A STUDY OF DENITROGENATION WITH SOME INHALATION ANESTHETIC SYSTEMS * †‡

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The presence of nitrogen as a large component of alveolar gas is a hindrance to the establishment of high tensions of oxygen or anesthetic agents in the alveoli. This is of importance in anesthesia since it not only makes suboxygenation possible (1, 2), but in addition prevents the maximum utilization of impotent anesthetic agents, thereby necessitating larger amounts of supplemental non-volatile drugs. Recent work regarding the uptake of nitrous oxide in man re-emphasizes the importance of maintaining high alveolar tensions of this gas to accomplish induction and maintenance of nitrous oxide anesthesia (3, 4). The tension of nitrous oxide is lowered if nitrogen is present in the alveoli as a diluent gas. It also is lowered if the volume of anesthetic gas is supplied to the body at a rate lower than the uptake of the gas by the body. Because of this, rebreathing of expired gases from which a large portion of nitrous oxide has been removed will prolong the time required to accomplish adequate saturation for anesthesia.

The rate and degree of denitrogenation is determined by two factors: (1) the degree of ventilation of the alveoli, and (2) the tension of nitrogen present in the inhaled atmosphere. A nitrogen tension of zero in the inhaled atmosphere is optimum for denitrogenation. The degree of ventilation may be decreased by respiratory disease, depressant drugs, airway obstruction, and by abnormal positions which interfere with adequate respiratory exchange. The degree of ventilation may be increased by pain stimuli, carbon dioxide retention, or by assistance to respiration which increases respiratory exchange. The amount of nitrogen in the inhaled atmosphere is influenced by the amount of rebreathing of expired air or ingress of ambient air. Rebreathing may occur with a low flow of gases from the anesthetic machine, incompetency of valves, and large dead space.

It was the purpose of this study to investigate denitrogenation by new methods of analysis (5). These methods provide material for teaching the rate and pattern of denitrogenation, using various anesthetic techniques, and for illustrating the degree of contamination of

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anesthetic atmosphere with nitrogen which may occur under various circumstances.

**Method**

Normal human volunteers were fitted with a standard Connell anesthesia face piece strapped tightly to the face in such a manner that no leaks could be detected with maximum voluntary expiratory pressure. The gas added to the system was 99.7 per cent oxygen. Nitrogen concentrations in the mask were sampled continuously by use of a Lilly nitrogen meter and recorded by a Sanborn direct-writing re-

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<th>Method</th>
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<td>Semi-closed, small Reservoir, 10 LPM flow</td>
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<td>Non-rebreathing</td>
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Mean = Time, in seconds, to reach stated level of nitrogen in expired air.
S.D. = Standard deviation.
n = Number of trials.

corder. Recordings were made using the following standard anesthetic systems:

1. Non-rebreathing.
2. Semi-closed, small reservoir (consisting of face-piece, elbow, breathing bag of 3 liter capacity with 10 liters per minute flow).
3. Semi-closed, large reservoir (consisting of face-piece, elbow, breathing bag of 5 liter capacity with 10 LPM flow).
4. Circle system (Heidbrink 9B):
   a. Closed.
   b. Semi-closed with 1, 2, 3, 4, 5, and 10 LPM flow.

The time required to lower the nitrogen concentration in the expired gas was measured. The effect of inward leaks or ingress of
air was investigated, using a subject following denitrogenation to a level of 5 per cent in expired gas. The leak was effected in three ways: (1) the subject took one normal breath of air, (2) a small leak was created by inserting a 15 gauge needle through the face-piece, and (3) the subject inspired deeply while using the semi-closed inhaler with the tail of the small reservoir bag open.

**RESULTS**

The data obtained are presented in table 1 and in figures 7 and 8. Representative tracings are shown in figures 1 through 6.

The interpretation of the data may be made both on the pattern of the tracing and the time required for denitrogenation.

*Figure 1* shows the tracing as obtained with a non-rebreathing system. In this tracing the low point of the cycle (inspiration) touches the base line indicating the absence of nitrogen in the inspired gas. It can be noted that this portion of the curve remains in contact with the baseline until expiration starts. This indicates the absence of re-breathing.

*Figure 2* is a tracing obtained with a semi-closed inhaler using 10 liters per minute flow. When this is compared with figure 1, a difference is noted in the inspiratory phase. At the first inspiration nitrogen concentration approaches zero, but with the few succeeding inspirations an appreciable concentration of nitrogen is inspired as indicated by the failure of the curve to reach the base line. Since ingress
of room air was avoided, the only source of this inspired nitrogen is from the expired gas of the preceding breath. This indicates the presence of some degree of rebreathing.

Figure 3 was obtained using the circle system with a 10 LPM. The inspiratory phase reveals a lower nitrogen tension than figure 2, indicating less rebreathing. However, the last portion of the inspiratory phase shows a step-like increase in nitrogen tension. This represents

the nitrogen from the previous expiration which has moved around the circle and is rebreathed, whereas the beginning portion of the inspiratory phase is lower because fresh gas being supplied to the circle is inspired first.

Figures 4 and 5 indicate the increase in the amount of rebreathing and the resulting prolongation of the denitrogenation time which oc-

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**Fig. 3.** Mask nitrogen concentrations occurring with the circle system, 10 LPM flow. At the arrow, the subject was given one breath of room air.

**Fig. 4.** Mask nitrogen concentrations occurring with a closed circle system. Arrows indicate emptying and refilling of 5 liter reservoir bag.

**Fig. 5.** Mask nitrogen concentrations occurring with semi-closed circle system using low flow. Arrow indicates 6 minutes elapsed time.
curs with lower flows. Figure 4 also shows the effect of emptying and refilling the bag with oxygen on lowering the nitrogen tension. This is only an effect of the resulting increase in the total flow.

Figure 5 indicates the nitrogen tensions which would occur when using a "500-500" cc. flow of nitrous oxide and oxygen. Although oxygen tensions of inspired gas have been found adequate with this technique (6), the degree of rebreathing would make this an inefficient means of supplying the large amounts of nitrous oxide necessary for saturation of the body.

The degree of contamination of the anesthetic mixture with nitrogen from inward leaks is shown in figures 3 and 6.

Figure 6. A similar recording was obtained if the patient inspired very deeply when the semi-closed system small reservoir was used and the tail of the bag left open.

Fig. 7. Graph showing the average denitrogenation curves of the various systems tested.
The contamination with nitrogen which occurs with these leaks not only decreases the oxygen tension of the inspired gases, but may reverse the gradient of nitrous oxide tensions between blood and alveoli. This latter event will decrease the rate of nitrous oxide uptake during induction and add to the decrease of oxygen tension in the alveoli during maintenance (7).

Figures 7 and 8 show the average denitrogenation curves of the various systems tested (fig. 7), and of the semi-closed system using 1, 2, 3, 4 LPM flows (fig. 8).

DISCUSSION

The denitrogenation time must be evaluated very carefully because the volume of respiratory exchange of the subject significantly alters the time required for denitrogenation. For example, the rate of denitrogenation with the semi-closed inhaler without carbon dioxide absorption may differ from an absorption system using comparable flows, because rebreathing of small amounts of carbon dioxide may alter ventilatory volumes and increase the rate of nitrogen elimination. It appears that, as would be expected, the rate of denitrogenation is affected by the rate of flow of gases more than by the system used. It also appears that with flow rates of 4 liters per minute or more, satisfactory denitrogenation occurs in approximately three minutes or less. The decreased time of denitrogenation using flows in excess of 5 LPM is small and probably would not justify the expense of larger amounts of gas for this purpose alone.
SUMMARY AND CONCLUSIONS

Using normal non-medicated volunteers the rate and pattern of denitrogenation was studied by means of the Lilly Nitrogen Meter. Tracings were obtained with non-rebreathing, semi-closed inhaler and circle systems at various rates of gas flow. The tracings were evaluated both as to time of denitrogenation and as to shape of the cycles. The inspired nitrogen tension was used as an index to the amount of rebreathing which occurred in the various systems. The effect of leaks of room air into the system was shown.

There appears to be no clinical advantage in the use of gas flows above 4 liters per minute for the purpose of denitrogenation. No clinical advantage in denitrogenation rate was demonstrated for any one of the various anesthetic systems studied if the flow rate was maintained above 4 LPM.

REFERENCES