PART TWO CHAPTER 4
THE RAMIFICATIONS OF
INTRAPULMONARY PERCUSSIVE VENTILATION (IPV®)
and associated
MECHANICAL INTRATHORACIC VESICULAR PERISTALTSIS

A DISCUSSION

In 1979 F. M. Bird conceived the technology required to internally percuss the pulmonary structures (within all patient populations) during repetitive "Percussive Sub Tidal Volume Deliveries". Internal Pulmonary Percussion had been attempted by clinical investigators for many years; however, it was only considered in deeply anesthetized patients. In order to internally percuss the pulmonary structures, a very high Inspiratory Flowrate, which approaches a square wave delivery, is required. It has long been known by Anesthesiologists that when a lightly anesthetized patient is ventilated with rapid sharp anesthesia bag compressions (near square pressure waves), the patient will “buck on the tube”. This phenomenon is associated with the “firing” of the Hering Breuer stretch receptors, secondary to the rapid stretching of pulmonary structures, causing a near immediate spontaneous physiological pulmonary expiratory effort.

Effective internal pulmonary percussion has led to the development of specific methods of effective lung Inflation directed toward the reduction of pulmonary barotrauma during the mechanical ventilation of the lung in Neonates through Pediatrics to large Adults with various Cardiopulmonary Compromises. A unique Inspiratory “step inflation” of the pulmonary structures during an “inspiratory interval” is enabled by the progressive delivery of successive Sub Tidal Intrapulmonary Volumes until the lungs are inflated to a pre-selected Dynamic Functional Residual Volume (D/FRC). Essentially, the IPV® concept was the first ventilatory protocol directed toward a "LUNG PROTECTIVE STRATEGY".

By employing the step inflation of the lungs in patients with various forms of airway obstructions (and associated low compliance), “Preferential Airway Delivery” has been reduced by allowing the lungs time to accommodate to their progressively mechanically increased volumes. This rationale is termed “Pulmonary Conformance”.

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Intrapulmonary Percussive Ventilation (IPV®), because it provides a method of diffuse peripheral intrapulmonary sub tidal volume delivery, is capable of serving as a transport vehicle to deliver therapeutic aerosols into the peripheral pulmonary airways.

In airways partially obstructed by mucosal and sub mucosal edema, retained airway secretions and/or bronchiolar spasm, the intrapulmonary delivery of a combined Alpha (vasoconstrictor) and Beta (bronchodilator) in an aerosolized form can simultaneously decrease the adhesive and cohesive forces of retained endobronchial secretions and reduce mucosal and sub mucosal edema and bronchiolar spasm, effectively increasing airway caliber.

Examining the third law of Newton which essentially states that “for each action there is an equal and opposite reaction”, one can realize the percussive flow of respiratory gases into the pulmonary airways must create a cephalad (head ward) counter flow.

Because the Intrapulmonary Percussive Ventilation (IPV®) concept provides for the formation of repetitive timed deliveries of Sub Tidal Volumes into the physiological airways under high velocities, there is sufficient energy to propel a component of each stroke volume into the peripheral pulmonary structures by means of a velocity/pressure energy exchange.
Essentially, the Percussive Ventilator (Percussionator®) is employed to deliver the timed intrapulmonary impulses of respiratory gases, based upon a Pneumatic Flow Interrupter and a combination Injector/Exhalation Valve called a Phasitron® which is positioned at the proximal airway.

Essentially the "minaturized Phasitron Breathing circuit" serves as the Respirator/Ventilator, which is located at the proximal physiological airway, to percussively deliver Sub Tidal Volumes directly into the physiological airway via invasive or non-invasive airways.
The FUNCTIONAL RESIDUAL CAPACITY (FRC) of the lungs is DYNAMICALLY (D/FRC) controlled by a step inflation of the lungs, diffusing oxygen downward as well as providing for the mechanical mixing of recruited alveolar CO2 within the peripheral airways. Following the percussive step inflation of the lungs during the period of Oscillatory Equilibrium (percussive mixing of intrapulmonary gases), a passive physiological expiratory airflow is programmed down to an ambient or an elevated post expiratory oscillatory baseline. Therefore, a major convective expiratory tidal volume exchange can be programmed after the percussive inspiratory interval to effectively “wash out” CO2.

The resolution of the various levels of pulmonary atelectasis can be effectively addressed while concomitantly minimizing tendencies toward the hyperinflation of dependent lung. After reaching the programmed increase in lung volume, the lungs can be held in a percussive apneustic plateau (oscillatory equilibrium).

Following the passive outflow of expiratory gases, an end expiratory Oscillatory Demand CPAP (OD-CPAP) can be programmed. IPV® allows the patient total spontaneous breathe through, while maintaining both inspiratory and expiratory intrapulmonary percussion.
A constant Oscillatory Demand Continuous Positive Airway Pressure (OD-CPAP) can be programmed with "a selectable amplitude" during spontaneous respiration to recruit semi or obstructed airways and/or resolve pulmonary atelectasis.

Endobronchial mechanical mixing within the peripheral pulmonary airways enhances diffusion and serves as a means of recruitment for convective gas exchange. Therefore, in reality, percussive intrapulmonary gas mixing associated with a sinousoidal lung volume change provides for two forms of mechanical ventilation concomitantly occurring within the lungs.

Essentially, through being able to balance a Diffusive/Convective Ventilatory Scheduling, IPV® or VDR® allows greater selectivity over the control of PaO2, PaCO2 and cardiac output. This is called "BALANCED VENTILATION".

PATIENTS WITH STIFF NON-COMPLIANT LUNGS CAN BE VENTILATED WITH BOTH DIFFUSIVE AND CONVECTIVE PROGRAMMING, EMPLOYING VOLUMETRIC DIFFUSIVE RESPIRATION (VDR®) AT REQUIRED PEAK RECRUITMENT PRESSURES.

The use of Oscillatory Demand Continuous Positive Airway Pressures (OD-CPAP) serves to flush the intrusive mechanical airway as well as to reduce a certain amount of anatomical dead space, resulting in a reduction of end tidal CO2.
In the presence of a right to left pulmonary shunt, OD-CPAP can be considerably more effective in terms of increasing paO2 than static PEEP by providing upper airway percussive gas mixing and decreasing the mean intrathoracic pressure.

Additionally, during the mechanical ventilation of the lung, cardiac output can be optimized in critical cardiopulmonary patient populations by major scheduling options.

IPV® with VDR® scheduling consists of an intrapulmonary diffusive mechanical mixing created by repetitive sub tidal volumes delivered in milliseconds as well as a convective ventilation with tidal exchange delivered in seconds. In other words, Volumetric Diffusive Respiration (VDR®) is two combined programmable ventilators, one providing normal tidal volume deliveries in seconds, while the other “percusses the lungs” with Sub Tidal Volumes delivered in milliseconds. Therefore, the big convective I/E ratio is expressed in seconds, while the little diffusive i/e ratio is expressed in milliseconds.

An associated adjunctive function of Intrapulmonary Percussive Ventilation (IPV®) is the enhancement of “Physiological Vesicular Peristalsis” within the thoracic bronchial, pulmonary and lymph circulations. The technology employed in the design of the IPV® or VDR® apparatus uniquely provides for the near instantaneous change over from an inspiratory inflow gradient to a no flow passive expiratory gradient during pulsatile (high frequency) intrapulmonary Sub Tidal deliveries.
The repetitive percussive intrathoracic endobronchial airway expansions and releases created by the injection of subtidal volumes delivered within the pulmonary structures serves to repeatedly stretch and narrow all vessels attached to airways within the thoracic cage, thus providing for a peristaltic pumping action. For “Maximum Vesicular Peristalsis”, at a given impulse the period of Expiratory Relaxation (Expiratory Time) must be longer than inspiration, preferably an i/e ratio of about 1:2.

The near instantaneous "Endobronchial Flow Reversals" programmed during the Inspiratory/Expiratory/Inspiratory transitions (called “Transition Penalties”) are under seven (7) milliseconds. This allows effective Intrathoracic Percussion at frequencies of over 800 cycles per minute. However, the most effective Percussive Frequencies for “Mechanical Intrapulmonary Vesicular Peristalsis” are from 100 to 150 cycles per minute.

The following treatise may be a bit technical for the average clinician; however, for those who want to visualize the time constants it may be helpful. Therefore, the next two illustrations can be scanned over without detracting from the overall understanding.

For example, at a percussive subtidal delivery rate of 200 cycles per minute with an i/e ratio of 1:2, with ten (10) millisecond transition penalties from Expiratory to Inspiratory, the “maximum effective Inspiratory Intrathoracic Flow Gradient Interval” is 60/300 = 0.3 or 300 milliseconds; 300/3 = 93 ms providing an effective Inspiratory Delivery Time and a 186 ms Physiological expiratory passive flow (relaxation) time.
It can be noted that the i/e ratio during “Intrathoracic Vesicular Peristalsis” plays an important role in maximizing the effective stroke volumes. Without sufficient reloading time, the Sub Tidal Volume will be marginally effective. It follows that without sufficient expiratory time the D/FRC will be increased.

Of critical importance for a “Maximum Stroke Vesicular Peristalsis” is the design inertia of the Ventilator, programmed as an Intrapulmonary Percussionator®. At 200 or more cycles per minute, the total time for a sub tidal delivery and recovery is 300 milliseconds. At 400 cycles per minute it is one half, or 150 milliseconds. With a 1:2 i/e ratio at 200 cycles per minute, there is only 43 milliseconds to deliver a sub tidal volume with a constant DESIGN transition penalty of 10 milliseconds.

If the DESIGN inertia of an Oscillatory Ventilator extended the transition penalty to 30 milliseconds, the maximum “Inspiratory Flow Gradient TIME” at 400 cycles per minute would be reduced from 43 ms to 30 ms and the “maximum expiratory flow gradient time” would be reduced to 60 ms. This represents a thirteen (13) ms encroachment upon effective stroke volume delivery.

Pure “Diffusive High Frequency Ventilation” is classified as “vibratory diffusion”. This form of High Frequency Ventilation delivers repetitive shock waves into the pulmonary structures with insufficient energy to provide for a clinically effective CONVECTIVE EXCHANGE. It has the ability of creating upper airway “molecular agitation” favoring oxygen delivery. As the signal travels downward through the physiological airways, it fades out secondary to frictional resistances before it can effectively mobilize CO2 from the alveoli into the peripheral airways. In theory, a "High Frequency Ventilator" delivering a therapeutic oxygen gradient to a patient with a depressed Respiratory Center, without a convective component to wash out CO2, could cause the patient to “die nice and pink” from a respiratory and metabolic acidosis.
The reason a positive phase high frequency vibratory device can not deliver a subtidal volume following the generation of a shock wave is that the diaphragmatic area producing the shock wave has limited displacement. Therefore, the (air borne) shock wave can have high instantaneous pitch amplitude, which is determined by the rate at which energy is administered to the diaphragm.

However, because the diaphragmatic displacement is limited, its linear travel restrictions deny it the ability to create a follow on high velocity tidal displacement with sufficient velocity/pressure conversion capacity to overcome endobronchial non elastic resistances. Therefore, a “Vibratory Device” is restricted to High Frequency Diffusion only, with a frequency determined by programming.

A Percussionator® Ventilator with “Percussive Programming”, employed to schedule Intrapulmonary Percussive Ventilation (IPV®), is a Time Cycled Device, with cycling rates, amplitude and i/e Ratios programmable. Therefore, because it is a time cycled flow interrupter with an adjustable energy application time, it is capable of a “long stroke Percussive Delivery”, that is; it can generate a shock wave which serves as the “pathfinder” for a (high energy) Sub Tidal Volume Delivery.

Of major importance is to have a Physical/Physiological Patient Interface to serve as an Injector/Exhalation Valve. It must have very low inertia (with near instantaneous full opening and closing valve action) to accommodate a near instantaneous change in Inspiratory to Expiratory to Inspiratory Flow Gradients. The Phasitron® transition has a response time of under seven (7) milliseconds as opposed to a piston oscillator with near a plus twenty one (22) ms transition penalty.

Directional flow through the three Intrathoracic circulations is provided by structural check valves. Flow through the cardiac circulations are: Bronchial Circulation- left to right, Pulmonary Circulation- right to left. Lymph collection from the thoracic interstitial spaces is directionally evacuated by an extensive (directionally check valved system) lymphatic drainage system, dumping into the venous circulation through the thoracic duct.
The lymph circulation would be expected to receive the greatest enhancement from a “Mechanical Vesicular Peristalsis” because it is the lowest pressure system with the greatest distribution (with the greatest number of check valves), being totally dependent upon a passive type “Physiological Thoracic Lymph Pumping action”. Whenever the physiological thoracic lymph pumping system is compromised by disease or trauma, the retention of excess protein in the interstitial spaces can lead to an interstitial edema, with a secondary decrease in the physiological pulmonary vital capacity.

The directional pressure/flow gradients within the pulmonary circulation between the right and left atria are essentially zonally controlled by the cardiac chamber valves. Therefore, the percussive pulsatile inflation and deflation impactions against the walls of the pulmonary vessels during “Intrapulmonary Percussive Ventilation” could serve to enhance the physiological “Peristaltic Vesicular Peristalsis” created by the dynamic myocardial structures.

Augmentation of the bronchial circulation with Intrapulmonary Percussive Ventilatory programming would be most effective within the pulmonary alveolar structures after the major diastolic reduction in systemic arterial pressures has occurred.

Optimally, a high amplitude Intrapulmonary Percussive Ventilatory program with a 1:2 i/e ratio, at a delivery rate of from 100 to 200 cycles per minute, would provide for a reasonable segmental vesicular reloading time, with a clinically effective stroke volume.

Theoretically, the greatest intrathoracic vesicular peristalsis may occur at Percussive IPV® cycling rates of about two to three times existing heart rates, with a 1:2 i/e ratio. It follows that the greater the impaction pressure (velocity of sub tidal volume delivery), the greater the propulsion forces.

NOTE: The use of any proximal airway restrictions such as PEEP or CPAP reduces the efficiency of any form of vesicular peristalsis.
IN SUMMARY

A basic understanding of the classical technological and physiological factors which allow the Intrapulmonary Percussion of the pulmonary airways without firing the Hering Breuer reflexes is necessary before the clinical ramifications can be understood. All covenants of the IPV® protocol can be delineated by available understandings related in the applicable physics text books and a functional knowledge of cardiopulmonary pathophysiology.

The concept of “Intrapulmonary Percussive Ventilation (IPV®)” and the critical care version “Volumetric Diffusive Respiration (VDR®)” for the ventilation of the lungs was introduced by F. M. Bird in 1979, and has been clinically evaluated in all patient populations with substantial review.

The primary purpose of this text is to elucidate the primary technological and physiological concepts, enabling a better understanding of the Clinical Revelations contained in variations of "Intrapulmonary Percussive Ventilation" and their combined derivatives.