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CHANGES IN INTRACUFF GAS VOLUME, PRESSURE AND GAS COMPONENT WITH NITROUS OXIDE ANAESTHESIA

(nitrous oxide anaesthesia/intracuff pressure/intracuff gas volume)

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To clarify the characteristics of endotracheal cuffs made of polyvinyl chloride (PVC), latex rubber (LR), and silicone rubber (SR), we made a comparative study on the change of intracuff pressure as well as on intracuff gas volume, gas component, and gas concentration in nitrous oxide. These changes were measured in a plastic bag filled with nitrous oxide. Nitrous oxide diffused into all cuffs in a concentration and time-related fashion. The rates of nitrous oxide diffusion in SR cuffs were considerable compared with those in LR and PVC cuffs. SR cuffs were also more permeable to oxygen and nitrogen than LR and PVC cuffs. Gas volume in SR cuffs rapidly increased within a short time and then decreased, though intracuff pressures did not change from the control values. On the other hand, gas volume and intracuff pressure in LR and PVC cuffs increased continuously with time. These findings suggest that the overexpansion of SR cuffs may cause tracheal obstruction and the high lateral pressure of PVC and LR cuffs may induce damage in the tracheal wall.

Friedlich Trendelenburg devised the first a cuffed tracheostomy tube(1), and damage of the tracheal wall has been reported. Cooper and Grillo(2) and Dunn et al. (3) found that damage to the tracheal wall were related to pressure of this tube. At present nitrous oxide is clinically the most widely used inhalation anaesthetics. In 1965, Eger and Saidman (4) found that a gas-filled space in the body will expand if the gas within it is less soluble in blood and other body fluids than is the gas respired. They showed that nitrous oxide, a gas 34 times more soluble in blood than nitrogen, when inspired in a concentration of 75 per cent, increased intestinal gas volumes 100-200 per cent in four hours and increased gas volumes in pneumothoraces 200-300 per cent in two hours. Stanley et al. (5) observed that in vitro, the same phenomenon presented in the endotracheal tube cuff. They reported that when the cuff filled with air was exposed to nitrous oxide, this gas would diffuse into the cuff with time and would increase the intracuff pressure as well as the gas volume. They also reported that due to increases in the intracuff gas volume, there would be some possibility of damage to the tracheal wall, under conditions of nitrous oxide anaesthesia. Cuffs clinically used are made of either latex rubber (LR), polyvinyl chloride (PVC), or silicone rubber (SR). We also measured changes in intracuff gas volume, intracuff pressure, gas component, and gas concentration with the lapse of time and our data are reported herein.

METHODS

Nitrous oxide diffusion was studied using 157 endotracheal tubes, each size 9 mm interdiameter. Cuffs in three different materials were used for our experiment: Portex blue line tube cylindrical cuffs made of polyvinyl chloride (PVC), T. Igarashi B-4 cylindrical cuffs made of latex rubber (LR), Dover all silicone tube cuffs made of silicone rubber (SR).

We devised the equipment shown in Fig. 1 for our experiment. By continuously infusing nitrous oxide 6 litre/min (100 % nitrous oxide) or mixed gas of nitrous oxide 3 litre/min and oxygen 3 litre/min (50 % nitrous oxide) into a thin plastic bag leading from an anaesthesia machine through a tube, we filled the bag and exposed the cuff to nitrous oxide. Outflow gas was controlled to prevent deflating the thin plastic bag.

Changes in Intracuff Gas Volume in 100 % and 50 % Nitrous Oxide

We sampled 7 pieces of each type, and filled them with 5 ml air using a calibrated syringe. Exposing each cuff to nitrous oxide, we measured the intracuff gas volume with the syringe through a three-way stopcock at the time of 15, 30, 45, 60, 90, and 120 min after filling. After the measurement, gas was returned to the cuffs.

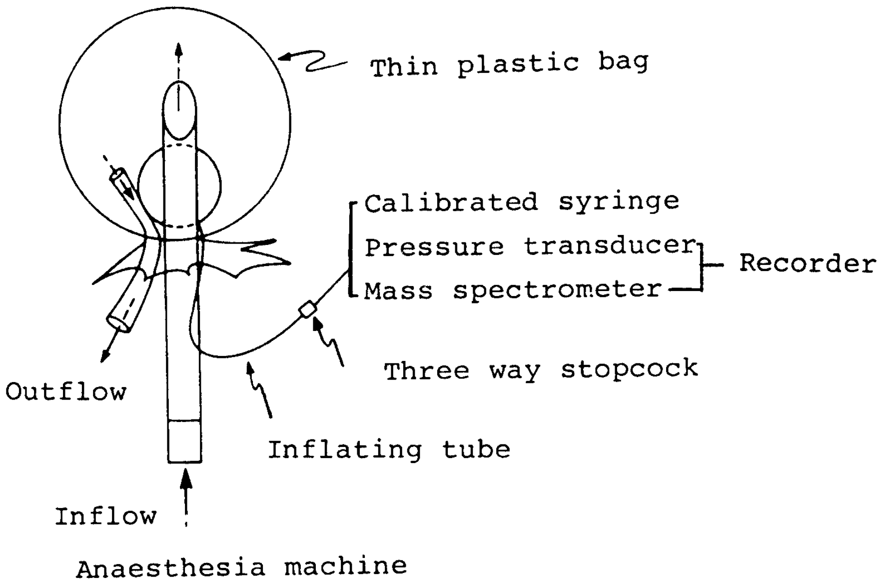

Fig. 1. Schematic diagram of the experimental apparatus.

<u>Changes in Intracuff Pressure in 100 % and 50 % Nitrous Oxide</u>

We sampled 7 pieces cuffs out of each type, and filled each cuff with 5 ml air. Each cuff was connected to a pressure transducer through a three-way stopcock. We Continuously measured intracuff pressure under 100 % and 50 % nitrous oxide, and recorded the values on a polygraph (RM-6000, Nihon Kohden, Japan).

<u>Changes in Intracuff Gas Component and of Concentration in 100 % and 50 % Nitrous Oxide in Oxygen</u>

We sampled 25 pieces of each type, filled them with 5 ml air and exposed them to 100 % nitrous oxide and to 50 %. We measured the component and concentration of intracuff gas using a mass spectrometer (Medspect II, Chemetron, U.S.A.) at 15, 30, 45, 60, and 120 min and recorded the data on an multipen-recorder (KB-6, Rika Denki, Japan). All experiments were done at 24°C, 50-60% relative humidity, and a barometric pressure of 750-758 mmHg in a temperature-and humidity-controlled room. Analyzing the data statistically, we obtained the mean value and standard deviation. The difference was considered significant all values of less than 5 %, determined by Student's t-test.

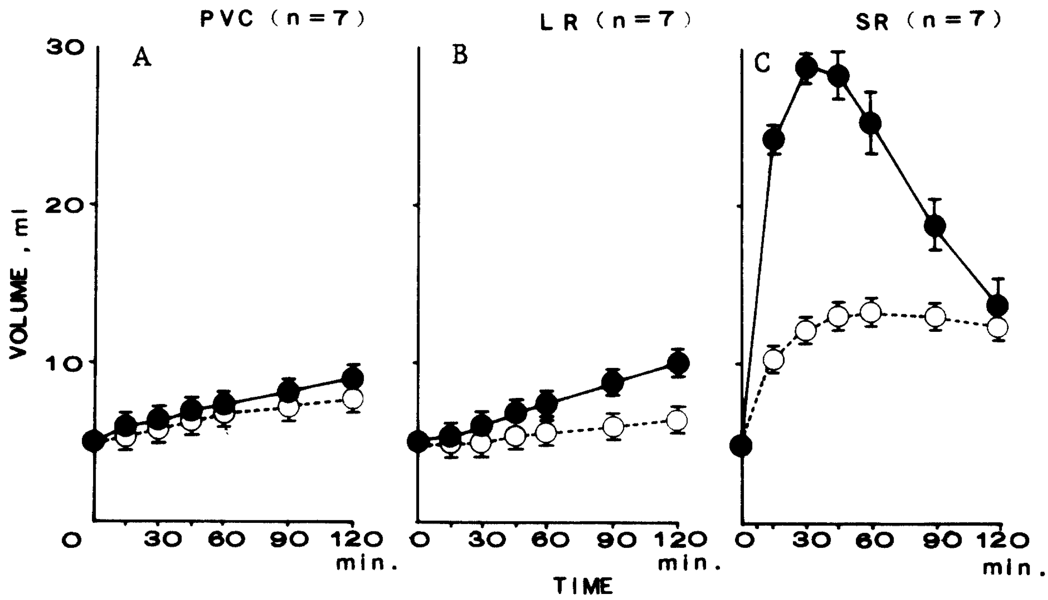

Fig. 2. Changes of intracuff gas volume in 100 % and 50 % nitrous oxide. (mean + SD)
● : 100 % nitrous oxide
○ : 50 % nitrous oxide in oxygen

RESULTS

Changes of Intracuff Gas Volume in 100 % and 50 % Nitrous Oxide

With 100 % nitrous oxide, the volumes of both PVC and LR cuffs increased and 120 min later, the volume of each type was double that of the control. With 50 % nitrous oxide, both PVC and LR cuffs increased in volumes with time and 120 min later the PVC cuffs were 1.6 times over the control and LR cuffs 1.3 times the volume of the controls (Fig. 2A).

In SR cuffs, with 100 % nitrous oxide, the gas volume increased 5 times and reached 24.6 ± 0.5 ml 15 min later. After 30 min, the value was 29.0 ± 0.5 ml. Thereafter, gas volume decreased gradually, getting down to 28.4 ± 1.5 ml 45 min later, to 25.5 ± 2.0 ml 60 min later, and to 13.9 ± 1.7 ml 120 min later. With 50 %, the cuff showed a volume increase by almost double and reached 10.4 ± 0.4 ml in 15 min and 13.6 ± 0.8 ml at 60 min (Fig. 2C). From that time, it began to decrease similar to findings with 100 % nitrous oxide. The value was 12.7 ± 0.2 ml at 120 min (Fig. 2B).

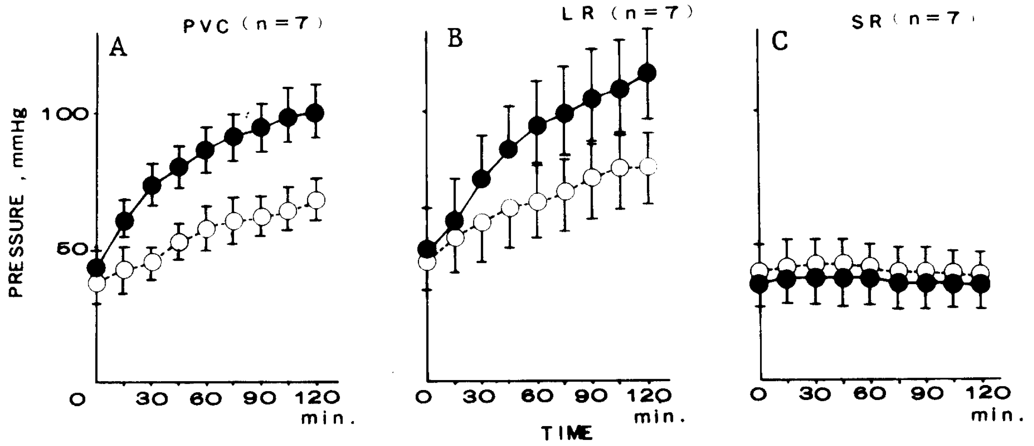

Fig. 3. Changes of intracuff pressure in 100 % and 50 % nitrous oxide. (mean + SD)
● : 100 % nitrous oxide
O : 50 % nitrous oxide in oxygen

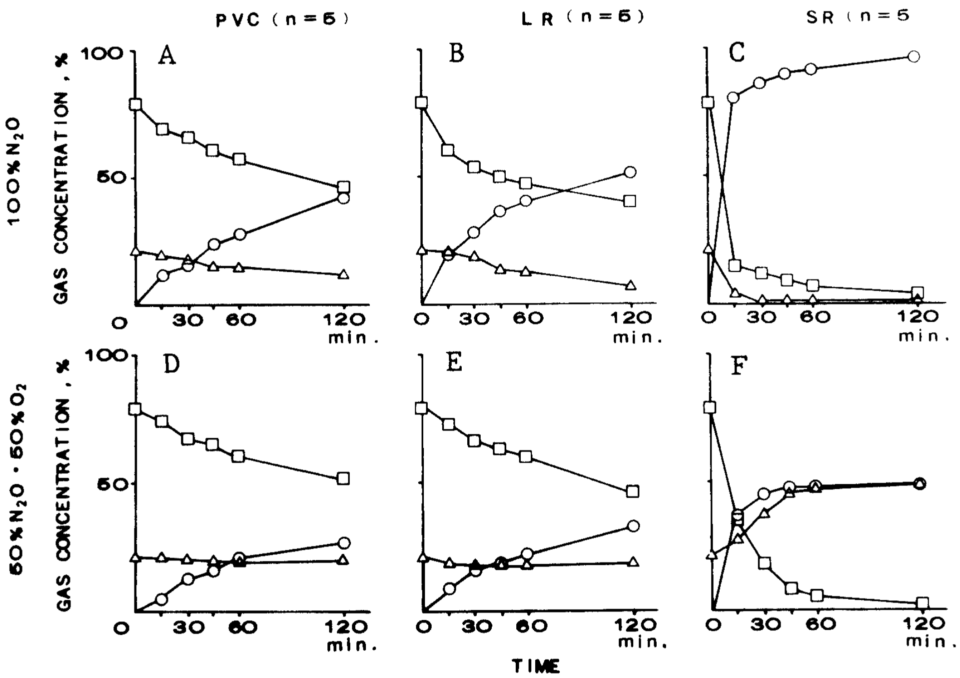

Fig. 4. Changes of intracuff gas component and of mean concentration in 100 % and 50 % nitrous oxide.
□ : nitrogen
Δ : oxygen
O : nitrous oxide

Changes in Intracuff Pressure in 100 % and 50 % Nitrous Oxide

The intracuff pressure of PVC and LR cuffs increased in both 100 % and 50 % nitrous oxide, with the lapse of time (Fig. 3A and B).

On the other hand, SR cuffs revealed no time-related pressure changes, and no difference occurred when the concentration of nitrous oxide was changed (Fig. 3C). The intracuff pressure was constantly fixed at 40 mmHg.

Changes in Intracuff Gas Component and of Concentration in 100 % and 50 % Nitrous Oxide

With 100 % nitrous oxide, the intracuff concentration of nitrous oxide in PVC and LR increased with time (120 min later: PVC 42.5 ± 1.1 %, LR 51.6 ± 0.5 %) and the nitrogen and oxygen decreased (Fig. 4A and B).

With 50 %, the increase of nitrous oxide concentration (120 min later: PVC 27.0 ± 1.0 %, LR 32.9 ± 1.3 %) and the decrease of nitrogen occurred with time and there was no change in concentration with oxygen (Fig. 4D and E).

In SR cuffs, the concentration of nitrous oxide was much higher than that of PVC and LR. With 100 % nitrous oxide, it was 90.0 ± 1.2 % at 15 min later, 92.2 ± 1.2 % at 60 min, and 96.0 ± 0.6 % at 120 min respectively (Fig. 4C). The nitrogen and oxygen decreased to 15.2 ± 1.0 %, and 3.9 ± 0.4 %, even in 15 min.

With 50 % nitrous oxide, the concentration of nitrous oxide reached 47.5 ± 0.8 % at 45 min later, while that of oxygen was 44.6 ± 0.6 %, at the same time (Fig. 4F). Changes were nil thereafter with these two gases. Nitrogen decreased just as in the case of 100 % nitrous oxide.

DISCUSSION

The reasons we use a cuff together with an endotracheal tube are: 1) Under general anaesthesia and ventilatory administration, cuffs prevent gas leakage and enhance an effective ventilation. 2) Cuffs prevent aspiration.

On the other hand, the use of cuffs often leads to complications. As the intracuff volume increases, the intracuff pressure increases, except for silicone rubber cuffs. As there is an pressure, the extent of the pressure, the cuff presses against the tracheal wall. Depending on the extent of the pressure, complications vary from erosions, inflammation, ulcer, scar, constriction, desquamation and fusing of tracheal cartilage, to oesophagotracheal fistula, and such (6-8). Due to intracuff volume increase, cuffs over-expand, inviting airway occlusion(9)

Table I. MOLECULAR WEIGHT, SOLUBILITY TO LIQUID PHASE AND DIFFUSION RATE COMPARED WITH OXYGEN, OF VARIOUS GASES

Gas	Molecular weight	Solubility at 37°C (mlSTPD/ml) per atm	Diffusion rate compared with oxygen
Oxygen	32	0.0239	1.00
Carbon dioxide	44	0.567	20.3
Helium	4	0.0085	1.01
Nitrogen	28	0.0123	0.55
Nitrous oxide	44	0.388	13.9

modified from "Basic and Clinical Artificial Ventilation"(12)

and edema of the vocal cords(10).

The manner in which gas diffuses into cuffs is influenced by the range of gas partial pressure, the chemical affinity of gas toward the cuff membrane, the thickness of the cuff membrane, the structure of cuff material, and molecular weight of the gas(5). Each of nitrogen, oxygen, and nitrous oxide shows some difference in partial pressures between inside and outside of the cuff. When the cuff membrane is permeable, gases continue to diffuse until the partial pressure of each gas is equalized(11). As a consequence, gases flow into the cuffs. When the gases does not flow out of the cuffs, or if the flow-out volume is less than the flow-in volume, the intracuff gas volume increases. If the situation is opposite, the intracuff gas volume decreases. Intracuff gas volume of SR changes with the lapse of time, but intracuff pressure shows no time-related changes either in the case of 100 % nitrous oxide or in 50 % nitrous oxide. With the PVC and LR, when intracuff gas volume increases, and the intracuff pressure increases markedly. At this point intracuff gas volume of LR is somewhat greater than that of PVC(Fig. 2). The thickness of PVC cuffs is 0.16 mm, LR 0.29 mm and SR 0.29 mm. As the cuff membrane of LR is somewhat thicker than that of PVC, permeability to nitrous oxide is: SR>LR>PVC. As for SR, under 50 % nitrous oxide, permeability to oxygen was equal to that the of nitrous oxide. On the other hand, with the PVC and LR, although the concentration of intracuff oxygen remained unchanged when the intracuff gas volume increased, the oxygen volume increased much more than the initial volume, thereby indicating that the oxygen had diffused. The oxygen volume was larger on PVC than on LR. As for nitrogen, it diffused on SR. In the case of PVC and LR, though the concentration of intracuff nitrogen decreased, the gas volume changed little. Decreases in the concentration are probably due to gas dilution(Figs. 2, 4). Stanley et al. (5) reported that among nitrous oxide, oxygen, and nitrogen, the first is the largest in its diffusion rate even though the molecular weight is the largest,(because of the difference in solubility into the cuff membrane), and that, nitrogen, in spite of the molecular weight being the smallest, diffusion rate is the smallest. Table I shows molecular weight and solubility of various gases to liquid phase (12). In the case of PVC and LR, under nitrous oxide, the intracuff pressure increased in proportion to the concentration, while with SR, the pressure was constant at 40 mm Hg. This shows that the compliance of SR is extremely large. As the permeability of SR is extremely good not only to nitrous oxide but also to oxygen and nitrogen, the gas diffusion and the changes of gas volume take place over a shorter period of time, compared with those of PVC and LR. This is one of the characteristics of SR. Under condition of 100 % nitrous oxide, conspicuous changes were observed: As for intracuff gas volume, the concentration of nitrous oxide rapidly increased until it passed 30 min, amounting to about 6 times the control value. Thereafter, however, in spite of the fact that nitrous oxide concentration continued to increase, the cuff gas volume decreased, to about 3 times the initial gas volume 2 hours later. In spite of the increase in intracuff gas volume, the intracuff pressure remained constant and the cuff material was considered to have been stretched and its surface area was considerably enlarged. It can be concluded that the fine structure of the membrane has changed and that nitrous oxide become permeable by the intracuff pressure. According to the above changes in gas volume, not only oxygen and nitrogen escaped from the cuffs but also intracuff nitrous oxide flowed out due to diffusion.

On the other hand, since the concentration of intracuff nitrous oxide increases with time, the difference of the partial pressure between inside and outside of cuffs decreased, and less nitrous oxide flowed in. With time, intracuff oxygen and nitrogen flowed out until it became 100 % nitrous oxide. At that time, providing that the nitrous oxide is compressed by the intracuff pressure, the partial pressure of intracuff nitrous oxide increases until it diffuses outside of the cuffs. Stanley et al. (5) reported that after filling 10 ml air into LR cuffs and then exposing them under 100 % nitrous oxide, 12 hours later, the intracuff gas volume had increased to 41 ml, that is about 4 times the initial gas volume, and that thereafter it decreased, getting down to 6.1 ml 48 hours later. Therefore, great care should be taken in the choice and manipulation of endotracheal cuffs.

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