Nitrous Oxide and Air-filled Balloon-tipped Catheters

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The differential solubilities of gases permit nitrous oxide (N_2O) diffusion into air-filled body cavities, increasing their size and/or pressure. An air-filled balloon-tipped catheter represents a body cavity that may be affected by the diffusion of N_2O, and could account for the authors' clinical observation that more gas was aspirated than injected during insertion of Swan-Ganz (S-G) catheters in patients receiving N_2O anesthesia. An accompanying increase in balloon diameter could conceivably account for difficulties in floating the tip into the pulmonary outflow tract. To help substantiate these observations, balloon volumes of three S-G catheters were measured at 0.5, 1, 2, 3, 4, 5, 10, 20, and 30 min in various N_2O and oxygen mixtures, and the diameters of the balloon were compared with published diameters of pulmonary outflow tracts. The volume changes were near maximum between 5–10 min, increasing to 30 to 150 per cent depending on the N_2O concentration. The increases in balloon diameter, when compared to pediatric pulmonary outflow tract diameters, could account for difficulties in passage of the catheter tip through the pulmonary outflow tract. These findings suggest that manipulation of S-G catheters under N_2O anesthesia should be done with intermittent deflation of the balloon every few minutes. (Key words: Anesthetic gases: nitrous oxide. Equipment: catheters, Swan-Ganz.)

DURING THE PLACEMENT of Swan-Ganz (S-G) catheters in patients receiving nitrous oxide (N_2O) anesthesia, we have observed that more gas volume was withdrawn from the balloon than was initially injected. We postulated that N_2O had diffused into the balloon causing an increase in volume. This study was designed to evaluate the effect of N_2O on the volume of the air space of the S-G catheter balloon.

Materials and Methods

Calibrated flow meters were used to deliver air or N_2O/oxygen (O_2) mixtures of 0/100 per cent, 25/75 per cent, 34/66 per cent, 50/50 per cent, 66/34 per cent, and 75/25 per cent into a 1.5 l container in which

a #7-French S-G catheter§ was placed. To verify the composition of gases being delivered an O_2 analyzer¶ was used; total flow rates of 1–2 l/min were used. The S-G balloon injection port was connected to a transducer** and pressure amplifier with digital display.†† Prior to each inflation, the S-G balloon was deflated until the amplifier reading was zero. This allowed return of the balloon to a neutral deflated configuration preventing excessive aspiration.

One ml (±0.025 ml) of air was injected into the S-G balloon with a precision gas tight syringe.‡‡ The same syringe was used to measure the volume aspirated from the S-G balloon. The time period from injection to aspiration was measured with a stopwatch. The S-G balloon and transducer dome were cleared of residual N_2O and O_2 by flushing with air between each determination. Balloon volume measurements were made with three different S-G catheters. Three measurements were made for each time interval.

The predicted increase in volume of the S-G balloon for the given concentration of N_2O was calculated as follows: the maximal increase in volume of an air-filled space exposed to a N_2O/O_2 mixture is

$$\frac{100}{100 - \text{per cent } N_2O \text{ in the environment}}$$

which is the multiple of the original that can be achieved.[1] The value obtained from this calculation was compared to the maximal volumes measured experimentally.

Results

The volume changes obtained from the three S-G balloons after exposure to various inflowing gas concentrations were compared to the predicted volume changes (fig. 1). The balloon volumes: 1) decreased in the air environment in all the catheters; 2) increased above the predicted values for all the catheters in the 25 per cent N_2O/75 per cent O_2 environment; 3) in-

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§ Edwards Labs, Inc., Santa Ana, California.
¶ Polaragraphic O_2 Analyzer 401®, Jewell Electronic Instruments, Inc., Model 82 T.F.S. 100 UADC 2082 1935·145.
** Bentley Trantec, Inc., Irvine, California.
†† Hewlett-Packard® Pressure Amplifier and Readout, Model 78201B.
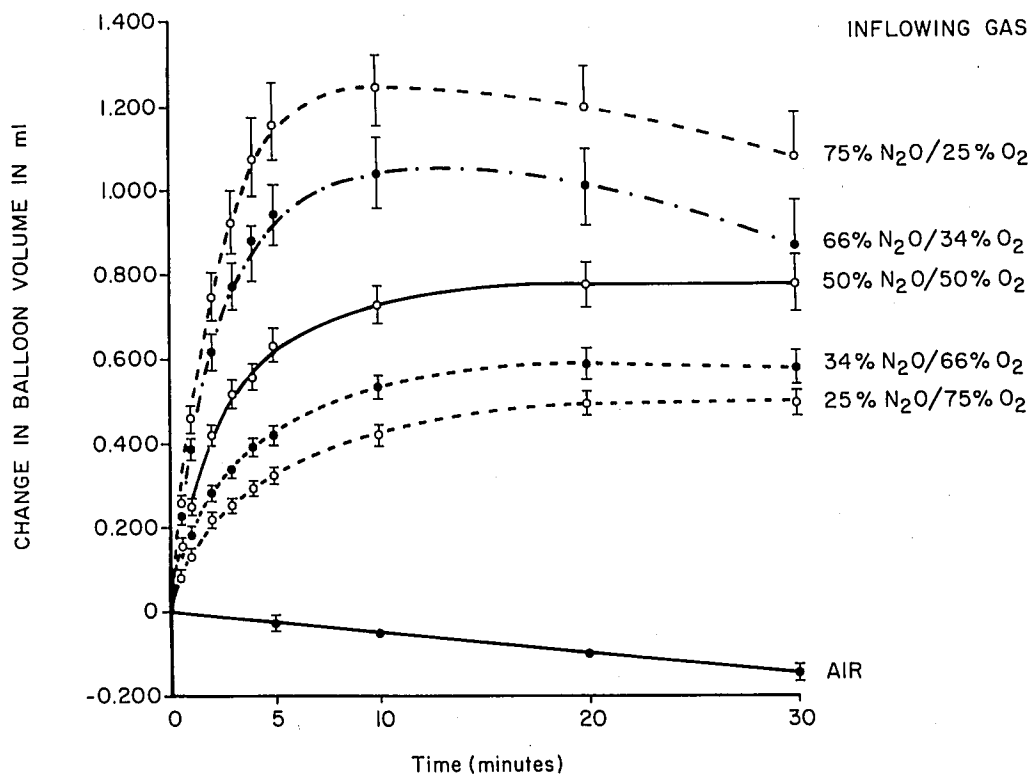‡‡ Hamilton Company, Reno, Nevada.

FIG. 1. The change from the initial 1-ml S-G balloon volume with time for the indicated inflowing gas concentration in three S-G catheters. The times listed are the duration of exposure of the air-filled balloon to the inflow mixture. The means ± SEM of three determinations in each catheter at the specified time are plotted. The $P < 0.001$ between the initial volume and each volume plotted, as per Student's t test.

creased above the predicted in two of three catheters in the 34 per cent N_2O/66 per cent O_2 environment while the other catheter had the predicted volume; 4) had the predicted values for one catheter and below the predicted value for two catheters in the 50 per cent N_2O/50 per cent O_2 environment; and 5) had less than the predicted volumes for all catheters in 66 per cent N_2O/34 per cent O_2 and 75 per cent N_2O and 25 per cent O_2 environments.

In a 100 per cent O_2 environment, all three S-G balloon volumes increased from 1 ml to a mean of 1.258, 1.350, and 1.500 ml each after 30 min. When the balloon was filled with 1 ml of gas of a composition identical to that in the environment (75 per cent N_2O, 25 per cent O_2) and observed for 30 min, two of the three showed decreases in their volumes (mean values of 0.650 and 0.792 ml). The other catheter did not change in volume.

TABLE 1. The Diameters of the Swan-Ganz Balloon with Corresponding Volumes Used for Inflation*

Inflation Volume (ml of air)	Balloon Diameter (mm)
0.0	2.34
0.2	2.34
0.4	2.41
0.6	2.67
0.8	2.92
0.9	9.91
1.0	10.16
1.2	11.56
1.5	12.70

* Data courtesy of P. J. Carter, Product Manager, Edwards Laboratories, Santa Ana, California.

Table 1 lists the diameters of the S-G balloon which correspond to a certain inflation volume. This shows a large and abrupt increase in balloon diameter between 0.8 and 0.9 ml of balloon volume.

Table 2 lists the relationships of age, height, and pulmonary ring diameter in children based on published data. Also included is the pulmonary ring diameter when the area of the normal pulmonary ring is reduced by one-half.

Discussion

Expansion or increase in pressure of a gas containing space within the body by N_2O has been well documented.[1] In the last few years interest in air-filled endotracheal tube cuffs has led to an appreciation of further potential hazards of N_2O.[2,3] The potential adverse effects of N_2O on the intraoperative use of S-G catheters have not been considered since their introduction into clinical practice. The #7-F S-G catheter was examined in this study because this is a commonly used size and proved sufficient to demonstrate the effects of N_2O.

In this experiment, the S-G balloons were placed in a gas-filled container. This does not negate the relevance of the observations made in this study to the clinical situation where the S-G catheter is placed in blood. The principles of diffusion due to a concentration gradient across two compartments separated by a membrane would still apply. The design of this experiment allowed a simplified approach to the evaluation of the diffusion of N_2O into S-G catheter balloons.

The onset of near maximal volume expansion occurred within 5–10 min following exposure to N_2O; this is well within a clinically relevant time period for most users of S-G catheters.§§ At any given N_2O/O_2 mixture, each of the S-G balloons evaluated expanded to a different degree. This is probably due to variations in the placement of the balloon on the catheter, the quality of the latex used for the balloon, and aging and deterioration of the latex. Properties of gaseous diffusion through synthetic material have been discussed elsewhere.[2]

Diffusion of air from within the balloon across a pressure gradient would explain the decrease of balloon volume in the air environment.¶¶ The balloon volume increased above predicted values in the 25 per cent $N_2O/75$ per cent O_2 and 34 per cent $N_2O/66$ per cent O_2 environment, presumably due to oxygen diffusion into the balloon. This possible mechanism was verified when the balloon volume increased in the 100 per cent O_2 environment.

Changes in the S-G balloon volume is associated with a nonlinear change in its diameter (table 1). The diameters were determined for volumes up to 1.5 ml since this is the maximum inflation volume recommended by the manufacturer. Hurwitt[4] tabulated the normal measurements of the pulmonary valve in children from autopsy reports. Based on information described in Mercer's article,[5] a 50 per cent reduction in pulmonary ring area would produce only small hemodynamic changes and no change in exercise tolerance. It is therefore possible that pediatric patients with smaller than normal pulmonary ring diameters may not be detected prior to insertion of a S-G catheter, and that the magnitude of the volume increases measured in our study could cause problems in passage of the catheter into the outflow tract. (Compare tables 1 and 2.) In addition, if expansion occurred over and around the catheter tip, problems may possibly occur with reading waveforms or with movement of fluid through the orifice.[6,7]

Use of the inspired gas mixture as the inflation medium for the balloon to prevent balloon expansion was evaluated using 75 per cent $N_2O/25$ per cent O_2. In two of the catheters, the volume of the balloon (and hence the diameter) decreased when the inflowing gas was used as the inflation medium. The fact that one catheter showed little change was surprising. One would have anticipated (as with the studies using air only) that the gas, under higher pressure in the balloon, would diffuse out. These results support the use

of the inspired gas mixture as the injectate to prevent balloon expansion when placing catheters in patients during N_2O/O_2 anesthesia. Use of a liquid medium for balloon inflation as an alternative is not recommended by the manufacturer, as it may be difficult to withdraw all of the solution and thus the balloon may remain inflated. In addition, if liquid is used to inflate the balloon, the flow-directed character would be decreased since the density of any liquid would be closer to that of blood and the advantage of a gas-filled balloon would be negated in "floating" the catheter. In conclusion, if balloons are filled with air during placement under N_2O anesthesia, they should be deflated every few minutes. This may be particularly critical in children.

TABLE 2. Relationship of Age and Height to Pulmonary Ring Diameter

Age	Height (cm)	Pulmonary Ring Diameter	
		Normal (mm)*	50 Per Cent Area (mm)†
3–6 mos	59	9	7
6–9 mos	65	10	7–8
9–18 mos	68–75	11	8
18–24 mos	81	12	8–9
2–3 yr	88	13	9
3–5 yr	97–105	14	10
5–7 yr	112–119	15	10–11
7–9 yr	124–128	16	11–12
9–11 yr	127–130	17	12
11–13 yr	138–151	18	13‡
13–14 yr (one case)	168	22	16‡
14–15 yr (one case)	165	20	14‡
15–16 yr (two cases)	140	19	13–14‡

* Data from Hurwitt[4] and † Mercer[5] except for ‡ values which were determined by the authors. Except where indicated in parentheses, the values were averages of five or more cases.

References

1. Eger EI: Anesthetic uptake and action. Baltimore, Williams and Wilkins, 1974, pp 171–183
2. Stanley TH, Kawamura R, Graves C: Effects of nitrous oxide on the volume and pressure of endotracheal tube cuffs. ANESTHESIOLOGY 41:256–262, 1974
3. Ravenos B, Lindholm CE: Pressure and volume changes in tracheal tube cuffs during anesthesia. Acta Anesthesiol Scand 20:321–326, 1976
4. Hurwitt E: The size of the pulmonary valve. Bull Int Assoc Med Museums 27:170–172, 1947
5. Mercer JL: Acceptable size of the pulmonary valve ring in congenital cardiac defects. Ann Thorac Surg 20:567–570, 1975
6. Shin B, Mc Aslan TC, Ayella RJ: Problems with measurement using the Swan-Ganz catheter. ANESTHESIOLOGY 43:474–476, 1975
7. Shin B, Ayella RJ, Mc Aslan TC: Pitfalls of Swan-Ganz catheterization. Crit Care Med 5:125–127, 1977