HIGH FREQUENCY VENTILATION: PAST, PRESENT AND FUTURE?

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High frequency ventilation of the lungs has become the most popular subject for research papers and review articles in the anaesthetic literature, with well over 1000 titles published so far. Why should this be so? The question has many answers. To the clinician, high frequency ventilation offers the prospect of improved patient care and perhaps reduced morbidity and mortality in the operating theatre and in critical care. To the respiratory physiologist it poses what at first sight appears to be a fundamental challenge to the accepted laws of respiratory mechanics, with adequate gaseous exchange resulting from the use of a tidal volume equal to, or even less than, the apparent deadspace volume. To the physicist it is a phenomenon which demands investigation and explanation within the framework of the laws of thermodynamics, acoustics and fluidics. Even research biologists believe that investigation of this subject may hold the key to understanding the gaseous exchange mechanisms in the lungs of lower animals and birds [47].

The most fundamental difference between high frequency ventilation (HFV) and conventional intermittent positive pressure ventilation (IPPV) is that with HFV the tidal volume (VT) required is approximately 1–3 ml kg/body weight, compared with 6–10 ml with IPPV. The increase in ventilation rate to frequencies of 60 b.p.m. or more in HFV is obviously mandatory if even comparable minute volume ventilation is to result. What is fascinating is that, if VT is reduced to the apparent physiological deadspace volume, in theory even an infinite increase in frequency could not restore adequate alveolar ventilation. The obvious solution to this paradox must be that the physiological deadspace volume is smaller than the generally accepted value of 2 ml kg⁻¹, at least in some situations.

The concept that pulmonary gas exchange could be maintained with such small tidal volumes is not new. As long ago as 1915, Henderson, Chillingworth and Whitney [24] speculated that "there may easily be gaseous exchange sufficient to support life even when the tidal volume is considerably less than the dead space". A series of simple but elegant experiments reinforced this view. They showed that tobacco smoke blown into a tube formed a long thin central plume, and that "the quicker the puff, the thinner and sharper the spike of smoke". When the puff of smoke stopped, "the spike breaks instantly everywhere and the tube is seen to be filled from side to side with a mixture of smoke and air".

More than half a century was to pass before the implications of these findings was appreciated. In 1969, Oberg and Sjostrand published details of a new ventilatory technique (now termed High Frequency Positive Pressure Ventilation) which operated at 60–100 c.p.m. with tidal volumes close to physiological deadspace volumes [39]. Shortly after, Lunkenheimer and colleagues noted that apnoea resulted from the application of transtracheal pressure vibrations in dogs, and that adequate gaseous exchange could be maintained for prolonged periods without any obvious bulk flow of gas [31]. This was the first reported use of what is now termed High Frequency Oscillation. Again, the technique appeared to go almost unnoticed until 1980, when Bohn and colleagues confirmed the adequacy of gaseous exchange, and showed that this could be maintained almost indefinitely [5].

Simultaneously, in the U.S.A., Klain and Smith [26] used a modified form of Sanders’ injector [46] to deliver high frequency gas pulses to the airway.

KEY WORDS
Ventilation; jet, HFJV.
This was the birth of High Frequency Jet Ventilation.

**CLASSIFICATION OF HFV TECHNIQUES**

The historical background above provides a useful method for classifying HFV techniques:

**High Frequency Positive Pressure Ventilation.**
Tidal volume is delivered via a normal sized tracheal tube with inspiration being the only active part of the ventilatory cycle (i.e. expiration achieved by passive lung recoil). Frequencies are usually in the range 60–120 c.p.m. (1–2 Hz).

**High Frequency Jet Ventilation.**
Tidal volume is delivered via a narrow cannula or injector resulting in a jet of high velocity gas, normally at frequencies of 60–600 c.p.m. (1–10 Hz).

**High Frequency Oscillation.**
Tidal volume is delivered via normal sized tracheal tubes and both inspiration and expiration are active and of approximately equal power, such as would occur with an oscillating piston or loudspeaker-based ventilator. Frequencies range from 2 Hz to more than 100 Hz (6000 c.p.m.).

**High Frequency Positive Pressure Ventilation (HFPPV)**
This technique uses either modified conventional IPPV ventilators or purpose-designed low compliance systems to deliver tidal volumes of 2–4 ml kg⁻¹ at respiratory frequencies of 1–2 Hz [39]. Systems have been developed also which incorporate expiratory valves, permitting a greater degree of controlled volume ventilation [49]. While in many cases a high pressure gas injector may be used within the ventilator, it is the nature of the gas pulse delivered to the patient which determines the classification. A jet injector sited some distance from the patient, but connected by a length of relatively large-bore tubing to the tracheal tube results in a pulse of gas which has a large surface area wavefront and a low velocity. In essence, the gas pulse acts as a piston within the tracheal tube. Any high frequency jet ventilator can therefore be used to provide HFPPV, but the converse is not true.

HFPPV has become popular in some centres, notably in Scandinavia, for endoscopy, and to a lesser extent for airways surgery [49]. This enthusiasm does not seem to be reflected worldwide, however, where HFPPV has made little clinical impact.

**High Frequency Jet Ventilation (HFJV)**
In HFJV, a burst of gas is delivered to the airway at high velocity via a relatively narrow cannula. Gas velocities in some systems may be as great as 300 m s⁻¹ (Mach 0.9). This pulse of gas represents the tidal volume, and is the only active phase of the ventilatory cycle, as expiration relies on passive recoil.

The entrainment of gas from a second, low pressure circuit is a common but not invariable feature [10]. However, Smith, Scott and Fischer [55] took the view that, in the clinical setting it would be difficult to control the final tidal volume, the inspired gas tensions and the degree of humidification required in such a system, because of unpredictable and varying patient compliance. In a system of this type, any increase in patient compliance reduces the entrained volume, leading to a reduction in tidal volume and alteration of the inspired gas tensions unless both “jet gas” and entrained gas have come from a common source [3]. The popularity of entrainment systems derives from the fact that, in most cases, only the low pressure gas stream can be humidified. As humidification is a prerequisite of HFJV of more than a few minutes duration, entrainment becomes an essential, if inefficient, feature. Only those systems in which the main jet gas is humidified can be used for prolonged periods if the hazards of airway damage, ciliary destruction and retention of secretions are to be avoided [51].

In essence, HFJV behaves as a Sanders injector [46] operated at a high frequency and small volume. As such, the important variables in clinical practice are the driving pressure, frequency and the inspiratory time (which determines the inspiratory to expiratory (I:E) ratio). The minute volume delivered depends only on the driving pressure and the I:E ratio, thus the ventilator will behave as a minute volume divider, with progressive reduction of tidal volume as frequency is increased. An understanding of this point is crucial to the clinical use of HFJV, as simply increasing the ventilation frequency will lead to a reduction in alveolar minute volume and hypercapnia.

The position of the jet injector within the airway has varied enormously from one centre to another [2, 9, 19]. The most common arrange-
ment is to site the injector at the proximal end of the tube, the low position (at the distal end of the tube) having fallen largely into disuse. It had been thought by some workers that this low position would enable smaller tidal volumes to be used by bypassing part of the system deadspace. Unfortunately, the efficiency of any jet injector depends upon the driving pressure used, the jet cannula to tracheal tube radius ratio, and the geometry of the injector itself [3]. Any advantage gained by using the low position is immediately offset by a reduction in the efficiency with which the jet controls gas flows within the tracheal tube. In addition, with the low position, even minor degrees of movement of the tracheal tube can lead to predominantly unilateral lung ventilation [19]. Fears have also been expressed regarding the possibility of direct mucosal damage in the region of the carina as a result of the high velocity jet impinging on this area, and because of thermal injury resulting from gas cooling as a consequence of the Joule–Kelvin effect as it issues from the jet injector [53].

Clinically, HFJV has been used in a wide variety of patients in the Adult Intensive Care Unit [55] and in the operating theatre for a wide variety of procedures including endoscopy and otorhinolaryngology, and thoracic, abdominal and neurosurgical techniques [19]. One unique attribute of HFJV is its ability to deliver adequate ventilation via narrow cannulae inserted by either the tracheal or transtracheal route (including the cricothyroid membrane), for both elective and emergency ventilation [10, 55].

High Frequency Oscillation (HFO)

In HFO the ventilator is usually a reciprocating pump of the piston variety, although some have been based on a loudspeaker system driven by an electronic oscillator. Both systems generate a sinusoidal respiratory flow pattern. From this, it follows that the I:E ratio is usually fixed at 1:1, although variable-ratio pumps have recently been described [19]. The pump is used to produce a reciprocating flow in the airways, whilst an auxiliary gas flow, usually termed the bias flow, is used to clear the extracted carbon dioxide and to provide fresh gases to the system. These systems behave as a T-piece circuit, and the efficiency of carbon dioxide removal is, at least in part, a function of the magnitude of the bias flow. The sinusoidal flow pattern is relatively easy to analyse mathematically, and it is not surprising that HFO has been used extensively in bench testing and animal experimentation [37].

While at first sight this might seem reasonable, it may in fact be quite inappropriate to use sine wave generators in fundamental research. In the analysis of linear systems which contain resistive, capacitative and inertial elements, the use of a sine wave input yields relatively little information as regards the mode of action of each element, and even less as regards the interactions between elements. If the input is a sine wave, the output at any point within the system can only be a sine wave. Whilst it is true that there may be differences in amplitude and phase shift between differing points in the system, these are the only signal modifications possible. Far more information may be derived by studying the effects of the network (i.e. the respiratory tract) on other types of waveform. In this respect, it might be more appropriate to study the behaviour of square and triangular respiratory waveforms.

Despite the extensive non-clinical use of HFO, there has been relatively little enthusiasm for its use in the clinical setting, and there is certainly no evidence to show any clinical superiority of HFO over other modes of ventilation.

Functional classification

Just as there is little standardization of HFV equipment, there is little agreement as regards the nomenclature in HFV studies. Froese and Bryan [19] have advocated the introduction of two broad functional classifications, namely high frequency ventilation-active, “HFV-A”, and high frequency ventilation-passive, “HFV-P”. HFV-A refers to those systems in which expiration is actively assisted, whilst HFV-P denotes entirely passive expiration. Each HFV mode can then be classified further according to the mode of action of the particular ventilator; thus classical HFJV systems would be HFJV-P, while those with a second jet activated to assist expiration would be HFJV-A. The appending of the suffixes -A or -P to other systems follows the same rule. While in the short term this might appear to confuse the situation further, it is only through a clear separation of ventilatory modes that the data derived by different workers can be analysed and interpreted. All forms of HFV are not the same and the general introduction of such a system of classification is long overdue.
MECHANISMS OF ACTION OF HIGH FREQUENCY VENTILATION

In the past 5 or 6 years, the plethora of papers concerned with the mechanisms of gaseous exchange during HFV have served only to confuse rather than clarify the situation. This is to be regretted, as many clinicians have become more, rather than less, confused about HFV. There are, of course, exceptions to any rule and there are several excellent reviews which can be recommended to the reader [11, 13, 19].

There are a number of mechanisms proposed to explain the apparent paradox of gaseous exchange in HFV.

Direct alveolar ventilation. There is no doubt that tidal volumes less than 2 ml kg⁻¹ will still produce direct alveolar ventilation of alveoli with short path lengths—that is, the more centrally situated alveoli. Even tidal volumes of 1 ml kg⁻¹ show this effect which, it should be noted, occurs even in normal spontaneous ventilation [6, 24]. In HFPPV and HFJV this mechanism probably accounts for 50–75% of gaseous exchange.

Asymmetric velocity profiles. The fluid dynamics within the conducting airways are complex, and are markedly different during inspiration and expiration. These effects are particularly marked in the region of bronchial bifurcations. The final result of these effects is an increase in convective transport of respiratory gases which should, in theory, favour oxygen delivery more than carbon dioxide elimination [23].

Taylor dispersion [56]. This is in effect a formal statement of the observations made by Henderson, Chillingworth and Whitney, mentioned earlier [24]. It proposes a mixture of convective transport along the airways, with diffusion occurring radially within each major bronchus. The exact contribution of this effect to overall gas transport is difficult to assess, but while it may play a minor role in HFJV and HFO, it is probably insignificant in HFPPV.

Cardiogenic mixing [50]. The cardiac impulse can produce small pressure waves within the thorax, which produces some degree of gas movement and mixing. The contribution of this effect to overall ventilatory exchange is minimal.

Accelerated diffusion. In all forms of ventilation, diffusion is ultimately responsible for conveying gases between the conducting airway and the alveolar units. The claim that this component is somehow accelerated in HFV is unsupported. This is hardly surprising, because the factor which primarily determines the rate of molecular diffusion of any gas of given density is the absolute temperature. Unless the temperature increases, there can be no acceleration of diffusion.

Acoustic resonance. A completely new approach to the understanding of HFV has been proposed by Lin and Smith [30]. In their analysis, the ventilator is modelled as an acoustic source—that is, a source of pressure waves which behave according to the laws of acoustics and thermodynamics. These pressure changes are conveyed to the patient who thus becomes an acoustic load—that is, a dissipator of acoustic energy. This analysis has two parts, namely the low frequency (0–50 Hz) and high frequency (50–20000 Hz) domains.

The low frequency acoustic model

Conventional lung modelling treats the lung as having two basic determinants of gas flow, namely resistance and compliance (or capacitance). There is a third element, inertance, which is usually ignored. This is reasonable at ventilatory frequencies less than 30–40 b.p.m., when its contribution is small, but as frequency increases the contribution of inertance to overall pulmonary mechanics becomes much more important. Ultimately, the principal determinant of tidal volume distribution will be inertance. Regional variations in airway resistance and segmental compliance will thus have a decreasing influence in gas distribution. This has been confirmed by several groups of workers in both experimental and clinical fields [27, 35, 42].

The inclusion of inertance in this model has another important consequence. Because the respiratory system can now be regarded as a three-
component model (namely resistance, capacitance and inertance) it behaves as a simple mechanical oscillator driven by a suitable exciting (i.e. ventilation) frequency. Using a standard formula and derived values for the parameters, it can be calculated that this frequency should be about 4–7 Hz in the adult human, 3–10 Hz in pigs and 4–8 Hz in dogs. The author and other workers have produced evidence to support these predictions [22, 43, 54]. It is interesting to note that, in dogs exposed to thermal stress, panting occurs at the resonant frequency of the animal’s respiratory system [34].

The implications of resonance are profound. In any resonant system there is an interconversion of potential and kinetic energy. In the case of the respiratory system, potential energy is represented by the intrapulmonary gas pressure, while kinetic energy is represented by movement of gas and the respiratory system as a whole. If the lung were to be ventilated at its resonant frequency, maximal gas movement would occur for minimal airway pressure swings—a feature of obvious clinical interest. In the case of the panting dog, resonance means that minimal energy expenditure is required to produce maximal gas movement. Such optimization of gas dynamics is obviously attractive to the clinician, but there is a drawback. If the ventilation rate matches the resonant frequency, an airway pressure swing of normal amplitude could result in dangerously maximized intrapulmonary pressures. This effect has been observed in experimental animals, with fatal results [54]. It would seem prudent that, unless the resonant frequency of any particular patient is known accurately, ventilation rates should be restricted to a maximum of about 3 Hz (180 b.p.m.).

The possible effects of resonance on other organ systems are as yet entirely speculative, but they could at best be unpleasant for the patient if not actually harmful, at least in the case of large amplitude movements [14, 21, 36]. This low frequency model does not mean that conventional respiratory physiology is wrong. In much the same way that Newtonian mechanics hold good for objects at low velocities, conventional pulmonary mechanics apply at low ventilation rates.

The high frequency acoustic model

The pulse of gas injected through the cannula in HFJV systems produces considerable acoustic output in the audio frequency range of 20 Hz–20 kHz (i.e. it produces noise). The exact frequency spectrum generated depends upon the radius of the cannula and driving pressure used [52]. The scatter of resonant frequencies of the trachea and bronchi extends from about 500 Hz for the trachea to 20 kHz for smaller bronchi [30]. Lin and Smith concluded that it was likely that the audio frequency output of the cannula would induce resonance within each bronchus. It has long been known that resonance within a tube results in considerable turbulence within the contained gas [41]. Such turbulence can increase considerably the rate of mixing of carbon dioxide and air [52]. If this were to occur in the airways there could be a considerable increase in the rate of carbon dioxide removal and oxygen delivery. A study has supported this view, and may be the first plausible explanation of “accelerated diffusion” [55]. It must be noted, however, that this is a convective mechanism, not a diffusive effect.

HIGH FREQUENCY VENTILATION : CLINICAL CONSIDERATIONS

Control of breathing

There is considerable confusion in the literature as to whether HFV per se causes inhibition of spontaneous ventilation [8, 16, 17, 28, 32, 57]. Such an effect is seen in experimental animals and in human infants, but not in adult humans, at least as regards HFJV. A study has confirmed that, providing arterial carbon dioxide tension is not depressed, spontaneous ventilation does occur during HFJV [55]. This allows HFJV to be used as a form of mandatory minute volume ventilation in the weaning of patients. It is not yet clear if this is the case with other HFV modes.

Gas trapping

This is a problem common to all types of ventilation, but assumes increasing importance as the ventilatory frequency increases. The effect is particularly marked if the expiratory time is reduced to less than 250 ms. The shorter the expiratory period and the greater the respiratory time constants, the lower the frequency at which gas trapping becomes a problem [45]. A modest degree of gas trapping is not always undesirable, and the term “auto-PEEP” may give a more balanced view of this effect [4]. It should be noted that the proximal airway pressure is a poor indicator of true intrathoracic pressure during HFV, and oesophageal pressure may be a better index for clinical use [55].
HIGH FREQUENCY VENTILATION

It has been argued that gas trapping is less likely to occur in HFO systems in which expiration is assisted [19]. If the conducting airways were rigid structures this might be true, but in reality the airways are more likely to close as a result of the negative pressure phase, with increased gas trapping and reduction of ventilatory efficiency [12].

Humidification during HFV

Humidification of the fresh gas flow during HFPPV and HFO is not a problem. Unfortunately, whilst HFJV is undoubtedly the most useful clinical mode of HFV, it is also the most difficult to humidify [51]. The need for good humidification in HFJV is paramount. The fresh gas flows required in HFJV when used clinically can easily exceed 30 litre min\(^{-1}\). Even 75% humidification would mean that the drying effect on the respiratory tract would be the equivalent of 7.5 litre of dry gas each minute. Early attempts to overcome this problem used a conventionally humidified low pressure gas stream which was entrained by the jet injector. The final gas mixture would at best be only 75% saturated and, in patients with reduced pulmonary compliance, this figure could decrease to as little as 10%. Clearly, those systems that rely on entrainment cannot be used clinically for more than the briefest period of HFV [38].

Cooling effects of HFV

Excessive cooling of the patient has entered the folklore of HFV as a practical problem. There is no documented evidence for such a claim, provided that adequate humidification is provided. The gas flows used in HFV may be high, but the thermal capacity of gases is very low. In contrast, the latent heat of vaporization of water is considerable. A few quick calculations reveal the relative importance of humidification in the prevention of cooling. In HFJV for example, at typical clinically used minute volumes, the cooling effect from the gas alone is the equivalent of about 250 kCal—about 7–10% of the daily calorie requirement. The cooling effect that would result from the use of dry gas, with the consequent latent heat losses from evaporation, would be approximately 3000–3500 kCal day\(^{-1}\). Thus simple warming of the inspired gas would produce little clinical benefit.

Prevention of aspiration

It has been claimed that high frequency ventilation prevents aspiration of pharyngeal contents by virtue of its “auto-PEEP” effect [4, 10]. While this is largely true in paralysed, anaesthetized patients, those who are capable of voluntary inspiration or coughing can still generate a negative tracheal pressure which could result in aspiration [55]. HFV cannot be relied upon as the sole means of protecting the airway from soiling.

Ventilator–patient interfacing

HFV can be used clinically in four ventilator-patient configurations: via conventional tracheal tubes; via narrow-bore insufflation tubes; via the minitracheostomy system; via direct tracheal puncture with small bore cannulae (HFJV) [55].

There is no doubt that the ventilator–patient interface can have a marked effect upon the efficiency of gaseous exchange, particularly with HFJV [3, 55]. Each interface has its own physical properties which influence the behaviour of the gas jet to a greater or lesser degree, depending upon individual geometry. This should be borne in mind when attempting to compare the results obtained by different workers, or in the extrapolation of results obtained in animals to the clinical situation.

IS THERE A FUTURE FOR HFV?

HFPPV. There is no doubt that HFPPV can produce adequate respiratory exchange for indefinite periods in many clinical situations, but there is no evidence to show that it is superior to low frequency techniques in any clinical setting. Most of the clinical enthusiasm for this mode of HFV has come from Scandinavia, where the technique appears to be popular for endoscopy [49]. While it may be true that HFPPV provides better operating conditions than conventional IPPV in this setting, there is no objective evidence of its superiority to low frequency jet ventilation using the same small-radius catheters for gas delivery [19].

HFJV. High frequency jet ventilation has found clinical support in a number of situations. Its role in the fields of thoracic and laryngotracheal surgery is now firmly established [15]. Its use in abdominal surgery is less clearly defined, but it may provide better operating conditions in
upper abdominal surgery because of the reduction in ventilator-related movement of the viscera in biliary surgery, and in extracorporeal shock wave lithotripsy, for similar reasons [48]. The technique is becoming popular in intracranial surgery, again because of the marked reduction in ventilator-induced movement of the brain during microscopic surgery [8]. Overall, there seems little doubt that HFJV will become commonplace in the operating theatre, one paper commenting that it “...should be included in the armamentarium of each operating room...” [40].

HFJV in intensive care. There are numerous anecdotal reports of HFJV succeeding where conventional ventilation has failed [40]. There is no doubt that HFJV can maintain ventilatory exchange in cases of major airway disruption and major air leaks following trauma or barotrauma [19, 40]. Some workers have shown that the magnitude of a leak can be reduced by HFJV, and have suggested that this could aid resolution [55]. While this would appear logical, there is as yet no evidence to support such a view.

A study of 63 patients with a variety of clinical pathologies who were ventilated with HFJV showed that many of the theoretical advantages proposed for HFJV do appear to exist clinically [55]. In particular, patients showed improved cardiovascular and renal function and, in many cases, improvement of pulmonary function when transferred from IPPV to HFJV.

In patients with increased intracranial pressure, transfer from IPPV to HFJV was associated with a significant reduction in intracranial pressure for a comparable arterial carbon dioxide tension [25]. If this reduction will prove beneficial in terms of mortality or morbidity remains entirely speculative.

Thus it seems certain that HFJV will have a clinical role for some time to come, and represents both a significant advance in therapeutics and a welcome addition to the armamentarium of the clinical anaesthetist.

HFO. While HFO can maintain adequate gas exchange for prolonged periods in many situations, there is as yet no clearly defined clinical role for this mode of ventilation.

A report in 1981, of a series of patients with neonatal respiratory distress syndrome treated with HFO, suggested that there was a significant improvement in oxygenation compared with that provided by conventional IPPV [33]. On closer inspection, however, the mean airway pressure generated during HFO was significantly greater than during IPPV. It has been shown that adequacy of oxygenation in respiratory distress syndrome is related to the mean intrapulmonary pressure [44], hence this result does not prove any advantage for HFO per se. In contrast, it is interesting to note that, despite the higher pressures involved with HFO, there was no greater degree of cardiovascular compromise compared with IPPV.

A large-scale trial in similar patients has recently been reported [7]. No significant improvement in morbidity or mortality was demonstrated in infants treated with HFO; indeed, this group showed a greater incidence of pulmonary air leak during the course of the study.

Despite the absence of any clearly defined clinical niche for HFO, there seems little doubt that it will continue to be used extensively in bench testing and animal experimentation. As mentioned earlier, this is largely because of the relative ease of analysis of the near sine wave pressure and flow characteristics of this mode, however limited this may be in terms of elucidating the fundamental physical behaviour of the respiratory tract [20].

CONCLUSIONS

HFV is here to stay. What has been disappointing in the past few years is the lack of standardization of terminology and methods. It is equally disappointing to note that, in many cases, researchers have failed to seek help from the fields of physics, mathematics, acoustics and engineering. Workers in these disciplines have developed valuable analytical methods which must be brought to the attention of enthusiastic, but somewhat amateur, clinicians. This lack of structured analysis has lead to the publication of many papers which describe facets of the curious behaviour of HFV, but without providing any physical explanation of these oddities.

Against this background, it is not surprising that many clinicians are confused about, or even intimidated by, HFV. What is urgently needed is a cohesive presentation to the clinician of the facts regarding HFV insofar as these are known, from the points of view of both basic physiology and clinical utility. The clinician is not without blame however, and it is depressing to hear that many
centres have “evaluated” HFV and dismissed it. If the basic physical principles of the techniques were not understood, then perhaps they were not evaluated fairly.

It is to be hoped, however, that our patients will not be denied the undoubted benefits of HFV, and HFJV in particular, simply because the exact details of its mechanisms of action are unknown. It may be worth recalling that conventional IPPV was used effectively for many years before its physiology was elucidated.

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