VENTILATION DURING BRONCHOSCOPY*

W. E. Spoerel, M.D., F.R.C.P.(C)† and P. A. Grant, M.B., B.S.

For bronchoscopy in the past, various techniques have been used for anaesthesia:

(1) Bronchoscopy without anaesthesia can be used only on infants or moribund patients, mainly for the purpose of providing tracheobronchial toilet. Special techniques of restraint must be used. A thorough diagnostic examination of the tracheobronchial tree is not possible.

(2) Bronchoscopy with local anaesthesia[1] requires that the patient is sufficiently co-operative to permit the administration of the local anaesthetic and sufficiently relaxed to permit proper positioning of the head in relation to the thorax for the performance of the examination. Again, premedication is critical as it has to provide pain relief and apathy without undue depression and still leave the bronchoscopist with a co-operative patient. Other problems are the untoward reactions to the local anaesthetic agent used, idiosyncratic and overdosage, remembering that the toxicity of local anaesthetic agents is the same when given endotracheally as when given intravenously.[2]

(3) With general anaesthesia the bronchoscopist and the anaesthetist share the airway; each one has access to it only intermittently and some compromise is required to maintain ventilation and perform the examination. The following techniques have evolved:

(a) Apnoeic oxygenation provides good conditions for bronchoscopy but the patient is subjected to respiratory acidosis and the time of examination is limited to approximately eight minutes.[3,4,5]

(b) A combination of general and topical anaesthesia can be used successfully with various techniques of intravenous anaesthesia; however, some degree of respiratory depression is unavoidable.[6]

(c) The ventilating bronchoscope allows the bronchoscopist to see but necessitates interruption of the ventilation for instrumentation and suction.[7,8]

(d) Some form of body or curiass respirator can be used to maintain ventilation by intermittent negative pressure. The equipment is cumbersome to use and ventilation is often ineffective particularly in patients with a reduced chest wall compliance.[9,10]

Sanders, in 1967, proposed the use of the venturi principle for intermittent positive pressure breathing by attaching a jet injector to the bronchoscope.[11,12] The principle of the injector is well known.[13] Various types of suction apparatus have been constructed on this basis and it is an integral part of several currently used respirators.

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†Department of Anaesthesia, University of Western Ontario, London, Canada.

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Investigation of the Jet Injector

If a jet of oxygen (A), is introduced into a tube (Figure 1) air will be entrained at the inlet of the tube and the outflow from the tube (B), will consist of the flow through the jet plus the volume of air entrained. The flow from the

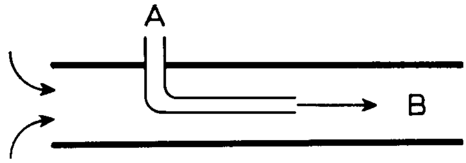

Figure 1. Diagramatic illustration of jet injector.

outlet of the tube depends on the volume flow rate of the jet and the diameter of the inlet of the tube.

In order to illustrate the principle of the jet a No. 16 gauge needle was used as a jet and attached to endotracheal tubes with internal diameters of 4, 6, 8, and 10 mm (Figure 2). If the size of the jet remained constant, the flow through the jet increased corresponding to the pressure applied to the jet. The total outflow from the tube, i.e., the volume flow through the jet plus the volume of air entrained increased as the diameter of the tube increased but the ratio between volume flow through the jet and total outflow remained constant for each combination of tube and jet, i.e., if the volume flow through the jet was doubled, the outflow from the particular tube used also doubled. If the size of the jet was varied for a given tube (Figure 3), the total flow through the tube increased proportional to the volume flow rate through the jet.

For the evaluation of the pressure generated by the jet, a 60-litre capacity metal drum was used as a lung analogue.[14] The approximation to the human lung is reasonably close; a pressure of 15 mm Hg will produce a tidal volume of about 750 ml in the model. To the metal drum, a short piece of thick walled rubber tubing with approximately 20-mm diameter was attached as a trachea. This trachea was intubated with either endotracheal tubes or bronchoscopes with inflatable cuffs to make an air-tight fit. The pressures in the lung model were measured by attaching a strain gauge to a special port-hole in the side of the drum or by using a sphygmomanometer. An "in line" pressure gauge was used to determine the pressure applied to the jet (i.e., driving pressure).

With the jet turned on, the pressure in the lung will rise rapidly to a plateau which will then be maintained constant until the jet is turned off (Figure 4). The rise of pressure is sufficiently rapid within the range of normal inflation pressures that ventilation rates up to 20 or even higher can be used.

The height of the pressure plateau is determined by the volume flow through the jet and the diameter of the tube. For a given tube and jet orifice, the height of the pressure plateau is directly proportional to the driving pressure of the jet. The pressure plateaus for two jets (1.19 mm and 0.84 mm diameter) and a series of endotracheal tubes are shown in Figure 5. When the injector is used as a ventilating device, the inflation pressure can be regulated by varying the driving

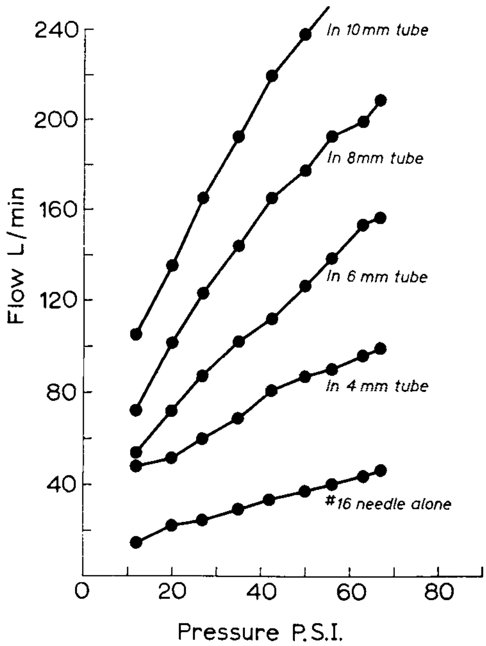

FIGURE 2. Total flow obtained with jet injector (No. 16 needle, diameter 1.19 mm) attached to various endotracheal tubes, using pressures from 20 to 70 p.s.i. applied to the jet. The lowest curve represents the flow through the jet alone.

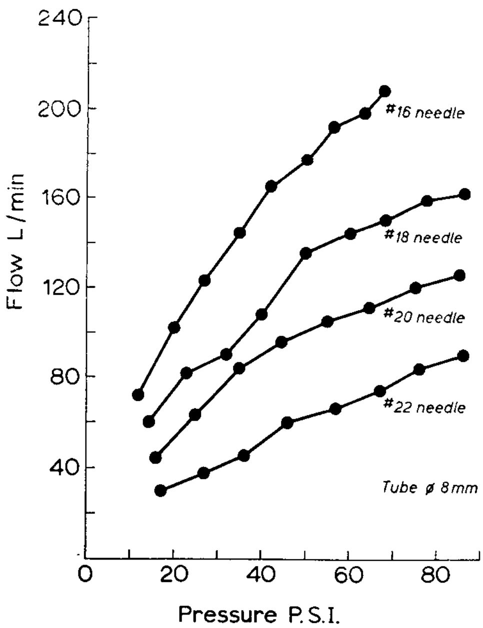

FIGURE 3. Total flow obtained through an 8-mm endotracheal tube with needles of various gauges as jet injectors. No. 22 = 0.41 mm, No. 20 = 0.58 mm, No. 18 = 0.84 mm, and No. 16 = 1.19 mm, diameter.

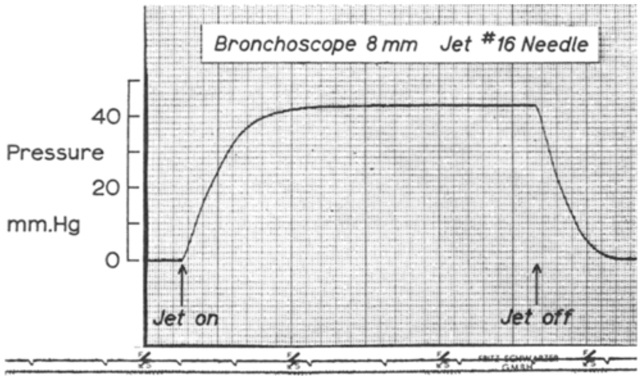

FIGURE 4. Typical pressure curve obtained with model lung using an 8-mm bronchoscope and No. 16 needle as jet.

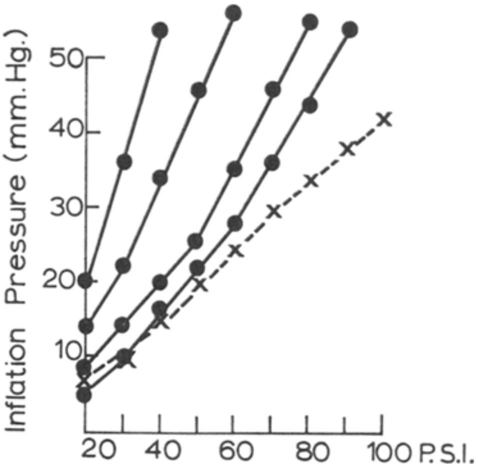

FIGURE 5. Inflation pressures obtained in model lung with a gauge 16 needle as jet attached to endotracheal tubes 7 to 10 mm in diameter. Inflation pressures obtained with a gauge 18 needle as jet attached to an 8-mm endotracheal tube is also shown (X . . . . . X).

pressure of the jet. For each combination of driving pressure, jet orifice, and tube diameter, only one inflation pressure can be attained, regardless of the volume or compliance of the lung. As long as the proximal end of the tube is open, the system is strictly pressure limited and the pressure will not rise higher on account of obstruction of the distal end of the tube.

If driving pressure and jet orifice are kept constant, the pressure plateau will vary inversely to the cross sectional area of the tube. A reduction in the size of the tube for a given jet and driving pressure will increase the inflation pressure in an exponential fashion as shown in Figure 6. This is of practical significance since during bronchoscopy the inflation pressure will increase with the introduc-

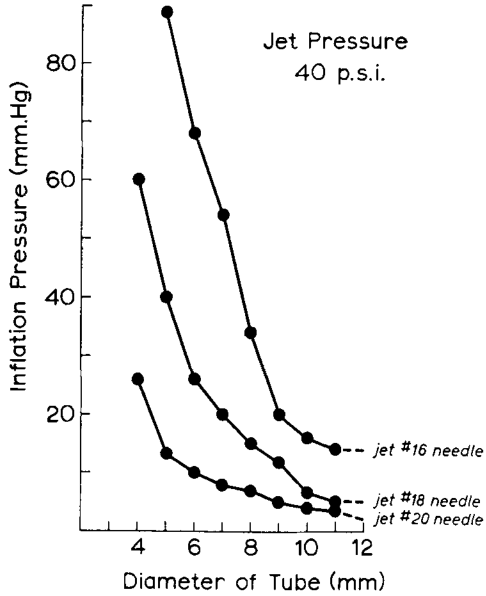

FIGURE 6. Inflation pressures (level of pressure plateau) obtained with 40 p.s.i. applied to three different jet injectors attached to endotracheal tubes of various diameters.

tion of a suction or an instrument on account of the reduction of the cross sectional area of the tube.

In bronchoscopy in adult patients the danger of excessive pressures is minimized by the discrepancy between the trachea and the bronchoscope which exists in most patients. Air is leaking back around the scope through the glottis and this reduces the inflation pressure considerably. In fact, in order to obtain an adequate inflation pressure, under these circumstances jet pressures may have to be used considerably in excess of those applied in an air-tight model. In children, where the instrument usually produces a snug fit and in adults with certain lesions, such as a tracheal stenosis, a small bronchoscope (Figure 7) with a relatively strong jet, as demonstrated here with a 6-mm Negus scope and a No. 16 gauge needle as jet, may produce potentially dangerous inflation pressures in the higher range of driving pressures, and for safe ventilation, the lower range, i.e., 20 to 40 pounds of pressure should be used. In order to establish a safe clinical approach, certain combinations of jets driving pressures and bronchoscope sizes can be obtained from work on models. If a combination is chosen that will provide satisfactory ventilation pressure in the low range of driving pressure, the pressure may then be quite safely increased during bronchoscopy in order to overcome the effect of a leak around the bronchoscope.

In examining our data obtained with endotracheal tubes and bronchoscopes, we found that consistently higher inflation pressures could be produced with endotracheal tubes than with bronchoscopes when identical combinations of jets and tube diameters were used. Clinical observations had indicated[15] that a con-

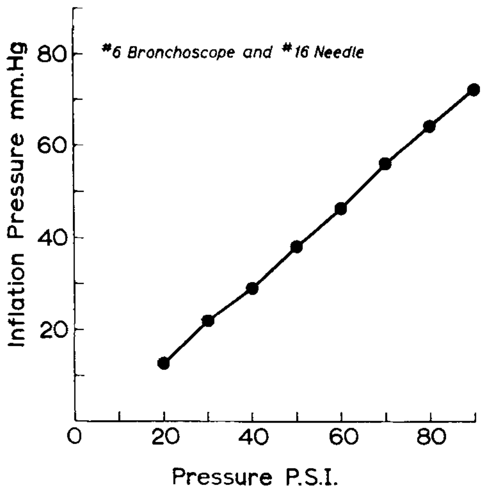

FIGURE 7. Inflation pressure with increasing pressures applied to jet (No. 16 = 1.19 mm) attached to a 6-mm bronchoscope (lung model).

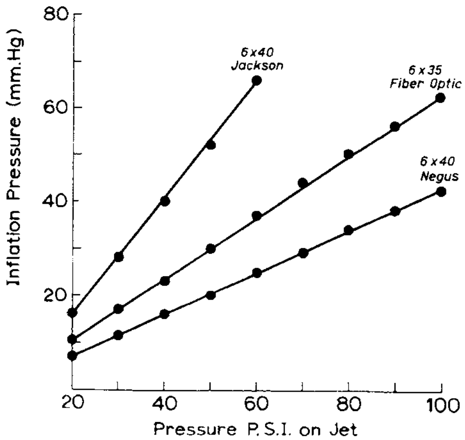

FIGURE 8. Inflation pressures obtained with the same size injector attached to three bronchoscopes: Jackson, Negus and Fiberoptic (American Cystoscope Makers Inc.). Diameter and length of instrument are indicated at the end of each curve.

siderably greater ventilation was obtained when the jet from the bronchoscope was attached to a cuffed endotracheal tube and the driving pressure left unchanged; the lesser efficiency of the bronchoscope was thought to be entirely due to the leak around the scope. A comparison of three different types of bronchoscopes of identical diameter at the distal end was made with the lung model (Figure 8). This revealed that the shape of the tube had a considerable influence. The Jackson bronchoscope is uniform in diameter throughout; it produces higher inflation pressures than the Fiberoptic and the Negus bronchoscopes. The latter

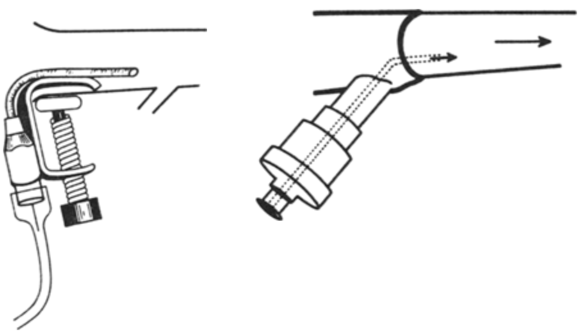

FIGURE 9. Attachment of jet at observer's end of bronchoscope with a small screw clamp (left) or through the side arm of the scope (right).

two instruments are cone shaped at the observer's end. Since the jet is situated at the wider end of the scope, i.e., in a tube of a greater cross sectional area, the inflation pressure generated should be lower in accordance with the data shown in Figure 6.

CLINICAL USE

Various methods of attachment of the jet to the bronchoscope have been tried and are satisfactory, as long as the jet is firmly fixed to the scope in such a way, that there is no interference with vision or instrumentation through the bronchoscope and that the jet is in perfect axial alignment with the tube. Any deviation of the axis of the jet from that of the bronchoscope will produce a noticeable reduction in the efficiency of ventilation. The jet may be readily introduced either over the edge of the observer's end of the Negus and Fiberoptic bronchoscope (Figure 9) or through the side arm. In this latter situation, the jet is completely out of sight which is ideal for the bronchoscopist but makes it necessary to check the axial alignment carefully prior to use.[16] For the Jackson bronchoscope, an attachment has been described in Sanders original publication.[11]

Two different methods of interrupting the flow of oxygen to the jet have been tried and both can be used satisfactorily:

(1) Manual interruption with some form of hand valve, the simplest of which can be made from the occlusive roller of an IV set.[17]

(2) Automatic interruption[15] with a Bird Mark II ventilator (Figure 10).

A standard anaesthetic technique is used in conjunction with this method of ventilation: induction with thiopentone and complete muscular relaxation, obtained with intermittent doses of succinylcholine. After pre-oxygenation, the bronchoscope is introduced and ventilation with the jet begun at a rate of 12 to 16 inflations per minute. Maximum muscle relaxation is necessary in order to increase the overall compliance and to eliminate the cough reflex. Adequacy of ventilation is judged by observing the chest excursions of the patient and the driving pressure of the jet is adjusted accordingly.

In 20 patients, blood gases were taken at the end of the bronchoscopic pro-

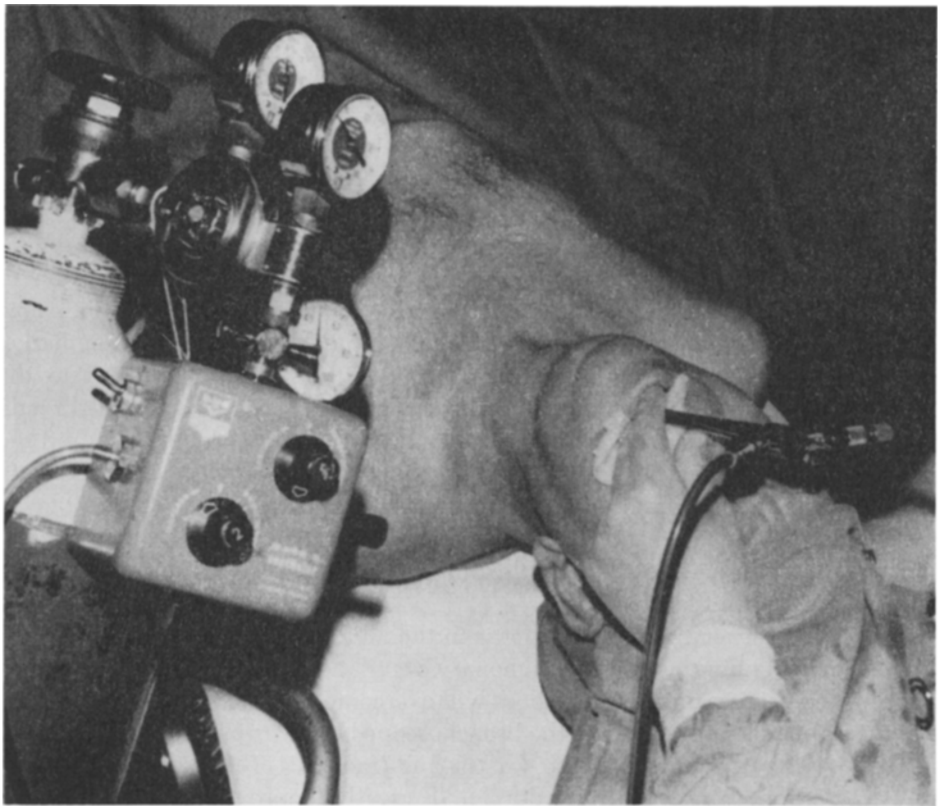

FIGURE 10. Equipment for automatic ventilation with jet injector using a Bird Mark II ventilator.

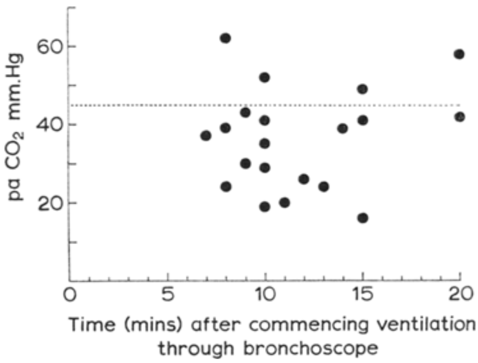

FIGURE 11. Arterial P_{CO_2} prior to termination of ventilation through bronchoscope in 20 patients.

cedure prior to withdrawal of the bronchoscope (Figure 11). All patients were well oxygenated; with an oxygen saturation greater than 96 per cent. The P_{CO_2} values showed that some patients were grossly over-ventilated while four values were higher than an acceptable level of 45 mm Hg. All of these patients were elderly (age 61 to 75), had chronic bronchitis and emphysema and a poor compliance.

Discussion

The Sanders technique of ventilation during bronchoscopy is equally effective to other ventilating techniques,[18,19] but simpler and more flexible and provides the best possible conditions for the bronchoscopist. It is now used as a routine in our hospitals. The jet, if properly placed, does not enter the visual field and does not interfere with any type of instrumentation or suction. If the duration of inflation is properly adjusted the bronchoscopist should only experience air flow similar to that of a normal quiet expiration when the jet is turned off. Ventilation can be maintained as long as required and no time limit is imposed to the bronchoscopist; suitable increments of thiopentone and succinylcholine will retain the patient relaxed and unconscious. Oxygenation is adequate at all times and the ventilation need never be interrupted. A similar technique has been used with advantage in bronchograms under general anaesthesia; a jet is attached to an open endotracheal tube and the catheter for dye injection can be manipulated into each main bronchus through the tube without any significant interference with pulmonary ventilation.

The leakage of air through the glottis in the adult patients represents the main problem in obtaining adequate pulmonary ventilation. In most patients, adjustments of the driving pressure of the jet will overcome this leak. In several patients we have slipped a latex cuff over the bronchoscope before its insertion and partially inflated it after the bronchoscope was in mid-trachea.[14] This did not appear to impede the bronchoscopic procedure and greatly improved the efficiency of ventilation. As an alternative, manual pressure above the glottis will reduce the leak and if properly applied does not interfere with the bronchoscopist.

According to these investigations, the jet injector used as a ventilator is entirely pressure limited. Only one pressure plateau can be reached for each combination of tube, jet, and driving pressure. This inflation pressure is independent of the compliance of the inflated lung. Obstruction of the distal end of the bronchoscope will not change the pressure inside the scope, as long as the proximal end is open. Obstruction of the observer's end of the scope would eliminate the air entrainment and only gas from the jet would enter the scope; this flow is relatively slow, even for the largest jet used, and several seconds of complete occlusion of a scope tightly fitting the airway would be required before the endobronchial pressure reaches dangerous levels in adults. For children, where the bronchoscope often fits the glottis snugly, it would appear safer to use a smaller jet, e.g., a gauge 19 or 20 needle.

In adults, where often high driving pressures are required to overcome the leak around the instrument, excessive pressure could occur when this leak is suddenly stopped, e.g., by inserting the scope deeply into the left main bronchus with simultaneous occlusion of the side holes of the bronchoscope. Although this possibility is remote, each combination of jet and bronchoscope should be tested and the maximum range of inflation pressure be known to the operator.

Summary

A brief review of techniques used to provide anaesthesia and ventilation during bronchoscopy indicates the advantage of Sanders' technique of ventilation, using the injector principle. A jet of oxygen, attached to an endotracheal tube or bronchoscope, entrains a volume of air several times greater than its own flow volume. The flow can be used to generate pressures sufficient for inflation of the lung. Intermittent positive pressure ventilation can then be produced by periodic interruption of the flow through the jet with the help of a manually operated valve or with a Bird Mark II ventilator.

The pressure generated depends on the volume of flow through the jet and the cross sectional area of the tube. An increase in the volume flow through the jet will produce a proportional rise in inflation pressure; reduction of the cross sectional area of the tube, leaving the jet unchanged, will produce an exponential increase in inflation pressure. This explains the higher inflation pressures obtained with a tube of uniform diameter, e.g., the Jackson type of bronchoscope in comparison to bronchoscopes with a cone shaped end.

Blood gas determinations in 20 patients show that adequate ventilation can be obtained during bronchoscopy while allowing the bronchoscopist complete freedom for observation and instrumentation through the bronchoscope. The only practical problem is a leak of air around the instrument which can prevent the attainment of adequate inflation pressures; this leak can be overcome by increasing the driving pressure of the jet and may be minimized by external supraglottic pressure. In children, the scope produces a snug fit, smaller jets and lower driving pressures must be used to avoid excessive inflation pressures.

Résumé

Une brève revue des techniques employées pour produire à la fois de l'anesthésie et de la ventilation au cours des bronchoscopies montre les avantages de la technique de ventilation Sander qui applique le principe d'injecteur. Un jet d'oxygène, attaché à un tube endotrachéal ou à un bronchoscope, entraîne un volume d'air dépassant de plusieurs fois son propre volume. Il est possible d'employer le courant pour produire des pressions suffisantes pour insuffler le poumon. On peut alors procurer une ventilation à pression positive intermittente en faisant des interruptions périodiques du courant à travers le jet à l'aide d'une valve manuelle ou d'un ventilateur Bird Marque II.

La pression engendrée variera selon le volume du courant à travers le jet et la surface de la coupe de section du tube. Une augmentation du volume du courant à travers le jet va augmenter proportionnellement la pression d'insufflation; une diminution de la coupe de section du tube, sans changer le jet, va produire une augmentation exponentielle de la pression d'insufflation. Cela explique les plus hautes pressions d'insufflation qu'il est possible d'obtenir avec un tube de diamètre uniforme, comme exemple, le bronchoscope du type Jackson en comparaison avec les bronchoscopes à l'extrémité en forme de cone.

L'étude des gaz artériels chez 20 malades a démontré qu'il est possible d'obtenir une ventilation adéquate du malade au cours d'une bronchoscopie tout en laissant à l'opérateur toute liberté pour l'examen et l'usage d'instrument à travers le bronchoscope. La seule éventualité qui créerait un problème serait une fuite d'air autour de l'instrument, ce qui pourrait empêcher d'atteindre les pressions d'insufflation désirées, cette fuite peut être neutralisée en augmentant la pression dans le jet et elle peut être réduite en employant de plus petits jets et des pressions inférieures pour éviter des pressions d'insufflation excessives.

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