

## EFFECTS OF NITROUS OXIDE AND OXYGEN ON TRACHEAL TUBE CUFF GAS VOLUMES

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### SUMMARY

The changes in the volume of the cuffs of 200 air-inflated tracheal tubes were studied on exposure to 70% nitrous oxide and 30% oxygen. The length of the cuff, its diameter, wall thickness and residual volume were measured. Increases in the volume of gas occurred in all tubes in a time-dependent manner. The tracheal tubes with low-pressure cuffs were more permeable to nitrous oxide and oxygen than those with high-pressure cuffs. Implications of these findings and the factors which govern the transmission rates of gases through cuff material are discussed.

*In vitro* studies and investigations in patients have shown that nitrous oxide and oxygen diffuse into air-inflated cuffs of tracheal tubes, thereby increasing their volume and pressure (Stanley, 1974, 1975; Revenäs and Lindholm, 1976; Bernhard et al., 1978). Overinflation of the cuff on the tracheal tube, secondary to the diffusion of nitrous oxide may lead to sore throat, glottic and sub glottic oedema and erosion of the tracheal mucosa. This study was undertaken to measure the changes in the volume of the cuff which occur during exposure to a nitrous oxide-oxygen gas mixture and to compare the physical characteristics of the cuffs of tracheal tubes used commonly in the United Kingdom.

### MATERIALS AND METHODS

The permeability of the cuffs of tracheal tubes to nitrous oxide and oxygen was studied in two types of tracheal tube. Group I consisted of tubes with low-pressure cuffs: Portex Profile, Searle Medical Sensiv and Mallinckrodt hi-lo. Group II contained tubes with high-pressure cuffs: Magill red rubber and Leyland Cuftrac latex. Forty tracheal tubes of each type were tested; 20 tubes of 9.0 mm i.d. and 20 of 8 mm i.d.

The 200 cuffed tracheal tubes were placed, in lots of 10, into a 6.5-litre capacity glass environmental chamber at approximately 1 atmosphere pressure. After complete deflation the cuffs were inflated with 10 ml air and exposed to a continuous flow of 5 litre min<sup>-1</sup> of 70% nitrous oxide and

30% oxygen for periods of 1, 2 and 3 h. The volume of gas in the cuff was measured at the end of these periods with a calibrated and lubricated 10-ml glass syringe using a three-way stopcock. Syringes and stopcocks were tested for leaks using a 20-s compression test before each investigation. The gas volumes withdrawn from the cuffs were measured at atmospheric pressure and at room temperature. All the investigations were performed at 21 °C and approximately 50% relative humidity.

The length, wall thickness, residual volume and diameter of 20 selected cuffs of each type were determined. Length and diameter were measured at residual volume with a Vernier caliper. The residual volume of the cuff was determined by connecting each tracheal tube cuff *via* a three-way stopcock to a 10-ml calibrated glass syringe. The residual volume of the cuff was defined as the maximum volume of air which could be introduced into an empty cuff while maintaining the pressure in the cuff at 1 atmosphere. A micrometer with friction thimble for standardization of measuring force was used to measure the thickness of the cuff.

### RESULTS

The exposure to the mixture of 70% nitrous oxide in oxygen resulted in a time-dependent increase in the volume of gas in the cuffs of all tubes (tables I-IV). The largest absolute change in gas volume occurred, in all the tubes, during the 1st hour. After 1 h the continued exposure to this gas mixture resulted in small but steady increases in the volume of gas in the cuffs.

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TABLE I. *Effects of nitrous oxide-oxygen (70-30%) on the gas volumes (mean  $\pm$  SD) in the cuffs of low-pressure tracheal tubes filled initially with 10 ml of air*

Tracheal tube	Size	Increase in cuff volume (ml)		
		1 h	2 h	3 h
Portex Profile	8 mm	4.5 $\pm$ 0.63	5.52 $\pm$ 0.49	7.37 $\pm$ 0.64
	9 mm	4.9 $\pm$ 0.57	6.87 $\pm$ 0.76	7.85 $\pm$ 0.46
Searle Sensiv	8 mm	5.3 $\pm$ 1.80	7.50 $\pm$ 1.90	10.35 $\pm$ 1.10
	9 mm	6.6 $\pm$ 0.62	8.76 $\pm$ 0.84	11.70 $\pm$ 1.06
Mallinckrodt hi-lo	8 mm	6.5 $\pm$ 0.40	9.70 $\pm$ 0.70	12.60 $\pm$ 0.70
	9 mm	6.8 $\pm$ 0.62	10.00 $\pm$ 0.87	12.73 $\pm$ 0.82

The tracheal tubes with low-pressure cuffs were more permeable to nitrous oxide and oxygen than those with high-pressure cuffs. The mean change in the volume of the cuff in Mallinckrodt hi-lo tubes and Searle Sensiv tubes was greater than that in Portex Profile tubes at 1, 2 and 3 h (table I). After 3 h exposure the increases in volume with 9.0-mm Mallinckrodt hi-lo, Searle Sensiv and Portex Profile tubes averaged 127, 117 and 78% respectively and with 8.0-mm Mallinckrodt hi-lo, Searle Sensiv and Portex Profile 126, 103 and 73% respectively (fig. 1).

In the group containing tracheal tubes with high-pressure cuffs, Leyland Cufrac latex tubes were more permeable to nitrous oxide and oxygen than Magill red rubber (table II). After 3 h exposure the increases in gas volume in 9.0-mm Leyland Cufrac latex tubes and Magill red rubber averaged 60 and 47% respectively and in 8.0-mm Leyland Cufrac latex tubes and Magill red rubber averaged 56 and 37% respectively (fig. 1).

Mean length of cuff, thickness, residual volume and the diameter of the cuff at residual volume are presented in tables III and IV.

#### DISCUSSION

The usefulness of cuffed tracheal tubes during artificial ventilation and their role in the prevention of aspiration have been well established in

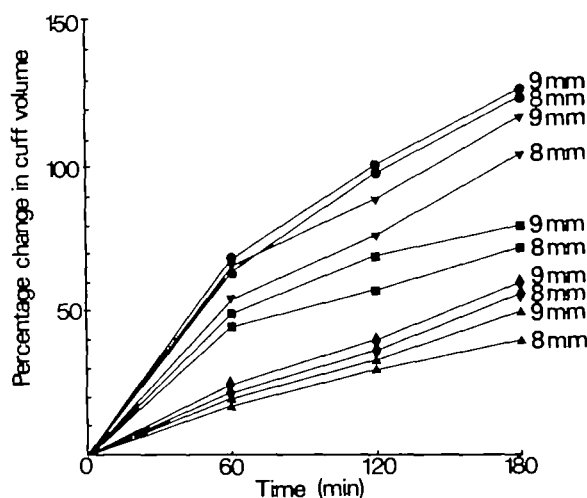


FIG. 1. Percentage change in cuff gas volume. ● = Mallinckrodt hi-lo; ▼ = Searle Sensiv; ■ = Portex Profile; ◆ = Leyland Cufrac latex; ▲ = Magill red rubber.

Europe. However, several complications relating to the cuffs have been reported. These include minor complications like sore throat, glottic and sub-glottic oedema and more severe complications such as mucosal erosion, cartilage necrosis and eventual tracheal stenosis (Nordin, 1977; Lewis, Schlobohm and Thomas, 1978). The frequency of these complications is related to the design of the

TABLE II. *Effects of nitrous oxide-oxygen (70-30%) on the gas volumes (mean  $\pm$  SD) in the cuffs of high-pressure tracheal tubes filled initially with 10 ml of air*

Tracheal tube	Size	Increase in cuff volume (ml)		
		1 h	2 h	3 h
Magill red rubber	8 mm	1.90 $\pm$ 0.28	3.1 $\pm$ 0.74	3.75 $\pm$ 0.64
	9 mm	2.02 $\pm$ 0.57	3.5 $\pm$ 0.94	4.70 $\pm$ 1.05
Leyland Cufrac latex	8 mm	2.20 $\pm$ 0.34	3.6 $\pm$ 0.40	5.60 $\pm$ 0.40
	9 mm	2.50 $\pm$ 0.25	3.8 $\pm$ 0.58	6.00 $\pm$ 1.40

TABLE III. *Physical characteristics of cuffs of 8-mm tubes (mean  $\pm$  SD)*

Tracheal tube	Length (mm)	Thickness (mm)	Residual volume (ml)	Diameter (mm)
Magill red rubber	41.0 $\pm$ 0.5	0.375 $\pm$ 0.025	0.0	12.0 $\pm$ 0.25
Leyland Cufrac latex	30.0 $\pm$ 0.2	0.375 $\pm$ 0.025	0.0	12.0 $\pm$ 0.25
Portex Profile	38.0 $\pm$ 0.44	0.125 $\pm$ 0.025	11.5 $\pm$ 0.25	27.0 $\pm$ 0.35
Searle Sensiv	39.5 $\pm$ 0.50	0.125 $\pm$ 0.025	6.0 $\pm$ 0.20	20.0 $\pm$ 0.25
Mallinckrodt hi-lo	45.0 $\pm$ 1.00	0.045 $\pm$ 0.003	22.0 $\pm$ 0.50	31.0 $\pm$ 0.25

TABLE IV. *Physical characteristics of cuffs of 9-mm tubes (mean  $\pm$  SD)*

Tracheal tube	Length (mm)	Thickness (mm)	Residual volume (ml)	Diameter (mm)
Magill red rubber	41.0 $\pm$ 0.50	0.375 $\pm$ 0.025	0.0	14.00 $\pm$ 0.25
Leyland Cufrac latex	30.0 $\pm$ 0.20	0.375 $\pm$ 0.025	0.0	14.00 $\pm$ 0.25
Portex Profile	38.4 $\pm$ 0.44	0.125 $\pm$ 0.025	13.05 $\pm$ 0.35	29.80 $\pm$ 0.30
Searle Sensiv	39.5 $\pm$ 0.50	0.125 $\pm$ 0.025	6.90 $\pm$ 0.20	22.25 $\pm$ 0.25
Mallinckrodt hi-lo	45.0 $\pm$ 1.00	0.045 $\pm$ 0.003	26.00 $\pm$ 0.50	32.00 $\pm$ 0.25

cuff, the duration of the pressure exerted on the tracheal mucosa and the area of contact between cuff and tracheal wall. This study demonstrates that nitrous oxide and oxygen can permeate into the cuffs of tracheal tubes and increase the volume of the cuffs in both high-pressure and low-pressure air-filled cuffs. These findings suggest that overexpansion of the cuff during anaesthesia can lead to an increase in cuff pressure on the tracheal mucosa and it may be a significant cause of those complications related to cuffs.

Many factors govern the rates at which gases pass through organic films. The volume of gas ( $V$ ) that will pass through the film is directly proportional to the difference in the pressure exerted by the gas on each face of the film ( $p_1 - p_2$ ), the area of the film exposed ( $A$ ) and the time ( $t$ ) for which permeation occurs and is inversely proportional to thickness ( $X$ ). This relationship may be expressed as:

$$V = \frac{P \times At(p_1 - p_2)}{X}$$

where  $P$  has a constant value for a specific combination of gas and cuff material at a given temperature and is known as the permeability constant or coefficient. Since permeability is dependent on both diffusion and solubility characteristics it is possible to write:

$$P = DS$$

where  $P$ ,  $D$  and  $S$  are the permeability, diffusion and solubility coefficients respectively for a given permeant/cuff system (Brydson, 1966). Gas solubility obeys Henry's Law and is proportional to the partial pressure, whereas the rate of diffusion of gases through the membrane is proportional to their concentration gradient and inversely proportional to the square root of their molecular weight.

The nature of both permeant and cuff material influence permeability. The size, shape and molecular weight of a permeant affect the rate of diffusion, whereas polarity of the molecules has a pronounced effect on the solubility coefficient (Hennessy, Mead and Stening, 1967). The rate of diffusion through polymers used in the manufacture of cuff material depends on the size of gaps between their molecules, which in turn is determined by the physical state of the polymer. In rubber the molecular segments have considerable mobility, so the rate of diffusion is greater than in any other type of polymer. Permeability characteristics of a polymer are associated with variations in molecular weight, the chain length of the molecules, the presence of a double bond, the degree of polymerization, the nature and quality of plasticizer and inert filler content. In the case of polyvinyl chloride film, permeability is also influenced by temperature.

The maximum increase in the volume of the cuff occurred in Mallinckrodt hi-lo tubes (table I).

These cuffs had the largest length and diameter and therefore the largest surface area and minimum wall thickness. Although the cuffs of Portex Profile and Searle Sensiv tubes were of similar length and wall thickness, their residual volumes were different. The cuffs of the Searle Sensiv tubes had a small residual volume (6–6.9 ml) and when filled with 10 ml of air were stretched more, thus affecting their wall thickness and leading to a greater increase in the volume of the cuff.

The smallest increases in gas volume occurred in Magill red rubber and Leyland Cufrac latex tubes probably as a result of their thicker wall, which presented a greater barrier to the diffusion of nitrous oxide and oxygen. However, if the inflated cuffs in this study were exposed to the nitrous oxide–oxygen mixture for long enough they would eventually contain gas at the same pressure and with the same composition as the gas mixture outside. The changes in the rate of change of cuff volume with time reflect a phase in this equilibrium process.

Stanley, Kawamura and Graves (1974) demonstrated that the diffusion of nitrous oxide caused a significant increase in gas volume in cuffs. Oxygen is less diffusible through the walls of cuffs and its contribution to the final volume in the cuff is considerably less. The diffusion of nitrogen out of the cuff was small despite its smaller molecular weight and the favourable concentration gradient (80% inside the cuff *v.* 0 outside). However, the factors governing the differences in partial pressure of the gases between the outside and inside of a cuff are complex. The pressure difference for each gas will be influenced by transfer of that gas into the closed space, by the transfer of other gases, and by any changes in pressure in the cuff consequent upon the changes in volume.

Stanley (1975) studied the effects of nitrous oxide on the volume and pressure of endotracheal tube cuffs in patients and found that the changes in volume were less *in vivo* than *in vitro*. One reason for this is that only the distal portion of the cuff, that is, the portion not in contact with the tracheal wall, is exposed to the inspired gases in patients, while the upper end of the cuff is exposed to atmospheric air. This will allow nitrous oxide to permeate the cuff from the lower end and progressively permeate to atmosphere through the upper end.

All cuffs are permeable to nitrous oxide, leading to increases in volume and pressure. The latter

may be associated with an increased frequency of tracheal trauma. This may be overcome by inflating the cuff with a sample of the inspired mixture of gases rather than room air, or by monitoring the pressure in the cuff with a device attached to the inflation line. Variations of pressure within the cuff can be observed and corrected as necessary. Another alternative is to use a pressure relief valve which will bleed off excess gases but maintain the volume of the cuff and the pressure required to produce a tracheal seal.

#### ACKNOWLEDGEMENTS

The author wishes to thank Mr T. W. Hung and Mr C. D. Raymond of Searle Medical Products for their valuable advice and supplies of Sensiv tubes, Mr P. C. Callaghan of Hartley Hospital, Colne for technical assistance and Mrs G. Hart for secretarial help.

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#### EFFETS DU PROTOXYDE D'AZOTE ET DE L'OXYGENE SUR LES VOLUMES DE GAZ DES MANCHONS DE TUBE TRACHEAL

#### RESUME

On a fait une étude sur les variations qui se sont produites dans le volume des manchons de 200 tubes trachéaux gonflés à l'air lorsqu'on les a exposés à 70% de protoxyde d'azote et à 30% d'oxygène. Nous avons mesuré la longueur, le diamètre et l'épaisseur de paroi de chaque manchon de même que son volume résiduel. Des augmentations dans le volume de gaz ont

été constatées dans tous les tubes, en fonction du temps. Les tubes trachéaux ayant des manchons à basse pression ont été plus perméables au protoxyde d'azote et à l'oxygène que les tubes dotés de manchons à haute pression. Les implications de cette découverte et les facteurs qui gouvernent le taux de transmission des gaz à travers le matériau du manchon sont débattus dans cet article.

#### AUSWIRKUNGEN VON STICKOXYDUL UND SAUERSTOFF AUF TRACHEALSCHLAUCHMANSCHETTEN- GASVOLUMEN

##### ZUSAMMENFASSUNG

Es wurden die Änderungen beim Volumen der Manschetten von 200 mit Luft aufgeblasenen Trachealschläuchen während des Aussetzens an 70% Stickoxydul und 30% Sauerstoff studiert. Die Länge der Manschette, ihr Durchmesser, Wandstärke und Restvolumen wurden alle gemessen. Eine Zunahme des Gasvolumens trat bei allen Schläuchen in Abhängigkeit von der Zeit ein. Die Trachealschläuche mit den Niederdruck-Manschetten waren Stickoxydul und Sauerstoff

gegenüber viel durchlässiger als Trachealschläuche mit Hochdruck-Manschetten. Die Folgerungen aus diesem Befund und die Faktoren, die die Durchgangsgeschwindigkeiten der Gase durch Manschettenmaterial bestimmen, werden diskutiert.

#### EFFECTOS DEL OXIDO NITROSO Y DEL OXIGENO EN LOS VOLUMENES DE GAS DE LOS ANILLOS DEL TUBO TRAQUEAL

##### SUMARIO

Se estudiaron los cambios del volumen de los anillos de 200 tubos traqueales inflados con aire, bajo la exposición a una mezcla de 70% de óxido nitroso y de 30% de oxígeno. Se midieron la longitud del anillo, su diámetro, el grosor de la pared y el volumen residual. Tuvieron lugar incrementos en el volumen del gas en todos los tubos, siendo estos incrementos función del tiempo. Los tubos traqueales con anillos de baja presión fueron más permeables al óxido nitroso y al oxígeno que aquellos de alta presión. Se discuten las repercusiones de estos resultados así como los factores que regulan los regímenes de transmisión de gases a través del material del anillo.