POSTOPERATIVE PULMONARY COMPLICATIONS USING DRY AND HUMIDIFIED ANAESTHETIC GASES

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SUMMARY
A controlled double-blind study was undertaken to ascertain whether humidification of the anaesthetic gas altered the pulmonary complication rate as compared with dry gas, when administered in a non-rebreathing system to adult patients undergoing abdominal and/or transthoracic operations. Eighty-four patients, anaesthetized on an average for 5 hours, were studied. Sequential analysis showed that there was no significant difference in complication rate between the humidified and the non-humidified groups. The complications in both groups were all transient and harmless. Under the conditions of the study, no reason was found to add the potential risks associated with routine use of humidifiers during anaesthesia.

It has been found that the cilia of the tracheal mucous membrane of tracheostomized rats stop beating when exposed to dry air (Dalhamn, 1956). Ink markers placed in the region of the carina in anaesthetized dogs have been found to move upwards more slowly during ventilation with dry gases, than when gases saturated with water vapour were used (Burton, 1962). These findings, together with the benefits of humidification after tracheostomy and during long-term ventilator treatment, have led to the view held by a number of anaesthetists that inspired gas always should be humidified, at least during prolonged endotracheal anaesthesia in order to prevent pulmonary complications.

The use of humidification, however, may add some risks such as infection from the humidifier, increased airway resistance (Cheney and Butler, 1968), possible interference with surfactant (Johnson et al., 1964) and risk of water intoxication when ultrasonic nebulizers are used, scalding, hyperthermia and condensation of water in the airways, when the water vapour delivered from hot water humidifiers exceeds body temperature. As has been stated (Editorial, 1970), "the technological achievements of the nebulizer manufacturers may outstrip our clinical knowledge, to the extent that harmful effects on the lung may be caused inadvertently".

This paper is a report of a controlled clinical study designed to ascertain whether the rate or severity of postoperative pulmonary complications is influenced by humidification of the inspired gas and to ascertain whether the possible advantages of humidification are great enough to outweigh the risks.

MATERIAL AND METHODS
A consecutive series of patients subjected to elective surgery was studied. All patients undergoing abdominal and/or thoracic operations were included, excluding only those with radiological evidence of pulmonary consolidation or atelectases within the 3 days preceding operation (2 patients) and one patient with a tracheo-oesophageal fistula. The patients were allocated blindly to the humidified or non-humidified gas group according to random numbers and since the statistical evaluation was planned to be a sequential analysis (Armitage, 1960), their allocation numbers were "paired" beforehand.

Postoperatively the patients were cared for by staff who did not know to which group the patient belonged, and the postoperative X-ray films were evaluated by radiologists also unaware of the procedure used.

Transthoracic operations were performed for diseases in the oesophagus or stomach; no patients in the series had heart or lung operations.

One patient was excluded after operation because pneumothorax developed within the first postoperative day; this was considered to increase the risk of pulmonary complication. Further major extrapulmonary complications did not appear in the observation period.

The patients were premedicated with pentobarbi-
tone and hyoscine or pethidine and atropine. Approximately one-fourth of the patients (see table I) received additional atropine medication i.v. within the first hour of anaesthesia because of a low pulse rate. Anaesthesia was induced with thiopentone and intubation was performed after suxamethonium. Nitrous oxide 70–75% in oxygen was used for maintenance and was in a few cases supplemented with small amounts of pethidine or halothane. Relaxation was provided by tubocurarine chloride. All the patients were manually ventilated at a rate of about 14 b.p.m. and total minute volume of 8–10 l./min, using a non-rebreathing system (Ambu-E valve). Atropine 1.0 mg and neostigmine 2.5 mg were injected before extubation. This was performed when the patient had regained adequate spontaneous respiration and had coughed on request and during repeated endotracheal suction. After transthoracic surgery a chest radiogram was taken before extubation to ensure that pneumothorax or atelectasis was not present.

Table I. Some details of patients and operations in the two treatment groups.

<table>
<thead>
<tr>
<th></th>
<th>Humidified group</th>
<th>Dry gas group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total no. of patients</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>Mean age (yr)</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>Mean duration of anaesthesia (min)</td>
<td>298</td>
<td>309</td>
</tr>
<tr>
<td>No. of transthoracic operation patients</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Mean age (yr)</td>
<td>63</td>
<td>69</td>
</tr>
<tr>
<td>Mean duration of anaesthesia (min)</td>
<td>499</td>
<td>565</td>
</tr>
<tr>
<td>No. of male patients</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>No. of abdominal operation patients</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>Mean age (yr)</td>
<td>52</td>
<td>49</td>
</tr>
<tr>
<td>Mean duration of anaesthesia (min)</td>
<td>217</td>
<td>205</td>
</tr>
<tr>
<td>No. of male patients</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>No. of upper abdominal cases</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>No. of patients given atropine during anaesthesia</td>
<td>11</td>
<td>15</td>
</tr>
</tbody>
</table>

When the patient was allocated to the humidification group, a hot water humidifier (Hygrothenn) was inserted between the bag and the non-rebreathing valve (fig. 1). The humidifier was a prototype produced by Simonsen & Weel, Copenhagen, and will not be commercially available. To avoid any risk of infection from the humidifier, it was constructed to tolerate autoclaving after each use and was filled with sterile, distilled water. A thermocouple was placed in the middle of the gas stream about 3 cm before the non-rebreathing valve. The temperature of the water in the humidifier was controlled by the thermocouple to maintain the temperature of the gas delivered to the patient at a pre-set value approximately 4°C below the patient's rectal temperature. Condensation of water, due to cooling of the gas from the humidifier to the patient proved that the gas was saturated with water vapour. The tubes were arranged so that all condensation returned to the humidifier. Thus 100% relative humidity at about 32°C was delivered to the patient, corresponding closely to normal conditions, i.e., 98% saturation at about 32°C at the level of the cricothyroid membrane during nasal breathing (Ingelstedt, 1956). Rectal temperature, skin temperature on the first toe and the gas temperature 3 cm before the non-rebreathing valve were measured every quarter of an hour.

It was found that the inspired gas temperature actually varied between body temperature and 6.5°C below this the gas accordingly being 70–100% saturated with water vapour at body temperature.

One to three days before anaesthesia a chest radiogram was obtained, and the Pco₂ and oxygen saturation were measured in each patient. Chest X-rays were repeated immediately after operation and
at least on the 1st, 2nd, 3rd, 5th, and 7th days after transthoracic operations and after abdominal operations at least on the 1st and 3rd days. The physiotherapist recorded whether the secretions were sticky and/or copious and the number of bronchial toilets was also recorded.

Carbon dioxide tension and oxygen saturation in arterialized ear-lobe capillary blood were measured daily for the first 5 days after transthoracic operations, and on the 1st, 3rd and 5th days after abdominal operations. Rectal temperature, pulse rate and respiratory rate were recorded every hour in the former, and at least twice daily in the latter.

None of the patients received ventilator treatment after operation.

After transthoracic procedures the inspired air was humidified for the first 3–5 days after operation by blowing an air-oxygen mixture at 10 l./min into the nasal cavity through a wide-bore tube projecting about 1 cm into the nostril. The air-oxygen mixture was humidified to 100% relative humidity at body temperature by the humidifier described by one of us (Lomholt, 1968). Patients in the abdominal group were given oxygen at a rate of 4 l./min through a nasal catheter for 4 hours postoperatively. All patients were given prophylactic treatment with antibiotics, carefully adjusted fluid therapy pre-, per-, and postoperatively, and daily lung physiotherapy. After 1 week each patient was classified in one of three categories by one or two experienced anaesthetists who had not been involved in the treatment of the patients, as follows:

- Pulmonary complication. No radiological or clinical signs of pulmonary complications were found within the first 5 postoperative days.
- (+) Pulmonary complication. A lobular (streaky) atelectasis appeared on the X-ray of the chest 3–5 days after operation without any clinical symptoms or specific changes in blood-gas values, and disappeared readily without any special treatment.
- + Pulmonary complication. Radiological evidence of pulmonary complications appeared within the first 5 postoperative days, with accompanying clinical symptoms and signs, and/or specific changes in blood-gas values.

Statistical analysis.

Evaluation of the results obtained in controlled studies is usually based on statistical calculations performed when a certain predetermined number of patients has been investigated. Similar information may be obtained by consecutive recording on a diagram of the results obtained in randomly selected patient-pairs, one of the patients in each pair having received the treatment to be investigated—the so-called sequential analysis (Armitage, 1960). One of the advantages of the method is that the investigation can be stopped as soon as a significant result is obtained, which often occurs with a smaller series of patients than if the more usual statistical methods had been applied to a similar problem.

The result in each patient-pair is analysed as if it is a study itself. If the result is the same in both patients in a pair, whether it is for instance + complication in both patients or - complication, there is no preference for any of the treatments and the patients are “discharged” from the analyses. In all other cases there is a preference for the treatment followed by no complication or the minor of the two complications and this is marked by an oblique line in the diagram (Fig. 2). After every preference there are four possibilities, in this investigation the following: (1) humidification diminishes the frequency of complications; (2) it increases the frequency; (3) it causes no significant changes; (4) the series is still too small to allow any conclusions to be reached.

In cases 1, 2 and 3 the investigation is completed. In case 4 it continues until next preference is obtained, and this is then analysed together with the data already obtained. Using a diagram with restricted design as in figure 2, one of the first three conclusions will sooner or later be obtained.

The diagram is constructed according to certain pre-selected values; 2 α and β represent the probability respectively for demonstrating a false difference or overlooking a true difference, corresponding to P<0.05. The symbol Θ represents the relation between preferences for one treatment and the total number of preferences. A diagram such as the one used, determined by a value for Θ of 0.85 is only able to disclose rather big differences. However, we found it satisfactory, because only a rather big difference in results in favour of humidification would lead to practical consequences.

The results and the patient's number was consecutively handed to an assistant in charge of the sequential analysis. The course of the lines, the "sample path", was known only by this assistant.
RESULTS

The sample path crossed the borderline of the diagram at the zero-line after 16 preferences (fig. 2), 8 for humidification and 8 for dry gas. Eighty-four patients had then been investigated. This allows certain limited conclusions according to the pre-selected values mentioned.

Any sample path crossing the upper or lower borderline in the diagram would have demonstrated a significant difference in favour of either humidification or dry gas, the humidification having reduced the complication rate approximately from 23 to 5% or having increased the complication rate from 15 to 50% or more (\( \sigma = 0.85 \) and the overall complication rate being about 20%).

Any sample path crossing the line ABC, significantly (\( P < 0.05 \)) excludes changes of this magnitude. As the sample path, however, actually crossed the line at zero level, a possible real difference in complication rate, which might be disclosed in investigations including larger groups of patients, is probably smaller, if there is any. The investigation gives no suggestion whether such a difference would be in favour of humidified or dry gas.

Of the humidified group of 42 patients 8 had + complication and 1 a (+) complication. Of the dry gas group of 42 patients 8 had + complication and 2 had (+) complication. These 19 cases gave only 16 "preferences" in the diagram, because 2 patients with + complication had outweighed each other, and in one pair + and (+) gave only one preference in favour of the non-humidified patient, who had the (+) complication. Further, in 7 pairs the humidified patient had + complication and in 8 pairs the non-humidified patient, while the "twin patient" in the pairs had no complication.

No lobar or total lung atelectases occurred, all the atelectases found being segmental or lobular, associated with slight or no decrease in oxygen saturation, and disappearing within 2 to 5 days. The consolidations were all minor, restricted to less than one lobe, and associated with moderate fever and slightly decreased oxygen saturation.

Table I shows the mean age of the patients and the mean duration of anaesthesia in the humidified and the dry gas group. Thirteen patients in the dry gas group and twelve patients in the humidified group were operated on by the transthoracic approach. The dry gas group also included a slightly higher number of upper abdominal cases and of male patients. As, furthermore, 15 patients in the dry gas group and only 11 in the humidified group had been given atropine during anaesthesia, the patients in the dry gas group as a whole may be thought to have run a slightly higher risk of developing pulmonary complications than the patients in the humidified group.

Seven patients undergoing splenectomy, 2 having had humidified and 5 dry gases, breathed for investigation purposes 100% oxygen for 15 min before and 2 hours after anaesthesia, and the resulting arterial oxygen tension values were measured. Changes in alveolar/arterial oxygen tension difference indicative of increased pulmonary shunt after operation were not found in any cases.

Table II shows changes in mean rectal temperature and skin temperature on the 1st toe in operations lasting more than 3 hours. The mean rectal temperature in the dry gas group is seen to have decreased by about 0.2°C per hour of anaesthesia.
study, water is not administered to the patient, but
not bring about serious drying. Why even prolonged anaesthesia with this system did
incorporated from the secretions before their viscosity in-
and as about half of the water content must be eva-
gases was preserved when a non-rebreathing system
was used. Thus with this system the originally dry
secretions cannot be completely removed by aspiration
and are known to be transported less effectively by the cilia than are moderately viscid secretions. During prolonged transthoracic operations copious thin secretions may pool in the dependent lung
because they are impossible to remove by suction and
because postural drainage and lung physiotherapy
cannot be employed during operation.

The rapidity of mucus transport during anaesthesia
might be of minor importance because the secretions
are, in any case, stopped at the endotracheal cuff.

It is our experience that even viscid secretions
after anaesthesia usually can be removed by lung
physiotherapy only but that expectoration is often
facilitated by postoperative humidification of the in-
spired air, which has few if any inherent risks (Lom-
holt, 1968). Only one patient in this series required
tracheobronchial suction after operation. The patient
belonged to the dry gas group and developed a seg-
mental atelectasis on the 3rd day after a thoraco-
abdominal operation lasting 9½ hours.

No serious pulmonary complications developed in
any of the groups. It should be emphasized that all
patients had received accurate fluid balance treat-
ment before and during anaesthesia.

The patients in the humidified group received fully
saturated gas at a temperature between that of the
body and 6.5°C below, corresponding to 70–100% 
saturation at body temperature, and this may in some
cases have been slightly above normal conditions
(Ingelestedt, 1956). Apart from this, the method of
humidification used is probably as near “physiologi-
cal” as possible. Further, it was completely sterile,
which is not easy to reproduce because autoclavable
humidifiers are, to our knowledge, not for sale. Fur-
thermore the humidification was probably more care-
fully controlled according to gas temperature than
would be possible in routine daily use.

DISCUSSION

If the frequency of occurrence of postoperative com-
lications were influenced by the use of dry or humid-
died gases during anaesthesia, then it would be
expected that differences would be demonstrated
after operation of the types included in this study,
which lasted on average for 5 hours.

Examination of the results disclosed no such
difference. This might seem unexpected in view of
the previously quoted papers and the general belief
in the value of humidification during anaesthesia.

Our unexpected result might be explained by the
following considerations.

In the dry gas group in the present study, the gases
were not administered directly to the mucosa as in
the animal experiments performed by Dalhamn
(1956), but through a valve to an endotracheal tube. As
shown by Déry and associates (1967), the valve
and the endotracheal tube act as heat and moisture
exchangers. Chase, Kilmore and Tomasello (1963)
found that almost half of the humidity in the expired
gases was preserved when a non-rebreathing system
was used. Thus with this system the originally dry
gases contain some humidity when they reach the tra-
chea. Consequently the drying of secretions, even
with the non-rebreathing system, may be moderate,
and as about half of the water content must be eva-
porated from the secretions before their viscosity in-
creases (Cragg and Smith, 1961), this may explain
why even prolonged anaesthesia with this system did
not bring about serious drying.

With the system used for humidification in this
study, water is not administered to the patient, but
the inhaled water vapour depresses evaporation from
the secretions. It was found in the patients in the
humidified group that secretions were more fluid and
ample when aspirated during anaesthesia than was the
case in the patients in the dry gas group. This,
however, is not necessarily advantageous, for watery
secretions cannot be completely removed by aspira-
tion, and are known to be transported less effectively
by the cilia than are moderately viscid secretions.

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