Inspired humidity in anaesthesia breathing circuits: comparison and examination of effect of Revell circulator

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Humidity levels of respired gases in spontaneously breathing patients were measured with a quadrupole mass spectrometer (Medishield Model MS-2) and compared between various anaesthetic systems during clinical anaesthesia. In studies of high flow rebreathing non-absorption systems the mean inspired absolute humidity averaged approximately 16 mg·l^{-1} (range 14.7 to 16.1 mg·l^{-1}) compared to a semiclosed circle absorption system (BOC MK III) in which values for absolute humidity varied from 6.8 ± 5.1 mg·l^{-1} for children through 9.5 ± 3.0 mg·l^{-1} for adults), and the closed circle absorption system in which values of 20.5 ± 2.3 mg·l^{-1} were only gradually reached. Addition of a functioning Revell circulator to the circle absorption system provided immediately markedly higher levels of inspired humidity during clinical use, either semiclosed (15.4 ± 5.1 mg·l^{-1} in children to 18.8 ± 2.4 mg·l^{-1} in adults), or closed (23.3 ± 1.8 mg·l^{-1} in adults). These markedly higher inspired levels of absolute humidity were attained during forced circulation of respired gas provided by the Revell circulator without the concomitant disadvantages of rebreathing or the potential hazards associated with some humidifying devices.

Key words

EQUIPMENT, CIRCUITS: Magill, Bain, Lack, T-piece, circle; EQUIPMENT: Revell circulator; HUMIDIFICATION: anaesthetic breathing circuits.

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There is general agreement on the need for humidification of dry gases for patient respiration in the intensive care unit but there is often less attention to the comparable need for humidity during clinical anaesthesia. Prolonged inhalation of dry gases has been shown to damage the structure and function of the mucosa of the respiratory tract[1,2] and may produce a decrease in lung compliance.[3] Adequate humidification may prevent the tendency toward hypothermia under anaesthesia[4,5] and is purported to decrease the incidence of postoperatie pulmonary complications.[6] Consequently, the degree of humidity attained in the gas mixture inhaled by the patient is an important factor to be considered in the selection of breathing system for clinical use and in the evaluation of the design and performance of anaesthetic apparatus.

Previous studies of humidity in anaesthetic systems have been done usually with intermittent sampling and measurement by hygrometric methods. Most of these studies have been on analogues rather than under actual conditions of clinical anaesthesia[6,7] The use of a mass spectrometer as reported in a study of conscious volunteers breathing through various anaesthetic systems[8] allows continuous dynamic assessment of water vapour tension together with the possibility of concomitant measurement of respired gases and anaesthetic vapours. This further study was undertaken to measure and compare inspired humidity levels occurring in patients during clinical anaesthesia while breathing spontaneously through various currently used anaesthetic circuits. A major purpose was to document during anaesthesia the effect on attained inspired humidity levels of forced circula-

tion of respired gases through the circle absorption system by using a functional Revell circulator and a divided chimney at the mask.[9]*

Methods

The patients studied included both adults and children and were in ASA physical status classification category I, undergoing relatively short urologic procedures. Spontaneous respiration was maintained throughout light general anaesthesia with nitrous oxide oxygen and halothane.

The systems studied included: Magill (Mapleson A), Bain (Mapleson D), Lack (Mapleson E)[10] Jackson-Rees modification of Ayre's T-piece (Mapleson D), and a circle absorption system (BOC Mark III) which was used both semiclosed and closed. In the circle absorption system paired studies were made on each patient with and without the Revell circulator and divided chimney incorporated into the circuit. The Revell circulator was adjusted to propel the gases within the circle system at a speed just sufficient to float the directional valves. Where possible without prolonging the anaesthetic or interfering with clinical care, all the different systems were tried sequentially on the same patient. Details of anaesthetic management were controlled by clinical anaesthetists not directly involved in the study. Consequently in non-absorption systems fresh gas flows varied from 6 to 9 $l \cdot min^{-1}$ according to individual anaesthetist's practice. The semiclosed circle absorption system, however, was consistently used with a fresh gas flow of 5 $l \cdot min^{-1}$ and the closed circle absorption system with only maintenance flow of about 200 ml oxygen per minute and addition of anaesthetic as needed for uptake.

Respired gases were continuously sampled at 30 $ml \cdot min^{-1}$ through a short heated catheter probe for the measurement of partial pressures of water vapour, anaesthetic vapour, oxygen and carbon dioxide using the Medishield quadrupole mass spectrometer (Model MS-2) and multiplexer with the output being recorded on an Elkomatic 4 channel chart. Calibration of water vapour tension was done before and after each study against both dry gas at room temperature and saturated water vapour above the surface of two water baths which were heated to approximately 26°C and 34°C respectively. Delay time for respired gases was 150 msec and for water vapor was approximately eight seconds. Temperature was measured with a previously calibrated Yellow Springs thermistor probe. In order to avoid an alteration in circuit configuration and the imposition of additional apparatus deadspace, a sampling block was constructed with an internal capacity no greater than that of a catheter mount or angle piece and which could simultaneously house the thermister and mass spectrometer probes. In the high flow non-absorption systems this sampling block was inserted instead of the usual connection between the circuit junction and mask or endotracheal tube. In the circle absorption system sampling was done from the inspiratory side of the chimney Y-piece. For comparison inspired values of water vapour tension were taken after apparent steady state levels were attained in each system. Measured partial pressures of water vapor were later converted to both absolute humidity and relative humidity values at the observed temperature with the aid of tables of saturated vapour pressure of water.[11] From the several observations with each system of equipment mean values were compared by Student's t test. Means and standard deviations are reported.

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Results

In all systems an initial rapid shift in inspired humidity was demonstrated. This was followed by a slower adjustment to a steady level of inspired humidity usually attained within 15 minutes except in the conventional circle absorption system in which the humidity level would continue to rise slowly for an hour or more. In the non-absorption rebreathing systems, where the recorded tracing clearly demonstrated the cyclic pattern of inspiration and expiration an average inspired water vapour pressure was selected with due regard for the observed respiratory waveform. From inspection of flow rate patterns in the non-absorption circuits it was determined that average inspired water vapour pressure levels were approximately 25 per cent above the lowest value observed in the respiratory cycle. Inspired absolute humidity levels calculated from observations of subjects on the Magill circuit ranged from 8.6 to 20 $mg \cdot l^{-1}$ depending on a number of factors including the relative volume of fresh gas flow and the extent of rebreathing.

When humidity levels in the Bain and Magill circuits were compared at equal fresh gas flow rates

TABLE I Comparison of inspired humidity levels observed in various systems during anaesthesia of spontaneously breathing children

System	*Airway temperature °C (±SD)*	*Vapour pressure of water mmHg (±SD)*	*Range of relative humidity %*	*Absolute humidity mg·l⁻¹ (±SD)*	*N*
Jackson-Rees	32.6 ± 2.8	17.1 ± 2.7	42–65	16 ± 2.2	12
Magill	31.2 ± 2.9	17.2 ± 1.7	42–68	16.1 ± 1.5	5
Lack	32.2 ± 1.0	16.8 ± 3.6	37–68	15.9 ± 3.6	5
Semi-closed circle absorption, no circulator	29.3 ± 5.5	7.2 ± 5.5	4–32	6.8 ± 5.1	5
Semi-closed circle absorption with circulator	28.9 ± 5.6	16.4 ± 5.8	48–64	15.4 ± 5.1	5

in adult patients the inspired absolute humidity in the Magill circuit averaged 14.7 ± 3.3 mg·l^{-1} while that in the Bain circuit averaged 15.9 ± 3.4 mg·l^{-1}. The Lack, Magill and Jackson-Rees circuits were compared in children at equal fresh gas flow rates of twice to three times estimated minute volume and the absolute humidity averaged 15.9 ± 3.6 mg·l^{-1}, 16.1 ± 1.5 mg·l^{-1} and 16 ± 2.2 mg·l^{-1} respectively (Table I).

Inspired humidity levels attained in the semiclosed circle absorption circuit were always much lower than those in the high flow non-absorption rebreathing systems and ranged from a mean of 6.8 ± 5.1 mg·l^{-1} in children to 9.5 ± 3.0 mg·l^{-1} in adults. When a functioning circulator was added to the semiclosed circle absorption system a considerable immediate increase in inspired humidity level was produced. In general the absolute humidity values actually doubled as an effect of the circulator. For ease in interpretation and comparison with previous studies[6,7] these observations of partial pressure water vapour in the semiclosed circle absorption system are presented on a graph which shows the relationship between temperature, water vapour pressure and relative humidity as well as absolute humidity in mg·l^{-1} (Figure). Among the conventional systems the highest humidity levels of all were obtained in the closed circle absorption system where an average inspired absolute humidity level of 20.5 ± 2.3 mg·l^{-1} was observed. Even these levels of humidity were further increased in immediate response to the circulating flows of a Revell circulator (Table II).

Discussion

Humidity levels in anaesthetic circuits depend on a number of factors. In general the level of humidity inspired from the high flow non-absorption systems depends on the configuration of the circuit and the degree of mixing of expired gases with fresh gas flow. When fresh gas flow is increased to avoid hypercarbia and hypoxia the observed levels of humidity fall and conversely humidity levels will rise if rebreathing increases.

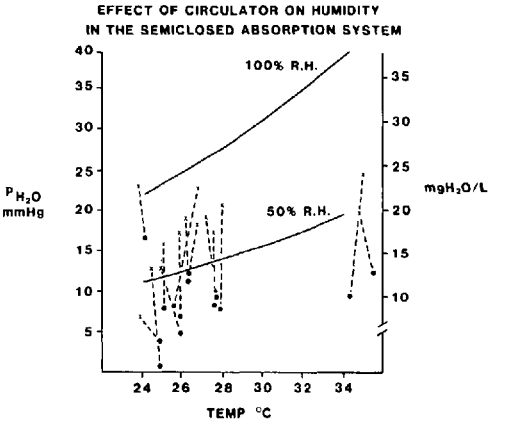

FIGURE Effect of the Revell circulator during use of the semiclosed circle absorption system (B.O.C. Mark III). Dotted lines show increase of inspired humidity measured in individual patients. • = lower value in each pair is before use of circulator. X = upper value is observed humidity with functioning circulator. The change is highly significant, $p < 0.001$.

TABLE II Comparison of inspired humidity levels sampled from various systems during anaesthesia in adults

System	*Airway temperature °C (±SD)*	*Vapour pressure of water mmHg (±SD)*	*Range of relative humidity %*	*Absolute humidity $mg \cdot l^{-1}$ (±SD)*	*N*
Magill	28.3 ± 2.3	15.5 ± 3.5	34–69	14.7 ± 3.3	15
Bain	27.5 ± 0.3	16.9 ± 3.5	65–75	15.9 ± 3.4	6
Semi-closed circle absorption, no circulator	26.4 ± 1.3	10.0 ± 3.1	32–55	9.5 ± 3.0	9
Semi-closed circle absorption with circulator	26.4 ± 1.3	19.6 ± 2.5	60–106	18.8 ± 2.4	9
Closed circle absorption, no circulator	27.9 ± 0.9	21.6 ± 2.4	65–75	20.5 ± 2.3	5
Closed circle absorption with circulator	28.2 ± 0.7	24.4 ± 2.0	75–100	23.3 ± 1.8	5

In the circle absorption system moisture is available from three sources: (1) that present in exhaled air, (2) that incorporated in the soda lime granules,[12] and (3) that amount liberated by the chemical reaction between carbon dioxide and soda lime. In the semiclosed circle absorption system due to the introduction of fresh gas flow on the inhalation side of the circuit and the presence of directional valves, the inspired tidal volume contains a high proportion of fresh gas, there is little mixing of expired air with fresh gas and consequently inspired humidity levels are lower than those obtained in the high flow non-absorption rebreathing circuits. However, use of the Revell circulator in the semiclosed absorption system to provide forced circulation of respired gases around the circle dramatically increases inspired humidity to about twice the level otherwise obtained. The increase in inspired humidity is due to a number of factors including mixing of respired gases and thereby a reduction of the effect of the fresh gas flow and to the greater mobilization of moisture from the hydrate of soda lime[12] as a consequence of the recirculation of respired gases through the absorber. In the closed circle absorption system the gradual attainment of high humidity levels is a known feature but here also forced circulation of respired gases by the Revell circulator can almost immediately increase the inspired humidity to maximal levels.

The levels of inspired humidity found in this study in the high flow non-absorption systems, in the semiclosed circle absorption system and in the closed circle absorption system are similar to findings of other authors despite differences in manner of measurement and the fact that the other studies involved analogue models and/or mechanical ventilation. This study provides new information that inspired humidity is markedly increased by use of a Revell circulator in the circle absorption system (either closed or semiclosed) and that the levels attained equal or exceed the observed levels in non-absorption systems at clinically used fresh gas flow rates. The finding that in a semiclosed absorption system a functioning circulator increases inspired humidity from below optimum[6,7] to approach maximal levels is especially pertinent because of the widespread frequent use of the semiclosed absorption system in North America.

Studies of apparatus deadspace have shown that the presence of a functioning Revell circulator and divided chimney in the circle absorption system removes the undermask deadspace and reduces the apparatus resistance.[13] It has now been shown in this study that the use of the Revell circulator also

provides increased humidity without the addition of special humidifying units. Since the increased humidity is accomplished without the imposition of rebreathing or other hazard to the patient this finding has important implications for the well being of patients in both adult and paediatric practice of anaesthesia.

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Résumé

A l'aide d'un spectromètre de masse, on a mesuré l'humidité absolue des gaz respirés spontanément à travers différents montages d'anesthésie par des patients sous anesthésie.

Pour les systèmes à grand débit de gaz avec réinspiration sans absorption de CO_2, l'humidité absolue moyenne était de 16 mg par litre (14.7 à 16.1 mg par litre). Pour le système demi fermé avec absorption (BOC MK III), ces mêmes valeurs étaient de 6.8 ± 5.1 mg par litre pour les enfants et 9.5 ± 3 mg par litre pour les adultes. Pour le système fermé avec absorption, l'humidité absolue parvenait graduellement à 20.5 ± 2.3 mg par litre. L'inclusion, dans les circuits avec absorption, d'un circulateur de Revell, élevait rapidement les niveaux d'humidité à 15.4 ± 5.1 mg par litre chez les enfants et à 18.8 ± 2.4 mg par litre chez les adultes pour le circuit demi fermé et à 23.3 ± 1.8 mg par litre pour le circuit fermé. Ces niveaux élevés d'humidité absolue sont possibles grâce au circulateur de Revell qui permet d'éviter les désavantages des systèmes avec réinspiration et les complications toujours possibles de certains appareils d'humidification.