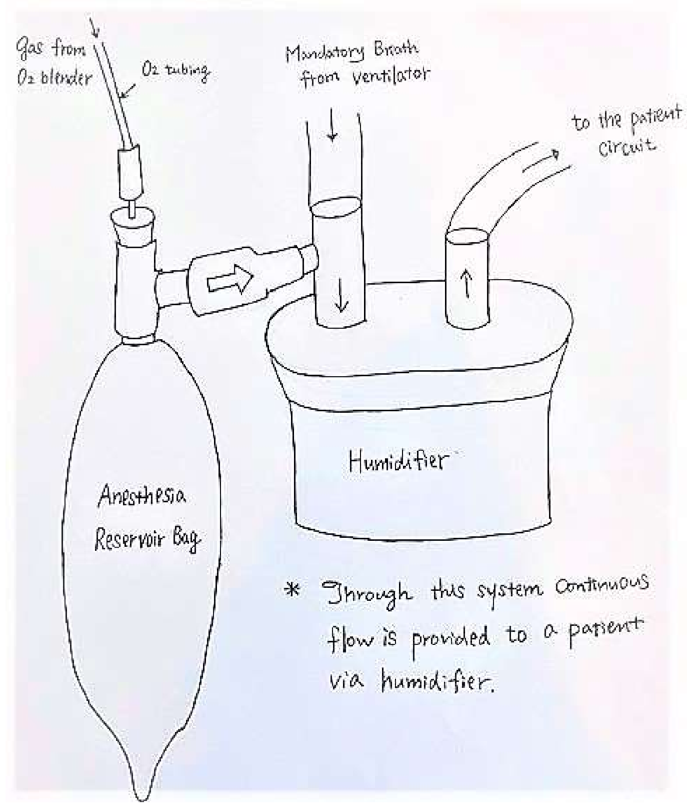

Figure 4

Figure 5

This initial IMV article [1] was followed by several other IMV publications [11-18] from the University of Florida group describing various aspects of this new mode of ventilation or method of ventilator weaning.

The next most significant change to IMV was a 1976 article by Dr. Barry Shapiro describing a method of synchronizing the mandatory ventilator breaths with the initiation of a spontaneous breath. It was called Intermittent Demand Ventilation (IDV). [19] According to Chatburn's types of IMV this was still IMV-Type 1.

It is difficult to determine how the acronym IDV got changed to SIMV, however, I seem to recollect that some ventilator company installed that function on their ventilator and called it Synchronized Intermittent Ventilation SIMV).

The SIMV style of IMV slowly became the most common form of IMV as it was instituted into the design of electronic and microprocessor-based ventilators.

Reasonably questions arose regarding the efficacy of IMV vs. SIMV, IMV vs AC; as well as IMV vs other weaning techniques. Many studies followed.

Clear evidence regarding ventilator weaning supports spontaneous breathing trial (SBT) over IMV or other styles of weaning. It is interesting to note that SBT is method where the patient is put to a daily weaning stress test to best predict successful ventilator discontinuation indicating that we ventilator specialists still do not understand enough about that transition to eclipse "asking the patient to tell us" each morning.

SIMV gained popularity and was the most widely used ventilatory mode for weaning, with 90.2% of hospitals preferring SIMV in a survey conducted in the 1987. [20]

From 1973 until the present there have been medical professionals opposed to the use of IMV. The more prominent among them Dr. Thomas Petty, who is credited for popularizing positive end-expiratory pressure (PEEP) was very opposed to IMV and spoke against it but put forth little evidence to back up his high-profile objections. Dr. Petty later reconsidered his position. [21]

Dr. Robert Kackmarek and colleagues in the New England area and the ARDS Net study group were generally speaking poorly of IMV around the country and the world, but in his own words, "Every head-to-head comparison of IMV and CMV has concluded that there are no differences in outcomes. The truth of the matter is that in large trials, IMV is as useful as CMV. [22]

It is interesting to note that the ARDSNet study conducted from 1995 - 1999 used only assist-control mode to determine that smaller tidal volumes (6ml/Kg) vs. larger tidal volumes (12ml/Kg) are more beneficial to ventilator patient when clearly the most common ventilator mode being used in country was IMV. It may cause one to wonder if the results are fully generalizable to patients with IMV modes and some spontaneous breathing.

It is not surprising that IMV being a mode of mechanical ventilator support that incorporates spontaneous breathing is very successful currently in its many forms.

The desired outcome of mechanical ventilation is spontaneous breathing and in as short a time as reasonably possible.

Even small revolutionary ideas and techniques can become seemingly normal over time.

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