National Academy of Sciences—National Research Council
Committee on Anesthesia

Workshop on Intensive Care Units

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MORNING SESSION

DR. HAMILTON, the Chairman, introduced DR.
S. F. SEELEY, liaison officer of the National
Academy of Sciences, who reviewed the his-
tory of the National Research Council and the
position of the Committee on Anesthesia. He
commented on the trend of including intensive
care units in present day hospital planning.
He referred to the hospital of the University of
Maryland where three surgical wards were
converted into an 8-bed intensive care unit
with supporting laboratory facilities. He also
stressed the necessity of cross fertilization and
collaboration with other committees of the
National Research Council as well as basic
science departments in carrying out studies in
the respective centers where intensive care
units are functioning.

Recent Developments in Planning Space
for Intensive Care Units

MR. WALLACE M. BROBERG: The architect
requires information as to the type and num-
ber of patients intended for an intensive care
unit, prior to the design stage. In those insti-
tutions that have intensive care units it has
been found that 5–10 per cent of the yearly
admissions to the hospital spend a portion of
their time in an intensive care unit. The
usual size of such a facility is 14–15 beds.

Two general types of architectural design
were discussed. One consists of a round
building oriented around a central nursing
unit, the prime purpose of which is to place
the nurse in as close a relation to the patient
as possible. Such units have functioned effi-
ciently and usually consist of 12 private
rooms which are glass enclosed. The second
is rectangular and may be located adjacent
to a recovery room. Ward bed type of
accommodations are available with movable
partitions employed to facilitate individual
care. Several of the advantages and dis-
advantages of both units were discussed.

Intensive Care in a Suburban Community
Hospital

MR. ROBERT G. BOYD, a hospital adminis-
trator, made the following remarks. Morris-
town Memorial Hospital is a suburban com-
munity hospital with 311 beds. As in most
hospitals of this kind today, it has relatively
few interns and residents—as compared with
the large medical centers. One effect of this,
insofar as our Intensive Care Unit is con-
cerned, is that we do not have continuing and
centralized medical supervision of the opera-
tion of the unit. We do, however, have a
special committee of the Medical Staff that
is charged with the general supervision of the
service.

We have a 14-bed recovery room for surgical
patients which closes at 8 P.M. Our In-
tensive Care Unit was created by remodelling
a 24-bed Pediatric Unit. In our Intensive
Care Unit there is one single bed room, two
double bed rooms, two 3-bed rooms and one
4-bed solarium. A significant functional de-
fect is that the patients in the four beds on
the solarium cannot be directly observed from
the nurses’ station.

Our unit therefore has 15 beds, of which
10 have been opened, and it has been in
operation for almost a year. During the first
nine months of 1963, 336 patients were ad-
mitted to the unit for a total of 1,085 patient
days of care. The five-day average length of
stay is, we feel, unduly long, and is caused
by shortage of beds in other areas of the
hospital, and possibly by inadequate policing
on the part of the medical staff. Our aver-
age occupancy ran around 60 per cent during
the first nine months of this year. We had
72 deaths in the unit, representing about 21
per cent of the patients admitted during the
above-cited period. The overall death rate
for all patients admitted to the hospital was
2 1/2 per cent for the first 9 months of 1963.
Of the 336 patients, 191 (56 per cent) were
surgical and 145 (43 per cent) were medical.

We are currently staffed for 6–8 patients,
but during short periods of time we can care
for up to a maximum of 10 with the following
staff:

<table>
<thead>
<tr>
<th>Shift</th>
<th>Registered Nurses</th>
<th>Licensed Practical Nurses</th>
<th>Floor Secretary</th>
</tr>
</thead>
<tbody>
<tr>
<td>7–3</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3–11</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>11–7</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

The above-mentioned coverage is about twice
that provided in other in-patient nursing units.

The rules covering the operation of our Intensive Care Unit may readily be divided into the following three categories:

(1) Those having to do primarily with the members of our medical staff.
(2) Those principally concerned with the patients.
(3) Those primarily having to do with the visitors to the Unit.

Those primarily concerned with physicians are as follows:

(1) The doctor in charge of the patient will be responsible for requesting admission or transfer to and from the Special Care Unit.
(2) The doctor in charge of the patient will be responsible for informing the patient and his family about the Special Care Unit.
(3) A special committee of the Executive Committee will review the experience of this area as well as assist in any difficulties which might arise in the medical management of this Unit.
(4) Prior to discharge of the patient from the Unit, his orders must be summarized by the attending physician. (The orders that must be summarized are only those that remain in effect when the patient is transferred.)

Following are the rules that are primarily applicable to the patient:

(1) Regardless of status (private, semi-private, ward) transfer will be made to that accommodation of the Special Care Unit best suited to the patient’s need.
(2) There is no need for patients to have private duty nurses in this unit. (This is really not a rule, but a necessary reassurance that we felt to be necessary when the rules were first issued.)
(3) Patients will not be admitted to the Special Care Unit unless their condition is acute at the time of admission. (When we first opened the Unit, all patients admitted to the service were automatically placed on the danger list. This practice was soon discontinued because it frequently caused undue concern on the part of the patient’s family.)
(4) Contagion cases will not ordinarily be admitted to the Special Care Unit. This includes postoperative thoracic cases with active tuberculosis. (We have a separate 12-bed contagion unit, which has been especially useful in connection with our program to control nosocomial infections.)
(5) Terminal care cases, chronic cases and disturbed or disturbing patients are not to be admitted.
(6) Children will be admitted to the Special Care Unit.
(7) The following diagnoses are ordinarily considered acceptable for admission to the Special Care Unit—provided the patient is in suitable condition for admission: (a) coma—except obviously terminal cases; (b) acute cardiac infarction—with shock or arrhythmias, acute respiratory failure or acute pulmonary edema; (c) acute hemorrhage and electrolyte problems; (d) poisonings; and, (e) appropriate surgical cases. All patients will be transferred from the Unit when the period of maximum care appears to be over.
(8) Although patients can be admitted to the Special Care Unit from any place within the hospital, under ordinary circumstances postoperative cases will go to the Recovery Room. Postoperative cases can bypass the Recovery Room under the following circumstances: (a) cardiac arrest cases; (b) open heart cases; and (c) at the special request of the operating surgeon, desperately ill cases may go directly to the Unit.

The following is the only rule that we have with regard to visitors to the unit. (There is a special room for visitors which is outside the main floor leading to our Intensive Care Unit.)

Visitors will be restricted to the immediate family with stringent control of the number of visitors at the bedside and duration of visit: no more than two at any time, and no more than five minutes every hour, except with special permission of the attending physician.

Seven Years’ Experience in an Intensive Care Unit

DR. MEYER SAKLAD: Dissemination of knowledge and improved means of therapy are not enough to guarantee better care for many seriously ill patients. In the foreseeable future there will not be enough people with the proper skills or enough apparatus, both diagnostic and therapeutic, to care for acute
derangements early enough, because the ratio of people qualified to give and the number of patients who need to receive specialized care is disproportionate. This is further aggravated by dispersal throughout the hospital of patients in acute need. The immediate alternative is to centralize patients who suffer from or who may develop conditions which may require early diagnosis and specialized treatment, to forestall catastrophe and to assign to this area specially qualified nursing and medical personnel. To further this philosophy a Surgical intensive care unit was established at the Rhode Island Hospital in 1956, and a Medical intensive care unit in 1958. There were certain considerations in planning these units.

**Location.** We believed that intensive care units should be so located as to be within easy access of the operating room, accident room and nursing units. They were placed on the floor directly above the operating room, for, in emergencies, the Anesthesia Department could be called upon and could be of service in the shortest possible time.

**Size.** The Surgical intensive care unit has 16 beds, and the Medical intensive care unit 12. These units, though separate, are ad-joining (fig. 1). The wing on the right is the Surgical intensive care unit, and that on the left the Medical intensive care unit. The two arrows point to the nursing control stations. This differs from the other nursing units where the control station is located at the junction of the two limbs of the Y figure. The Surgical intensive care unit has two 4-bed rooms, one 3-bed room, one 2-bed room and three singles. The Medical intensive care unit has two 5-bed rooms, and two singles. One criticism of both layouts, however, is that on occasion there is need for more single rooms and, further, the single rooms are not large enough. It is desirable that single bedrooms be at least 1½ times as large as ordinary single bedrooms, to better care for the critically ill. This becomes especially important when monitors and ventilators are necessary. The sexes are not mixed in multiple-bed units. No distinction is made between service and private patients. Of great importance is the need for a resident's bedroom, a small laboratory and a large waiting room. These are off to the right of the Surgical intensive care unit. In planning these units one must recognize that there will be greater need for storage space, linen, drugs, apparatus and the like. Inasmuch as
these units are placed directly over the operating room they can be reached from the operating room by a staircase in a very short time. An alarm system is incorporated so that the Anesthesia Department can be called upon for assistance when needed. The units are supplied with small ventilators, airways, endotracheal tubes, laryngoscopes, etc.

**Staffing and Nursing.** The nursing complement is listed in table 1. In July 1963 this number of nurses was able to give 9.2 hours of nursing per patient per day on the Surgical intensive care unit and 7.1 hours per patient per day on the Medical intensive care unit. This, many think, may not be enough, but we are limited by nursing shortages.

**Medical.** The Surgical intensive care unit

<table>
<thead>
<tr>
<th>Table 1. Intensive Care Units Staffing Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>SURGICAL Intensive Care Unit</td>
</tr>
<tr>
<td>Registered Nurses</td>
</tr>
<tr>
<td>Days</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>1</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>MEDICAL Intensive Care Unit</td>
</tr>
<tr>
<td>Registered Nurses</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>Practical Nurses</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Administrative Sec.</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Ward Helper</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

has a resident in constant attendance. He lives on the unit. The Medical intensive care unit has a resident assigned to the unit, but he is not committed to stay there.

**Administration.** Each of the intensive care units has its own head nurse, and she in turn is responsible to a nursing supervisor. Medical administration is the responsibility of the resident assigned to the unit. It is he who makes the decisions as to which patients stay and who leaves the unit, and it is he who is responsible for medical judgment in emergencies.

**Experience.** Table 2 depicts our experience for the year 1962. During this time we had 1,113 patients in the Surgical intensive care unit. The number of patients in the Medical intensive care unit was 589. This latter figure is no longer a realistic number, for during 1962 the Medical intensive care unit was an 8-bed unit and now the patients are taken care of in the originally-designed intensive care unit which is of 12 beds. We expect the future number of patients to be treated in the Medical intensive care unit to be considerably more than 589. The patients on the Surgical intensive care unit amounted to 5.3 per cent of hospital admissions and the Medical intensive care unit 2.9 per cent. The sum of patients in both units was equal to 8.2 per cent of the total admissions to the hospital. This figure is less than we expect in the future, for it will be increased considerably by the larger number of patients

<table>
<thead>
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<th>Table 2</th>
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<tr>
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<tr>
<td></td>
</tr>
<tr>
<td>No. Patients</td>
</tr>
<tr>
<td>Surgical I.C.U.</td>
</tr>
<tr>
<td>Medical I.C.U.</td>
</tr>
<tr>
<td>Percentage of Total Admissions to Hospital</td>
</tr>
<tr>
<td>Surgical I.C.U.</td>
</tr>
<tr>
<td>Medical I.C.U.</td>
</tr>
<tr>
<td>8.2</td>
</tr>
</tbody>
</table>

* In 8-bed unit, before transfer to 12-bed unit in May, 1963.
that we expect to be taken care of on the Medical intensive care unit. We believe that the figure will be closer to 10 per cent. To those who may be planning an intensive care unit and wish to have some idea of the number of beds which might be required, 8.4 per cent of the patients operated upon went to the Surgical intensive care unit.

Except for the year 1958, there has been an increasing demand for the utilization of the intensive care unit. The number of patients accommodated should level off at the present load unless there is a reduction in the number of days the patients spend on this unit. The utilization in the year 1958 was unfortunate and was the result of a misunderstanding between the staff and the administration in regard to added cost to the patient for use of this unit. As it now stands, there is no additional charge to the patient. The patient continues to pay the same rate in this unit as he did in his original accommodations in the hospital.

By far the greatest number of patients treated in the Surgical intensive care unit were from the general Surgical and Neurosurgical services. Except for the year 1958 surgical utilization has been near-constant. It is very important, however, to note the increasing utilization by the Neurosurgical service (fig. 2). The percentage of patients operated upon by the Surgical service who went to the intensive care unit fell from a high of 19 in 1956 to about 13 at present. This is less than half of the 30 per cent of the Neurosurgical patients who go to the Surgical intensive care unit. The total number of all the patients operated upon by other services who go to the Surgical intensive care unit is less than 5 per cent. Whether this is proper or not is very hard to determine. Many ill patients operated upon on other services return to their original units because there are advantages. Members of the orthopedic, urological and ophthalmological services feel that in general the specialized care that their patients may require on occasion is best obtained on their original units. It is hard to decide, sometimes, where a patient would be better off. The patient in shock, with multiple fractures in need of traction, might sometimes be better off in the intensive care unit and at other times on the Orthopedic unit where specially-trained orthopedic nurses and orthopedic residents are immediately available.
Figure 3 depicts the source of admissions to the Surgical intensive care unit. It may be noted that the number of operations has increased from about 11,000 to close to 14,000. The total number of admissions to the unit, however, has not increased at the same rate. In the year 1956 the number of patients who went directly from the operating room to the intensive care unit was close to that of patients who went from the operating room to the recovery room and thence to the intensive care unit. It is important to note that the number of patients who go from the operating room directly to the surgical intensive care unit has decreased over the years, whereas the number of patients who go from the operating room to the recovery room and then to the intensive care unit has increased during the same interval. This may be because of the need for very careful observation directly after surgery. Another reason is the need for continued monitoring after the period of operation. It is easier to do this in the recovery room than to hazard a period of poor monitoring or care during transportation.

Figure 4 shows the possible sources of admission to the intensive care units. The Medical and Surgical intensive care units are located side by side. There might be need on occasion to transfer patients between the Medical and Surgical intensive care units. This should not always be dependent upon whether the patient is a medical or surgical problem. There is really no great distinction between the respiratory and circulatory prob-
lems of medical and surgical patients. Having the medical and surgical intensive care units side by side will also allow one unit to use the beds in the other, if required. It should be possible to admit patients to these intensive care units directly from the admitting office and the accident room.

Respiratory units are assuming an important place in patient care. One of the reasons for their establishment is the particular type of attention these patients require. Where the respiratory unit should be placed in relation to the surgical intensive care unit and the medical intensive care unit is debatable, but certainly it ought to be close by. If close by, it becomes possible to move a patient from the intensive care unit to the respiratory unit and back again if needed. This should not, however, deny the patients on the intensive care unit, surgical or medical, good respiratory care when necessary. Patients should be able to come to this respiratory unit directly from the medical or surgical wards also, or if they are surgical patients, from the operating or recovery room.

Organization of Intensive Care Units: Results in Cases of Respiratory Failure

DR. D. V. BATES: It has been quite evident from the different points made by previous speakers that there are many different kinds of Intensive Care Units. For the past five years we have been running a medical Intensive Care Unit concerned with respiratory and cardiac problems and with relatively little responsibility for postoperative care. The remarks I am going to make are concerned with management of respiratory cases in this Unit and with the general lessons we have learned which we feel may be important in terms of future organization. I might remark at the beginning that medical intensive care is mainly respiratory care and cardiac management, and these two aspects to the problem include almost all medical cases except those of acute renal failure.

In table 3 are shown some of the essentials for such a Unit. The first unquestionably is the provision of specially trained nursing staff. These nurses must be confident and competent in managing respirator problems and tracheotomies, and the fact that an untrained nurse, however senior, cannot undertake this work is one of the main reasons for having an Intensive Care Unit in the first place. Twenty-four hour gas tension analysis facilities are obligatory and there can be no economy in this item. We have also found it essential that the senior resident staff should not rotate every three months since they are barely competent before they are moved. In addition, the main responsibility for cases should, I believe, rest with Attending Staff since no resident who has not had special training in this discipline is capable of taking care of these cases until he has had at least three months on the ward. The last point is that it is essential to have proper servicing of respirators on the Unit if an efficient service is to be given. In this meeting it is perhaps tactless of me to call the liaison with the Anesthesia Department an important "detail," but it is of course extremely important that there should be a close modus vivendi with the Department of Anesthesia. I think it is a good principle that the Department of Anesthesia is responsible for everything that occurs in the Recovery Room, and they act as consultants on the Intensive Care Unit. In fact, the anesthetist on duty is the only person who has unquestioned access to all the equipment on the medical Intensive Care Unit and the nurses have permanent instructions to lend at any time any equipment from this ward to the anesthetist on duty. No one else may borrow it.

In table 4 are shown some more details of the organization which are we think important. It is very useful to combine this work with cardiac intensive care since in this way the load is kept relatively constant. We have no
TABLE 4. Practical Details of Organization

1. Combination with cardiac intensive care (pacemaker work).
2. Single rooms must be available.
3. Attending staff on 24-hour call.
4. Gas tension laboratory on unit (resident and attending staff trained to use).
5. Must have—a) Triggerable and automatic respirators.
   b) Minimum of types of respirators.
   c) Complete ancillary equipment.

There is no doubt that single rooms must be available, and some of the contemporary suggestions that an Intensive Care Unit should be a sort of barn full of machinery is, we think, a retrograde step. Attending Staff must be on twenty-four-hour call because the ultimate responsibility for the cases is theirs, a point I mentioned earlier. As far as equipment is concerned, we feel from our experience that you will need both the triggerable and automatic respirators and in fact we have standardized on the Bird respirator and the Engstrom. These two instruments together make an ideal combination and we think it important that both should be available for different types of case. There is obvious wisdom in having a minimum of numbers of types of respirators since this makes training much easier. Lastly the ancillary equipment must of course include portable X-ray apparatus and other equipment which should be permanently available on the ward.

One of the problems so very rarely considered in this field is what, if you go to a great trouble to set up such an organization, you may hope to achieve. In Table 5, I have set out our experience with the first 94 respiratory admissions to this ward and you will see that a number of these patients have been admitted more than once or have had more than two episodes which have required intensive respiratory care. I want to comment on the few of the categories shown in this table. You will see that our survival rate in patients with cardiac disease is very low and this is because they are people who have been put on respirators after cardiac arrest and their deaths were not of course primarily respiratory. In the case of the renal failure patients, the only patients considered in this table are those who have required respirator treatment as a result of respiratory failure secondary to severe renal failure. Our success has been so limited with this group that we now feel that it is probably better to put down an endotracheal tube than to do a tracheostomy. Notice that we have saved so far everyone in status asthmaticus, and since this table was prepared we have had two additional cases both of whom have lived. I will return to this point later.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Number of Respiratory Admissions</th>
<th>Number of Patients</th>
<th>Alive</th>
<th>Dead</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emphysema</td>
<td>18</td>
<td>14</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Pulmonary fibrosis</td>
<td>12</td>
<td>7</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Neurological</td>
<td>13</td>
<td>7</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Post-thoracotomy</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>-cardiac surgery</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>-other operations</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Cardiac disease</td>
<td>6</td>
<td>6</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Renal failure</td>
<td>6</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Status asthmaticus</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Drug overdose</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Chest injury</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0</td>
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<tr>
<td>Tetanus</td>
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<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hypoventilation/obesity</td>
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<td>0</td>
<td>1</td>
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<tr>
<td>Pneumonia (acute)</td>
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<tr>
<td></td>
<td>94</td>
<td>78</td>
<td>45</td>
<td>33</td>
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Table 6. Respiration Details

<table>
<thead>
<tr>
<th>Type</th>
<th>Days</th>
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<tbody>
<tr>
<td>Cuffed Mörch tube</td>
<td>90/94</td>
</tr>
<tr>
<td>Endotracheal tube</td>
<td>3/94</td>
</tr>
<tr>
<td>Mask</td>
<td>1/94</td>
</tr>
<tr>
<td>Engstrom respirator</td>
<td>42</td>
</tr>
<tr>
<td>Bird triggered</td>
<td>52</td>
</tr>
<tr>
<td>Bird automatic</td>
<td>7</td>
</tr>
<tr>
<td>Total respirator days</td>
<td>801</td>
</tr>
</tbody>
</table>

\(= 9\frac{1}{2}\) days per patient episode (Range 1-82)

<table>
<thead>
<tr>
<th>Type</th>
<th>Average age of patients treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial blood gas</td>
<td>analysis (6 per patient episode)</td>
</tr>
<tr>
<td></td>
<td>553</td>
</tr>
<tr>
<td>Average age of all</td>
<td>48 years</td>
</tr>
<tr>
<td>patients treated</td>
<td></td>
</tr>
</tbody>
</table>

Table 6 gives some indication of how the 94 respiratory episodes have been handled. You will see that we are in favor of a cuffed Mörch tracheotomy tube and in only one case have we used a mask and respirator only. The Engstrom and the Bird have been used about equally, and you will notice here an important figure that the average number of respirator days per patient is 9\frac{1}{2}. I have been very surprised at some of the information we have been given at this symposium, that the average patient stay in some of these so-called Intensive Care Units has been only four or five days. From the respiratory point of view if the average time on a respirator is 9\frac{1}{2} days, the average stay on the Unit will of course be close to three weeks. We have found that an average of six arterial blood gas studies will be required per patient episode, and I want you to note particularly the last point in this table, namely that the average age of all our patients has been only forty-eight years: this in spite of the fact that we are not a pediatric Intensive Care Unit and have in fact only treated two children in the whole series. It is often suggested that this work is a sort of geriatric resuscitation; as far as we are concerned this outlook is incorrect. In table 7 are shown the main causes for the hypoventilation which necessitated respiratory care. You will notice that no fewer than five patients have been precipitated into CO₂ narcosis by treatment with morphine and oxygen, and this still remains an important cause of respiratory failure. You will notice under the post-surgery category—exhaustion, and here we feel that respiratory assistance is often needed to prevent a dangerous slide into respiratory failure.

We have had 34 deaths on patients who have been on respirators and have been fortunate to obtain autopsies on 28 of these. The results of these examinations are shown in table 8. Nine of these patients who died essentially of left ventricular failure, or pulmonary edema, were cardiac cases, mostly of infarction, and their deaths cannot be called respiratory. In eight, the cause of death was a lung infection we were unable to eradicate, and we find that the accurate diagnosis of chronic infection in the lung when patients

Table 7. Principal Causes of Hypoventilation

<table>
<thead>
<tr>
<th>Cause</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronic lung disease, infection, CO₂ narcosis</td>
<td>28</td>
</tr>
<tr>
<td>Neuromuscular</td>
<td>18</td>
</tr>
<tr>
<td>Post surgery, inc. Pco₂</td>
<td>7</td>
</tr>
<tr>
<td>Exhaustion</td>
<td>13</td>
</tr>
<tr>
<td>Renal failure</td>
<td>6</td>
</tr>
<tr>
<td>Group I with morphine and O₂</td>
<td>5</td>
</tr>
<tr>
<td>Asthma and CO₂ narcosis</td>
<td>5</td>
</tr>
<tr>
<td>Overdose of depressant</td>
<td>5</td>
</tr>
<tr>
<td>Chest injury</td>
<td>3</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>94</td>
</tr>
</tbody>
</table>

Table 8. Causes of Death

<table>
<thead>
<tr>
<th>Cause</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary edema, left vent. failure</td>
<td>9 (5 renal and 4 cardiac)</td>
</tr>
<tr>
<td>Ineradicable lung infection</td>
<td>8 (7 bronchopleural fistulae and abscesses)</td>
</tr>
<tr>
<td>Cerebral damage</td>
<td>5</td>
</tr>
<tr>
<td>Uncontrollable CO₂ retention</td>
<td>3</td>
</tr>
<tr>
<td>Pulmonary embolism</td>
<td>3 (2 with uncontrolled CO₂ retention)</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
</tr>
</tbody>
</table>
Table 9. Emphysema

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 patients/18 episodes/9 survivors</td>
<td></td>
</tr>
<tr>
<td>Age range 38–69; Mean 59 years</td>
<td></td>
</tr>
<tr>
<td>$\text{PCO}_2$ start—Lowest 62 mm. Hg</td>
<td>Mean 86 mm.</td>
</tr>
<tr>
<td>Highest 132 mm. Hg</td>
<td>Hg</td>
</tr>
<tr>
<td>$\text{O}_2\text{Hb}$ start—Lowest 53%</td>
<td>Mean 65% (air</td>
</tr>
<tr>
<td>—Highest 79%</td>
<td>breathing)</td>
</tr>
</tbody>
</table>

are on respirators is often a difficult matter. In at least one of these patients the chest X-ray gave no indication of the extent of infection in the lung and the physician looking after the case, who happened to be myself, was unaware of the extent of this infective process until the autopsy examination revealed it. It also makes the point that lung infection with antibiotic resistant organisms is a very real hazard in some of these patients. In five of the patients, death was due to cerebral damage and in four of these the cerebral damage had occurred before the patient was transferred to us and had been due to delay in giving respiratory assistance. In only three of the fatal cases was death due to $\text{CO}_2$ retention which we could not control by the use of this equipment. In our view, unreliable $\text{CO}_2$ retention is a relatively rare cause of death in these patients once respirator care is available. Two of the three cases had severe emphysema and the other a severe $V/A$ disturbance and bronchiolitis.

It is very hard indeed to compare results from one Unit to another. In table 9 you will see our experience in treating fourteen patients with eighteen episodes of severe $\text{CO}_2$ narcosis—all of these patients suffering from emphysema. Nine of them have had at least two years of useful life after the episode of resuscitation. You will notice the mean age of these patients was fifty-nine years and that the $\text{PCO}_2$ at the beginning of resuscitation averaged 86 mm. of mercury. This will give you an idea of the severity of the cases I am talking about. You will find in the literature successful resuscitation recorded from patients whose $\text{PCO}_2$ never went much above 58 mm. of mercury and I am not talking about that kind of relatively mild case. We have learned that the type of emphysematous patient who particularly needs this attention is one whose most normal lung has become involved with acute pneumonia. He rapidly develops severe arterial unsaturation and $\text{CO}_2$ retention and if you can get him around this episode, his prognosis in terms of function may be good. In table 10 are shown the results in four patients with status asthmaticus. Here you will see the $\text{PCO}_2$ at the beginning averaged 94 mm. of mercury. All of these patients have made excellent recoveries and we are quite certain that the use of respirator assistance in status asthmaticus is very clearly indicated whenever the $\text{PCO}_2$ rises much above 70. No one can answer the question yet whether patients ever die in status asthmaticus without severe $\text{CO}_2$ retention. Certainly we have not seen this and suspect that death always occurs from cardiac arrest consequent upon severe hypercapnia. In one of these patients resuscitation was only possible because of the use of muscle relaxants at the same time as the respirator assistance was applied.

In conclusion, I would like to say that in our experience respiratory intensive care is extremely rewarding work. Very few corners can be cut if the best team is to be kept available for this work, and the points I have set down as essentials in an organization of this type are, we believe, just that. In our experience there is great satisfaction to be derived from doing this job extremely well, and there is much important medicine to be learned from studying carefully the clinical problems which pass through such a Unit. I have in this brief review been unable to do more than sketch the kind of work a respiratory Intensive Care Unit may expect to do and to try to tell you why, in my view, this work is important and will continue to be so.

Table 10. Status Asthmaticus

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 patients/5 episodes/no deaths:</td>
<td></td>
</tr>
<tr>
<td>Age range 6–65; mean 38 years</td>
<td></td>
</tr>
<tr>
<td>$\text{PCO}_2$ start—Lowest 71 mm. Hg</td>
<td>Mean 94 mm. Hg</td>
</tr>
<tr>
<td>Highest 130 mm. Hg</td>
<td></td>
</tr>
</tbody>
</table>

All alive and well/no residual $\text{CO}_2$ retention

Note: This group noted to be very sensitive to high inflation pressures: hypotension if more than 15 cm. H$_2$O.
General Discussion

Sister M. Darcy of the Mayo Clinic briefly discussed the 48 bed cardiovascular unit under her direction. Registered nurses, practical nurses and aides were integrated in the staffing of this particular unit. No physician is in constant 24-hour attendance. Dr. John Severinghaus pointed out that the techniques of endotracheal intubation, the proper care of patients under hypothermia, the elements of pulmonary ventilation, the care of a patient having had a recent tracheostomy and the principles of the relaxants in convulsive states might profitably be taught to nurses. Dr. Peter Safar suggested that the intensive care unit nursing staff be absolved from the routine hospital orders and especially trained to perform some of the functions suggested by Dr. Severinghaus. Dr. Bates and Sister Darcy believed that a 4–6 months' training for a registered nurse would be sufficient to allow her some independent judgment. The routine introduction and orientation of other nursing personnel is usually one month in duration. Dr. Bates pointed out the advantage of rotating other members of the house staff through the intensive care units for short periods to familiarize them with the facilities available. Dr. Severinghaus opened a general discussion of who is to have the ultimate responsibility of admitting the patient to an intensive care unit, their care in the unit, billing of the patient, and the general administration of the unit. During the discussion it was pointed out that multiple arrangements were possible and that various factors in the individual hospital would probably play the most important role in determining who has ultimate responsibility of the unit. Mr. Boyd pointed out that the patient is billed an additional $2 per hour in the intensive care unit in his hospital. This is added to the basic cost of his hospitalization. It was pointed out that Blue Cross in both New York and New Jersey fully covers the patient in intensive care units. Dr. Pontopidan of the Massachusetts General Hospital in Boston presented the results of a survey in his hospital on the number of patients who might require critical care (table 11). His definition of the groups is as follows:

<table>
<thead>
<tr>
<th>Table 11. Massachusetts General Hospital Intensive Care Unit Subcommittee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey of &quot;critical care&quot; patients:</td>
</tr>
<tr>
<td>6/29, 7/1, 7/11–1962</td>
</tr>
<tr>
<td>&quot;Critical&quot; patients</td>
</tr>
<tr>
<td>Total of all classes (daily average)</td>
</tr>
<tr>
<td>I 35 &quot;Critical&quot;</td>
</tr>
<tr>
<td>II 155 &quot;Intensive&quot;</td>
</tr>
<tr>
<td>III 409 &quot;Average&quot;</td>
</tr>
<tr>
<td>IV 213 &quot;Ambulatory&quot;</td>
</tr>
<tr>
<td>812</td>
</tr>
<tr>
<td>&quot;Critical&quot; care patients represent 4% of the total</td>
</tr>
</tbody>
</table>

I. Critical Care: A patient in need of or potential need of lifesaving devices or activities. A patient who is critically ill, who needs highly skilled nursing care, and close and frequent, if not constant nursing observation.

II. Intensive Care: A patient who requires considerable nursing care and/or observation and instruction, but who does not require lifesaving activities. (Considerably more than average share of nursing time.)

III. Moderate Care: A patient who requires periodic treatment and/or observation and instruction. (Average share of nursing time.)

IV. Ambulatory Care: A patient who requires a minimal amount of nursing care. (Considerably less than average share of nursing time.)

The respiratory care unit admitted 120 cases per year; the average population was 5–6 patients per day and that this required 4–5 registered nurses per shift and 1½ house staff members. The cost was calculated at $60–$70 per patient per day over normal hospital costs (table 12). Sister Darcy then pointed out that the cost to the patient for care in an intensive care unit is less than if the patient employed private duty nurses in a single hospital room.

The Committee further considered the problem of the ultimate responsibility to the patient in the intensive care unit. Dr. John Kinney commented that no single physician can cover an acutely ill patient for 24 hours per day for 5–6 days, the average length of stay. Therefore the responsibilities must be shared. Dr. R. M. Cherniak was of the opinion that an attending supervisor whose
TABLE 12. Bed Capacity, Staffing and Cost

<table>
<thead>
<tr>
<th></th>
<th>Respiratory Unit</th>
<th>Intensive Care Unit (Medical Ward Pts.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed capacity</td>
<td>5-6</td>
<td>18</td>
</tr>
<tr>
<td>Aver. no. of nurses per shift</td>
<td>4-5</td>
<td>3-4</td>
</tr>
<tr>
<td>Aids per shift</td>
<td>0</td>
<td>2-3</td>
</tr>
<tr>
<td>Cost to hospital for room, board and nursing per patient per day</td>
<td>$101.00</td>
<td>$44.50</td>
</tr>
<tr>
<td>Physician Staff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>1.5 full time</td>
<td>Visits Only</td>
</tr>
<tr>
<td>Resident</td>
<td>1.0 full time</td>
<td>Med. Residents</td>
</tr>
<tr>
<td>Cost per patient per day</td>
<td>$25.00</td>
<td>$2.50 (underestimated)</td>
</tr>
<tr>
<td>Total cost per patient per day</td>
<td>$126.00</td>
<td>$47.00</td>
</tr>
</tbody>
</table>

sole responsibility is the administration of an intensive care unit should be appointed. He would be assisted by a resident from each of the medical, surgical and anesthesia services who would be on call 24 hours a day. This was considered essential as emergencies must be dealt with immediately and only a facility which provides 24-hour coverage could correctly deal with such situations. The result is a team approach headed by the attending supervisor but including the referring physician as well as the three members of the resident staff. Dr. Bates suggested that the transfer of a patient from the care of the referring physician to the intensive care unit partially absolves that physician of patient responsibility. The supervisor of the unit was then primarily responsible for the care of the acute situation. When the acute problem was resolved the patient was then transferred out of the unit and back to the care of the referring physician. It was his opinion that the anesthesiologist is the most important consultant for the supervisor of the intensive care unit, but that anesthesiologists as a whole do not want to become involved in running an intensive care unit. Dr. Arthur Keats questioned the advisability of transferring a patient from a referring attending physician ("trained") to a facility where the responsibility rests primarily with a member of the resident staff (not completely "trained"). Mr. Boyd concurred, and suggested that the referring physician be specially trained by appropriate members of the medical staff and then allowed to use these facilities of the intensive care unit at his discretion. Dr. Cherniak, however, suggested that this might be very difficult for a busy practitioner, inasmuch as an acutely ill patient required constant surveillance. Dr. Peter Safar commented that such a unit should be of an interdepartmental nature and administered by the department of anesthesia because of its 24-hour presence and availability. The referring physician would admit the patient to the unit but then submit to the rules of the intensive care unit. This seemed advisable because the majority of patients in an intensive care unit have respiratory problems with which an anesthesiologist by virtue of his training is especially skilled. Dr. Hamilton suggested that it would be impossible to establish general rules because the parochial problem in each institution would be paramount in determining the proper administration. Sister Darcy reported that the referring physician takes care of his respective patient in the intensive care unit but that the chiefs of services are the primary consultants. The importance of having large enough cubicles or rooms sufficient to accommodate the necessary equipment was pointed out by several people.

**Afternoon Session**

**Problems in Design to Provide Maximum Sepsis Control and Patient Privacy While Maintaining Maximum Nursing Surveillance**

Dr. John M. Kinney: Many physicians and surgeons would contend that the design features of an intensive care unit belong in
the province of the architect and the engineer planning a new intensive care unit. These specialists are very much in need of specific, factual information from the medical staff on the type of patients they intend to take care of, and certain hazards to any hospitalized patient who may become seriously ill. Professional staff have to know what they want, why they want it, and be able to persuade both the architects and the hospital administration and the community of the importance of the extra expenditures which a properly designed unit requires. I would like to devote this discussion to a particular kind of hazard which may be inherent in the design of an intensive care unit, namely, the hazard of cross infection.

Figures 5 and 6 show the hospital routes of infection which are of particular concern when we are taking care of ill patients in a segregated area, where undoubtedly infection will be a primary problem with some, and a secondary problem with many. As surgeons, we think a lot about the problems of skin
disinfection, and less about the problems of airborne contamination. There is a great deal of controversy about the exact role of airborne bacteria in surgical sepsis, however everyone agrees that it does play some role. It is difficult to minimize problems of airborne spread when the original design of an intensive care unit has been faulty. The various factors in routes of hospital infection indicate that under airborne infection we must discuss three kinds of transmission: droplets, dust, and droplet nuclei. The distinction here is one of size. Particles that are known as droplets have an aqueous center carrying varying numbers of bacteria and are usually over 100 microns in diameter. These settle extremely rapidly, but on the other hand they undergo continuous evaporation and if their settling takes place over any significant distance there will be total evaporation so that the final result is droplet nuclei containing bacteria (particles under 10 microns), which are small enough to remain suspended and to drift about on the air currents. Intermediate materials (dust particles between 10 and 100 microns), have varying settling rates depending on size. If one follows the particles that are emitted by a human sneeze, the mean size is around 10 microns and here there is a very slow but definite rate of settling. The important clinical fact is that larger particles are usually removed by the upper airway with the mucous blanket and by ciliary action. However, the small particles, droplet nuclei, float around in the air, are carried into the terminal airway with whatever bacteria are present, ride along and actually settle out in vulnerable areas. They undoubtedly have a lot to do with airborne infection that results from improper control of ventilation.

Studies by Wells at the Harvard School of Public Health on the distribution of a million droplets in one sneeze, according to size, show that roughly \( \frac{2}{3} \) of these particles are down in the 10 micron range or below. They carry bacteria as a rule and they are the ones that float around like smoke particles in the air. This air can only be sterilized by exposure to radiant energy from an ultraviolet source or by actual removal in the ventilating system. For this reason, the type of ventilation in intensive care areas assumes extra importance. There must be adequate air change per hour, not only for the comfort of patients and staff, but there must be extra air changes per hour in order to prevent the accumulation and transfer of bacteria on droplet nuclei, from septic patients to staff and from septic patient to uncontaminated patient within the unit. The work of Riley and O'Grady shows that when there are only six air changes per hour, which is considered the minimum for proper odor control, that droplet nuclei are cleared relatively slowly. In contrast when one moves to 10 air changes per hour or more, it is possible to clear droplet nuclei reasonably rapidly, and to maintain less than 10 per cent of the total which normally would be present.

The next problem is recirculation of air. Most industrial air conditioning provides up to 70 or 80 per cent recirculation. Since air coming from a septic patient area can carry bacteria which will seed an air conditioning system, and then begin to multiply on the filters and on the refrigeration coils, if recirculation is allowed, it is important that the air conditioning equipment be positioned so that it is convenient to service this regularly with proper germicides. Removal of filters is essential so that the air conditioning system does not transmit back to the patient area more bacteria than actually received.

The “recovery room” approach to intensive care is very common. The reason is usually as follows. Maximum nursing coverage is required, as well as complex equipment, and this is currently available only in the recovery room. Therefore, the administration and the staff either use part of the existing recovery room, enlarge the recovery room, or build a new facility just like the recovery room. In nearly every case this leads to prolonged care of acutely ill patients in a large open room with bed areas separated only by curtains. If one asks why this happens, one usually receives one of the following answers in support of the large open room: (1) it is easier for maximum patient surveillance, (2) it requires less total nursing staff, (3) it is less expensive to build and requires less floor space per bed. Very seldom does one hear any discussion of two additional factors: the
fact that open areas facilitate cross infection, and that they provide much less in patient privacy. These two factors are not particularly important for the patient who is in the recovery room for a few hours, emerging from a general anesthetic. They assume tremendous importance in the prolonged care of patients who, though ill and septic, are fully aware of their surroundings and terrified by acute clinical problems that they witness. In order to provide a clean air supply for these patients as well as privacy, it appears important (1) to have one bed per individual room, or a three wall cubicle, (2) to ventilate with outside air conditioning, either without recirculation, or to be otherwise designed so that there can be adequate bacteriologic control, and (3) to provide ultraviolet barrier of proper design for intensive care areas. I would like to make a final point here. The seriousness of airborne bacteria is not only a function of the cleanliness of air entering the patient area. It is also a function of the design in terms of the arrangement of furniture, the material used for flooring and walls, and whether there is an effective cleaning of horizontal surfaces with a liquid germicide.

In summary, in an intensive area not only the grossly septic patient but every patient is an exercise in bacteriologic control. Standard procedures for asepsis are seldom effective in a poorly designed unit. Proper design for containment of bacteria around a septic patient is similar to that for the exclusion of bacteria in an area around a clean patient. Neither containment nor exclusion can be effective if many patients receive prolonged care in a large room with only curtained bed areas. This is in addition to the fact that the presence of intensive care patients in an open area shared with the regular recovery room will increase the bacterial exposure of postoperative patients. Separation of beds into cubicles or rooms not only improves aseptic care but also gives each patient dignity and privacy, and helps the staff to consider and treat each patient as an individual.

"Humidification" of Inhaled Gases

DR. H. F. HELMHOLZ: Normal airway secretions are not sufficiently viscous to prevent their movement by ciliary-action, but drying increases viscosity and can produce crustiness. Total body dehydration causes production of more viscous secretions. In order to prevent or reverse increases in viscosity (i.e., decreases in mobility) of secretions, all evaporation must be prevented, and often it is necessary actually to add water via inhaled gas.

In considering humidification certain things must be kept in mind. When any gas is inhaled it is warmed and moistened. One liter of dry gas at average room temperature will increase in volume to 1.11 liters in the lung. Temperature change accounts for 50 ml. of the increase and humidification for 60 ml. increase in volume. Gases evolved from the liquid state or allowed to flow from high pressure cylinders are for all practical purposes bone dry. Rarely is the air fully saturated with water vapor at room temperature; we are rarely exposed to 100 per cent relative humidity at any temperature. In the winter, most heating systems produce very dry air indoors. At any given temperature, there is a maximum mass of water that will vaporize into a given volume of gas.

Although methods of humidification are various, the basic principles are the same. To attain saturation of a gas with water vapor, adequate surface for evaporation, time of exposure and heat of vaporization must be provided. Therefore when dry gas is brought into contact with water, water temperature (and gas temperature) will fall unless there is an adequate source of heat. Humidification of one liter of lung gas requires approximately 250 gram calories. A daily ventilation of 15,000 liters, if dry gas is inhaled, requires that approximately 375 Kilogram Calories and 650 ml. of water be supplied by the body. If body temperature is above that of inhaled gas, additional particulate water must be provided as a mist or fog so that as temperature rises source of vapor will not be from the airway wall or secretions.

For purposes of calculation, volume of saturated gas is used as a reference in table 13. Usual room temperature partial pressure of water vapor in saturated gas can be remembered as 20 mm., content as 0.2 ml. per 10 liters, and for body temperature, 47
mm. and 0.434 ml., respectively. Even when gas which is 100 per cent saturated at any given temperature is inhaled the following tabulation shows the amount of water per hour needed to saturate gas at normal body temperature.

<table>
<thead>
<tr>
<th>Temperature °C.</th>
<th>Prep Water Vapor Tension in Saturated Gas</th>
<th>CHO mg./liter Saturated Gas</th>
<th>CHO ml./10 Liters Saturated Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.6</td>
<td>4.8</td>
<td>0.048</td>
</tr>
<tr>
<td>5</td>
<td>6.5</td>
<td>7.6</td>
<td>0.076</td>
</tr>
<tr>
<td>10</td>
<td>9.2</td>
<td>9.3</td>
<td>0.093</td>
</tr>
<tr>
<td>15</td>
<td>12.8</td>
<td>12.7</td>
<td>0.127</td>
</tr>
<tr>
<td>20</td>
<td>17.5</td>
<td>17.1</td>
<td>0.171</td>
</tr>
<tr>
<td>22</td>
<td>19.8</td>
<td>19.2</td>
<td>0.192</td>
</tr>
<tr>
<td>25</td>
<td>23.8</td>
<td>22.8</td>
<td>0.228</td>
</tr>
<tr>
<td>30</td>
<td>31.8</td>
<td>30.4</td>
<td>0.304</td>
</tr>
<tr>
<td>35</td>
<td>42.2</td>
<td>39.2</td>
<td>0.392</td>
</tr>
<tr>
<td>37</td>
<td>47.1</td>
<td>43.4</td>
<td>0.434</td>
</tr>
<tr>
<td>38</td>
<td>49.6</td>
<td>45.7</td>
<td>0.457</td>
</tr>
<tr>
<td>39</td>
<td>52.5</td>
<td>48.1</td>
<td>0.481</td>
</tr>
<tr>
<td>40</td>
<td>55.3</td>
<td>51.0</td>
<td>0.510</td>
</tr>
<tr>
<td>41</td>
<td>58.3</td>
<td>53.6</td>
<td>0.536</td>
</tr>
<tr>
<td>42</td>
<td>61.5</td>
<td>56.3</td>
<td>0.563</td>
</tr>
<tr>
<td>46.1</td>
<td>76.0</td>
<td>68.7</td>
<td>0.687</td>
</tr>
</tbody>
</table>

These amounts of water in suspension will always lead to “rain out” in the tubing, mask, hood, or tent in which it is present. Adequate “humidification” for purposes of preventing airway water loss, thus requires “rain out” if inhaled gas is below body temperature. Small particle size will tend to delay but not prevent “rain out,” and is of importance only in this respect.

When dry gas is to be humidified, the following table gives amounts of water needed per volume of dry gas flow, as well as per volume of lung ventilation, needed to prevent evaporation from the airway.

<table>
<thead>
<tr>
<th>Body Temperature °C.</th>
<th>Mg./liter</th>
<th>ml./10 liters</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>24.2</td>
<td>0.242</td>
</tr>
<tr>
<td>38</td>
<td>26.5</td>
<td>0.265</td>
</tr>
<tr>
<td>39</td>
<td>28.9</td>
<td>0.289</td>
</tr>
<tr>
<td>40</td>
<td>31.8</td>
<td>0.318</td>
</tr>
<tr>
<td>41</td>
<td>34.4</td>
<td>0.344</td>
</tr>
<tr>
<td>42</td>
<td>37.1</td>
<td>0.371</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Body Temperature °C.</th>
<th>Ml. per Hour of Gas at Room Temperature</th>
<th>Ml. per Hour per 10 liters/minute of Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>28.90</td>
<td>26.04</td>
</tr>
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When a dry gas is bubbled through water at room temperature (22° C.) or a surface for evaporation is provided in any other way, for each 1 ml. of water evaporated, 583 ml. of water will be lowered 1° C., in temperature (or a lesser volume, lowered more, etc.). When this happens a gradient of temperature develops between the water and the air and heat flows into water. Depending upon evaporation, heat conductivity of container, temperature of any diluting gas, and relative air and water temperatures, any humidifier to which heat is not added from another source will fall in temperature to well below room temperature, a steady temperature being reached only after a long period. The temperature drop will be rapid at first, then be slower and slower until equilibrium is reached. This equilibrium temperature will be lower, the greater the flow of gas being humidified.
Since gases and air have relatively low heat capacities and usual water containers are made of materials which are poor heat conductors, the temperatures reached are usually five to fifteen degrees below room temperature.

It should be emphasized that many humidifiers provide for air dilution of gases used when a ventilator is used to bring fluid into a gas stream. To obtain 40 per cent oxygen, 3 liters of air will be mixed with each liter of oxygen to provide 4.5 liters at lung conditions. To obtain 70 per cent oxygen 0.6 liters of air will be added to each liter of oxygen to provide 1.8 liters at lung conditions. Thus in using tables to estimate whether sufficient water is being utilized to supply that needed to prevent evaporation, dilution as well as flow from gas source must be kept in mind. Though room air is never completely dry, rarely will relative humidity be over 30 or 40 per cent.

One should not forget, when "humidifying" an environment for a patient, that heat transfer from the patient to his environment must be maintained, and that evaporation of water, the most effective method available, is decreased or prevented by the humidification process.

Finally, it can be seen from the above considerations that whenever the normal humidifying system of the body is insufficient or bypassed, when secretions are already crusted or too viscous, saturation of gas below body temperature will not be therapeutic. Either a heavy mist must be provided, or gas must be fully saturated at or above body temperature. Saturation of gas above body temperature plus a fog or mist will best insure addition of water to secretions. A reasonably dense mist in a confined space is best assurance of adequate prevention of evaporation when temperature is kept below that of the body.

The Recognition and Management of Respiratory Insufficiency

DR. R. M. CHERNIAK: Respiratory insufficiency implies that there has been a failure of the respiratory system to supply sufficient oxygen to the blood and to maintain a normal arterial partial pressure of carbon dioxide, so that hypoxia either alone or in combination with hypercapnia develops. When hypoxia and hypercapnia develop acutely it is a true emergency which requires immediate therapy. Unless it is really obvious, however, acute respiratory insufficiency may not be recognized unless the physician is suspicious of its presence. It is, therefore, essential to know the mechanisms leading to respiratory insufficiency and the methods of recognition of this condition before proper therapy can be instituted.

Insufficiency for oxygenation may be present as a result of:

1. A diffusion defect, which develops when the quality of the alveolar capillary membrane is altered, or when there is a reduced pulmonary capillary bed available for diffusion.

2. A venous to arterial shunt within the heart or the lungs so that there is admixture with arterialized blood of hypoxic and hypercapnic blood which has bypassed functioning alveoli.

3. Altered ventilation-perfusion ratios throughout the lung, such as either perfusion of poorly ventilated alveoli (venous-admixture-like-perfusion) or ventilation of poorly perfused alveoli (dead-space-like ventilation).

4. Alveolar hypoventilation, or "respiratory failure."

In the first three of these situations there is only insufficiency for oxygen exchange or hypoxia, as long as the well-ventilated, well-perfused alveoli are hyperventilated. On the other hand when the alveolar ventilation is inadequate, the hypoxia will be accompanied by hypercapnea. Since this condition may present a true emergency requiring immediate remedial measures, it is important to emphasize its pathophysiology.

Pathophysiology of Respiratory Failure. The volume of air which is moved into and out of the lung during breathing (the minute ventilation) is composed of a dead-space component, which does not take part in gaseous exchange, and an alveolar component, which supplies oxygen to and removes carbon dioxide from the pulmonary capillary blood. The alveolar ventilation will fall whenever the physiological dead space increases without a proportionate increase in minute ventilation, or when the minute ventilation falls.
This fall in alveolar ventilation is exceedingly important, for the alveolar CO₂ tension is intimately related to and dependent upon the alveolar ventilation. For any given level of metabolism and CO₂ production, a change in alveolar ventilation will cause an inverse change in alveolar PₐCO₂. Since the arterial PₐCO₂ is virtually identical with the average alveolar PₐCO₂, a decrease in alveolar ventilation without a proportionate fall in CO₂ output will result in a rise in arterial PₐCO₂ or hypercapnia. Similarly an increase in CO₂ production without a comparable rise in alveolar ventilation will also result in hypercapnia. The hypercapnia is always accompanied by hypoxia, unless the patient is inhaling an oxygen enriched mixture.

Clinical Manifestations of Respiratory Failure. Respiratory failure may develop in a wide variety of patients who may be suffering from:

(1) Bronchopulmonary disease, particularly those with airway obstruction. Patients with pulmonary parenchymal disease such as pneumonia, pulmonary vascular disease such as thromboembolic phenomena, or pleural disease encroaching on the lung volume as in pleural effusion or pneumothorax are usually only hypoxic, the alveolar ventilation being sufficient to provide an adequate elimination of carbon dioxide at rest. However, the added ventilatory demands of superimposed bronchial obstruction, infection, or pulmonary congestion in these patients may precipitate acute respiratory failure with severe hypoxia and carbon dioxide retention.

(2) Diseases of the chest wall or thoracic cage. Respiratory failure may develop in patients with neuromuscular disease such as myasthenia gravis, poliomyelitis, the Guillain-Barré syndrome, tetanus, muscular disease of the chest cage such as kyphoscoliosis or severe obesity, and patients suffering from severe chest injuries.

(3) Failure of the central control of respiration, the medullary respiratory center having lost its sensitivity to carbon dioxide. This can occur as the result of drugs which depress the sensitivity of the respiratory center such as overdosage of barbiturates, narcotics, opiates or tranquilizers, or an excessive amount of anesthesia. It can also develop when the cerebral spinal fluid pressure is increased because of expanding intracranial lesions, cerebral vascular accidents, or head injuries. Rarely, it may develop as the result of encephalitis, bulbar poliomyelitis or syringobulbia.

In addition, in patients with respiratory disease and chronic carbon dioxide retention, the respiratory system may lose its ability to respond to excessive levels of carbon dioxide. The hypoxia, though normally not playing a prominent role in stimulating respiration, may become the principal regulator of the respiratory drive. The administration of oxygen to such patients may eliminate the stimulus to the peripheral chemoreceptors. In addition, the use of barbiturates, tranquilizers, or narcotics in patients in whom the medullary respiratory centers are already depressed will obviously result in a further diminution of alveolar hypoventilation with severe retention of carbon dioxide, and may eventually lead to coma and even death.

Acute respiratory insufficiency should be suspected in any of the patients mentioned above, particularly those in whom an acute respiratory infection such as bronchitis or bronchopneumonia, or asthma, or acute heart failure has developed. Chronic respiratory insufficiency, however, frequently develops insidiously, but should be suspected when chronic right-sided heart failure and polycythemia are present, since they are frequently associated with chronic carbon dioxide retention.

The clinical manifestations of respiratory insufficiency will depend upon the severity of the respiratory insufficiency. The clinical signs which may be elicited are those due to the primary disease process, those due to the precipitating factors, and those due to hypoxia and carbon dioxide retention.

The clinical findings resulting from hypoxia and hypercapnia are predominantly neurologic, the severity depending upon the level of hypercapnia and acidemia. Although some of these clinical manifestations may be encountered in other conditions with a lowered pH, the presence of hypercapnia in addition to acidemia would appear to greatly increase
the severity of the neurologic signs and symptoms. Disturbances of consciousness are most frequently observed. The patient may be very depressed or show evidence of confusion and hypomanic activity with hallucinations. Extreme lassitude, drowsiness, somnolence and coma may eventually develop. Headache is a frequent complaint and papilledema may develop. It would appear that the increased cerebral blood flow associated with an elevated arterial $P_{CO_2}$ and hypoxia may account for the headache and some of the mental changes. It is likely that the papilledema is related to an increase in cerebrospinal fluid pressure, but the exact mechanism of its development is uncertain.

Muscular movements such as fine tremors of the facial muscles and intermittent jerking of the fingers and arms are a characteristic feature of hypercapnia. Frequently there is a flapping tremor or "asteresis" as is seen in hepatic coma. Coarse myoclonic jerking of the trunk and arms and occasionally generalized convulsions may occur. In severe states of respiratory failure the limbs may be flaccid and the tendon reflexes absent. The plantar responses either remain flexor or are equivocal, although an extensor plantar response has been elicited occasionally.

Though acute hypoxia and hypercapnia are frequently precipitated by an acute infection, constitutional signs of infection are minimal or absent, the temperature being subnormal in many cases, and the white blood count being low, normal or only slightly elevated. There is frequently a marked tachycardia while the blood pressure may be high, low or normal. Congestive heart failure which is also frequently precipitated by the acute infection is often present, while other cardiovascular signs such as generalized vasodilatation with profuse sweating and peripheral collapse may be present, particularly in severe respiratory failure.

**Diagnosis of Respiratory Failure.** Since the clinical manifestations of respiratory insufficiency leading to hypoxia and hypercapnia are nonspecific, they will only aid in arriving at the correct diagnosis of the underlying condition if the attending physician is suspicious of the presence of respiratory failure. Unfortunately, unless it is extremely obvious, it is virtually impossible to assess the adequacy of the alveolar ventilation clinically. Cyanosis, if present, is an indication of severe hypoxia, but severe hypoxia may be present without cyanosis. What to the clinician's eye is adequate chest movement, and the stethoscopic assessment of adequate aeration, is not to be replied upon, despite the claims of many. The definitive answer can only be obtained if the possibility of an inadequate alveolar ventilation is suspected and confirmed by analysis of the arterial blood.

Analysis of the arterial blood in respiratory insufficiency will reveal the presence of hypoxia and an elevated $CO_2$ tension, thereby establishing the diagnosis of alveolar hypoventilation. In acute respiratory failure, the total $CO_2$ content may be little elevated, and the $CO_2$ combining power or the whole blood buffer base (Singer and Hastings), both indices of alkali reserve, are normal. In chronic respiratory failure, on the other hand, there has been compensation for the elevated $P_{CO_2}$ with elimination of chloride and retention of base and bicarbonate. As a result, the $CO_2$ content, and the $CO_2$ combining power are high. In addition, the serum chloride is low and the serum potassium may be elevated.

It is apparent that the diagnosis of alveolar hypoventilation is best established by the direct or indirect measurement of the arterial carbon dioxide tension. This can be determined directly with either the bubble technique of Riley et al., the Severinghaus carbon dioxide electrode, the micro-Astrup technique, or indirectly by determining the arterial pH and the total carbon dioxide content.

In addition, it has recently been shown by Collier et al. that the mixed venous carbon dioxide tension can be quickly estimated by a rebreathing technique in both normal subjects and individuals suffering from pulmonary disease. Recently a modification of this technique which can be used by even the smallest of hospitals has been described by Campbell and Howell. The simplified technique entails having the subject rebreathe about a liter of pure oxygen from a small anesthesia bag for one and one-half minutes, and after about a two-minute rest, the gas mixture in the bag is again rebreathed for 15 seconds. The concentration of carbon dioxide in the gas mixture is then analyzed with a $CO_2$ analyzer.
such as the infrared analyzer or the Schölander or Haldane apparatus, or a simpler device.

This technique yields an estimate of the mixed venous carbon dioxide tension. Since the difference between the mixed venous and the arterial carbon dioxide tensions is approximately 6 mm. of mercury at any level of carbon dioxide tension, the arterial $P_{CO_2}$ can be estimated. Thus, utilizing this technique, it is relatively easy to determine the arterial carbon dioxide tension even in the comatose or apneic patient. This procedure is performed by the house officers as part of the assessment of all respiratory cases admitted to the Winnipeg General Hospital. The finding of an arterial carbon dioxide tension greater than 45 mm. of mercury indicates that the alveolar ventilation is inadequate and that respiratory failure, a condition which requires urgent treatment and correction, is present.

**Management of Respiratory Failure.** Since the management of respiratory failure is basically similar under most circumstances, one may speak of its management in general terms, though obviously there are specific adjuncts to the therapy of particular conditions. The therapeutic approach to respiratory failure is based on the physiologic disturbances present. Thus, the treatment should be designed to provide and maintain an effective alveolar ventilation so that there is adequate elimination of carbon dioxide, and to reduce the metabolism or the work of breathing by relieving airway obstruction or pulmonary congestion.

The presence of bronchial obstruction due to thick viscous secretions is frequently a considerable factor in the development of hypoxia and carbon dioxide retention in patients with chronic respiratory disease. The infection, with excessive secretions which may be difficult to raise, and inflammatory swelling of the bronchiolar mucosa play a major role in airway obstruction. It is most important that these patients receive adequate hydration and a fluid intake of 3 liters of fluid/day should be ensured. The administration of bronchodilating agents and liquefying agents such as potassium iodide, nebulized liquefying enzymes, or detergents such as Alevaire or Tergemist, and adequate humidification of the inspired air aid greatly in liquefying the secretions, making them easier to raise and thereby diminishing airway obstruction. Control of infection with intensive antibiotic therapy, particularly intramuscular penicillin, should be achieved early. When these measures are inadequate, bronchoscopic aspiration of the retained secretions should be undertaken.

Aerosol inhalation of bronchodilating agents is exceedingly helpful in reducing bronchospasm and the mechanical work of breathing. Patients who are able to cooperate should be asked to exhale maximally before inhaling the aerosol, thus carrying the bronchodilator deep into the bronchial tree during inspiration. Severely obstructed patients should be given nebulized bronchodilator for 5 minutes every 30-60 minutes. If the patient is unable to cooperate sufficiently to take a deep breath, the bronchodilator aerosols may be administered with an intermittent pressure breathing apparatus.

Oral aminophylline with or without ephedrine should be administered 3-4 times daily if possible. Aminophylline may also be administered freely by vein or rectum and is frequently exceedingly helpful in initiating treatment in patients whose airways are so severely obstructed that inhaled bronchodilator cannot reach the bronchioles in appreciable quantities. The diuretic effect of aminophylline, by reducing pulmonary congestion, may also be beneficial in reducing the work of breathing.

**Heart Failure.** An exceedingly important consequence of chronic hypoxia and hypercapnia is right ventricular heart failure which develops because of a high pulmonary vascular resistance. Although the mechanism of production of the increased pulmonary vascular resistance may vary in different situations, hypoxia and in most cases hypercapnia aggravate the condition by causing vasoconstriction of the pulmonary vasculature.

The presence of jugular venous distension, hepatic enlargement and peripheral edema is suggestive of right ventricular heart failure. On the other hand, it has been pointed out that edema rarely develops in patients with chronic respiratory disease unless the arterial carbon dioxide tension is elevated, and it has
been postulated that the compensatory reabsorption of bicarbonate and base leads to expansion of the extracellular space and produces tissue edema.

Left ventricular failure probably also develops in patients with chronic respiratory disease as a result of depression of the myocardium by prolonged hypoxia and hypercapnia, the added load of an increased circulating blood volume due to secondary polycythemia, and increased fluid retention associated with an elevated $P_{CO_2}$. The resultant pulmonary congestion further alters the elastic properties of the lung and increases the work of breathing, and further aggravates the respiratory failure. Digitalis should be administered whenever heart failure is present. In addition, the patient should be placed on a salt-free diet and diuretics administered when necessary.

**Oxygen Therapy.** All patients with respiratory failure are suffering from a considerable degree of hypoxia which must be relieved. The hazards of the administration of oxygen to patients who are unable to maintain an adequate alveolar ventilation have been emphasized by many. Nevertheless, it should be pointed out that these patients are suffering from hypoxia, which must be relieved. If, during oxygen therapy, increasing mental stupor or confusion, a decrease in ventilation or a rise in arterial carbon dioxide tension occurs, despite intensive therapeutic measures, a mechanical aid to respiration is indicated.

**Gastric Suction.** In patients suffering from barbiturate intoxication, it is frequently desirable to insert a gastric tube so that the stomach contents can be aspirated. This should only be done if a cuffed endotracheal tube has been inserted so that aspiration of gastrointestinal contents is impossible. This is important because aspiration pneumonia frequently develops if the stomach is aspirated before the airway is intubated. In addition, we have frequently noted acute gastric dilatation with "coffee-ground" gastric contents in patients suffering from acute respiratory failure. We have, therefore, made it a practise to insert a gastric tube following intubation or tracheotomy in all patients with respiratory failure.

**Respiratory Stimulants.** In mild barbiturate intoxication, the intravenous administration of a stimulant may wake the patient. In our experience, however, the administration of respiratory stimulants to the patient who is heavily narcotized is of no avail. In addition, despite the fact that some drugs are touted as being barbiturate antagonists, none is, in fact, capable of doing this. However, when the patient with barbiturate overdosage is in the mildly responsive state, the administration of caffeine, amphetamine, or ethamivan may lessen the patient's drowsiness so that nursing care is simpler. However, at any time, the use of respiratory stimulants is only an adjunct to therapy and should only be used along with provision of an adequate alveolar ventilation and circulating blood volume. In cases of acute respiratory failure due to pulmonary or extrapulmonary disease, respiratory stimulants are not indicated and may be harmful, for they may lead to stimulation of non-respiratory as well as respiratory muscles, with marked increase in $CO_2$ production which the respiratory apparatus may be incapable of eliminating. In such cases it is imperative that therapy should be directed at reducing the resistances to breathing when possible, and providing an adequate alveolar ventilation.

In order to provide an adequate alveolar ventilation it is essential to maintain a patent airway. In the comatose or semi-comatose patient it is usually necessary to instill an endotracheal tube. In our hands, if the patient is unconscious or still requires respirator therapy after 36 hours, or if secretions are a problem, a tracheostomy is performed. The tracheostomy should be performed over a bronchoscope or if this is not possible over the endotracheal tube. A rubber cuff which can be inflated should be placed around the tracheostomy tube so that respirations may be controlled if necessary.

**Tracheostomy Care.** Whenever an endotracheal tube is inserted or a tracheostomy is performed, inspired air is no longer exposed to the nasal mucosa where it could be humidified. It is, therefore, essential to provide adequate humidity to the respiratory tract for crusting and thickening of mucus develops unless the humidification is carefully attended to. This can usually be accomplished by the nebulization of oxygen or compressed air...
through saline or detergent, preferably heated to as close to body temperature as possible, into a perforated plastic adapter placed securely over the tracheostomy opening. If this is not available frequent instillation of several drops of saline into the tracheostomy opening are of great benefit.

Due to the almost continuous suctioning which most patients with tracheostomies require, there is nearly always some degree of tracheal trauma and infection. It is important that the nursing staff be trained in absolute sterile technique as well as the performance of effective but gentle suction. Suction should be carried out with a curved catheter on a Y tube, with only one opening at its tip. The curve allows for easier passage into the left main bronchus. The single opening at the tip of the catheter is preferred since the tracheal mucosa may be damaged if the vacuum is exerted through side openings while the catheter is being withdrawn from the trachea, particularly if a plug is attached to the distal opening.

A separate sterile catheter should be used each time the patient requires suctioning. The catheter should be inserted into the tracheobronchial tube for no longer than 10 to 15 seconds at a time and suction should be applied only during its withdrawal. As indicated by auscultation, the catheter should be directed into the right or left main bronchus as far as it will go, and then immediately withdrawn with a twisting motion. Too often, the catheter is pushed up and down the tracheobronchial tree, almost completely obstructing the airway for long periods of time.

The foot of the bed should be elevated about 12 inches and the patient turned from side to side every half hour to facilitate drainage of the bronchial secretions to that part of the trachea which is accessible to the suction catheter. Intensive physiotherapy with “chest pounding” should be carried out frequently. Bronchoscopy may be necessary again on the third or fourth day following tracheostomy, or on repeated occasions, in order to remove blood clots, crusts and inspissated secretions.

*Assisted or Controlled Respiration.* If the patient is apneic, mouth-to-mouth resuscitation may be necessary until an endotracheal tube can be inserted. If possible, some form of positive pressure breathing should be used to either assist or control respiration through the endotracheal tube. The simplest form of positive pressure breathing is, of course, achieved by compressing an anesthesia bag or a Ruben’s bag containing oxygen.

The use of automatic respirators is not without some undesirable consequences. It is important to understand some of the adverse effects which may develop. Some respirators are active only during inspiration and produce only intermittent positive pressure patterns while others may allow for a negative pressure during expiration. Depending on the expiratory resistance offered by the respirator the airway pressure may be high during expiration as well. An elevated airway pressure tends to impede venous return to the right heart and, in patients with diminished circulatory reserve, may seriously depress cardiac output, so that the blood pressure may fall. This may be corrected by ensuring for a prolonged expiration time or the addition of a negative pressure during expiration. On the other hand, a negative pressure during expiration, or for that matter, unimpeded expiratory flow may permit collapse of the smaller bronchi and lead to air trapping. Thus, a negative pressure expiratory phase should likely only be used in patients suffering from circulatory collapse or impending circulatory failure while an adjustable resistance during expiration may be desirable at all times.

When assisted respiration is all that is necessary the patient-triggered intermittent positive pressure breathing units (IPPB) have proved to be an exceedingly useful and practical adjunct to the management of the patient with respiratory failure and carbon dioxide retention. The patient-operated IPPB is a particularly convenient and effective means of administering nebulized bronchodilators and detergents. Since this apparatus requires that the patient produce an initial negative pressure in the thorax to initiate inspiration, it is immediately apparent that the patient who is extremely fatigued or whose respiratory muscles are weak or paralyzed may be unable to activate the machine. Also, constant attention is required whenever IPPB is used, since while breathing oxygen, the patient may
actually depress his minute ventilation considerably. The patient must, therefore, be encouraged constantly to take deep breaths as long as IPPB is administered.

If the patient is apneic, excessively fatigued or unable to achieve an adequate alveolar ventilation with assisted respiration some form of automatic apparatus is necessary to restore the alveolar ventilation to normal levels. Most respirators used nowadays deliver a positive pressure into the upper airway. However, it should be pointed out that a tracheostomy is not without its complications. The cuirass body respirator (Emerson) should be tried first, if at all possible, to provide an adequate alveolar ventilation.

**Monitoring the Patient on a Respirator.**

Since the respirator is being used to provide an adequate alveolar ventilation it is imperative to monitor the patient frequently to ensure that the arterial $P_{CO_2}$ is maintained at normal levels. Ideally, therefore, the arterial or "rebreathing" $P_{CO_2}$ should be monitored and the respirator adjusted to maintain the $P_{CO_2}$ at normal levels.

If the principles of operation of respirators are understood several other observations at regular intervals will help to ensure that the respirator is still providing an adequate ventilation and that no pathology is developing in the lungs. The force generated by any respirator during inspiration is expended against the resistance within the respirator, the resistance to flow in the tracheobronchial tree and the viscous and elastic resistances of lung and chest wall. If any of these resistances increase it will require more force to provide the same tidal volume. Conversely, if the resistances decrease it will require less force to provide a given sized-breath.

There are two basic principles of operation of automatic respirators: (1) the controlled pressure respirator (Bird Respirator) in which the maximum airway pressure is adjusted by the operator to provide a suitable tidal volume, and (2) the controlled volume respirator (Engstrom Respirator) which discharges a predetermined volume of gas during each inspiratory phase. So long as there is no change in resistance to inflation, or leak in the airway, both the controlled pressure and controlled volume respirator will deliver a constant tidal volume. If the resistance of the lung rises, the controlled volume respirator will overcome the increased resistance by delivering the tidal volume to the patient at a higher pressure. However, since the pressure cutoff has been preset on the controlled pressure respirator the amount of gas forced into the patient will fall reciprocally.

Thus it is important to appreciate that a pressure-controlled ventilator will increase its frequency if the patient’s resistance to inflation increases, will chatter in the face of complete obstruction, or hiss and fail to terminate inspiration if there is a leak in the airway. With a volume-controlled ventilator, on the other hand, increases in resistance to inflation or a leak in the airway will be reflected by changes in the airway or monitoring pressure.

Once an adequate alveolar ventilation is ensured, as evidenced by a normal arterial $P_{CO_2}$, the respirator should be monitored at frequent intervals by observation of the airway pressure and tidal volume in a volume-controlled respirator, and by observation of the respiratory rate and, if possible, the tidal volume in the pressure-controlled respirator. The time-operated respirator, such as the Emerson "iron lung," is unable to recognize changes in resistance to distension and provision of an adequate ventilation can only be ensured by determination of the arterial $P_{CO_2}$.

In addition, it is imperative to analyze the arterial $P_{O_2}$ daily. As long as the oxygen concentration of the inspired gas is constant, the arterial $P_{O_2}$ is a sensitive indicator of minute pathological changes in the lung. A fall of arterial $P_{O_2}$ frequently precedes clinical signs or X-ray findings by several days, and should be taken to indicate the development of poorly or non-ventilated areas of lung which are still being perfused. The attending physician should then institute a vigorous effort to expand the lungs in order to open up small areas of atelectasis, and bronchoscopy to remove accumulated secretions may be necessary.

**In summary,** it is important to reiterate that respiratory failure implies an inability on the part of the lung to provide adequate oxygenation and elimination of carbon dioxide. This is the result of an inadequate alveolar ventila-
tion in relation to the metabolic production of carbon dioxide. The management of respiratory failure, therefore, should be intensive and directed at the reduction of the metabolic production of carbon dioxide, particularly measures directed at the work of breathing, and the provision of adequate alveolar ventilation by assisting or controlling respiration. When controlled respiration is instituted, the adequacy of respiration should be assessed by measurement of the arterial $P_{CO_2}$. Further monitoring of the respirator depends on the type of respirator used. In addition, daily estimation of arterial $P_{CO_2}$ will provide early indication of the development of changes within the lung.

**Long Term Resuscitation in Intensive Care Units**

**Dr. Peter Safar:** For the past eight years, my associates and I have been active as consultants in the treatment of respiratory and circulatory distress in medical and surgical patients. Prior to 1958, at the Baltimore City Hospitals, we experienced the frustrations of trying to provide respirator care and unconscious patient care in various locations of the hospital without the help of trained inhalation therapists and specially-trained nurses. In 1958, therefore, we initiated the establishment of an Intensive Care Unit adjacent to the postanesthesia recovery room.

In 1961 similar intensive medical and nursing care was initiated at the Presbyterian-University Hospital of Pittsburgh. Policies and routines were recommended by a subcommittee of the Joint Committee on Patient Care. This Intensive Care Unit Sub-committee consists of one representative from each of the following: Surgery, Medicine, Infectious Diseases, Neurosurgery, Nursing, Administration and Anesthesiology, with the Chief Anesthesiologist as Chairman. These units are for patients of all departments and not limited to respirator cases. All patients requiring continuous assisted or controlled ventilation, however, are admitted to these units.

At present we are temporarily working in an improvised unit with only six beds, with single rooms available nearby for isolation cases, staffed by one special team of nurses. Of the 376 admissions during the past year approximately one-third were medical, one-third neurosurgical, and one-third other surgical admissions.

The smooth functioning of an Intensive Care Unit depends on interdepartmental cooperation and on the following three factors: (1) well-defined responsibilities and authority, (2) the physical set-up, and (3) standardization of certain procedures.

**Responsibilities and Authority.** Teamwork based on mutual respect is usually more effective than authority established by edict. Nevertheless, a few policies were found to be essential for avoiding conflicting treatment orders and for maintaining continuity in patient management.

The present **Intensive Care Unit Policy** of the Presbyterian-University Hospital of Pittsburgh is as follows:

**Purpose:** The Intensive Care Unit is for patients who require intensive medical and/or nursing care. Patients who are not salvageable should not be admitted.

**Admissions and Discharges:** The patient’s physician recommends admission and discharge and remains in charge of the patient in the Intensive Care Unit. He must accept standard I.C.U. procedures.

Should there be no bed available for a salvageable patient in need of intensive care, the head nurse in the I.C.U. asks the physician for discharge of the patient who, in her opinion, needs intensive care least. If agreement cannot be reached with the patient’s physician, she asks the Chairman of the Intensive Care Committee for a resolution of the problem in consultation with the appropriate Chief of Service.

Each patient should have a clear-cut assignment to a single service.

**Orders:** All treatment orders should be written by the medical or surgical resident in charge of the patient. Exceptions are: (a) orders for respirator care (assisted or controlled ventilation) which are to be written by the anesthesiologist, (b) orders for preoperative medication and immediate (recovery room) postoperative care which may be written by the anesthesiologist and/or surgeon, and (c) emergency orders which are to be written by any physician attending the patient.
The physician writing such orders should be certain that the physician in charge of the patient is notified of the emergency.

Respirator Care: Decisions for start and discontinuance of respirator care should be made by mutual agreement between the physician in charge of the patient and the anesthesiologist.

Anesthesiology Consultation: The Department of Anesthesiology provides emergency and consultation service 24 hours per day. All physicians not primarily in charge of the patient, including anesthesiologists, work on a consultation basis.

I.C.U. Committee: The I.C.U. Committee recommends I.C.U. policies and patient care routines to the Executive Committee of the Staff and assists in the resolution of major problems concerning planning and running of the unit.

Nurses' Training: The special training of graduate nurses in the Intensive Care Unit should be under the professional guidance of the Intensive Care Unit Committee in cooperation with the Director of Nursing.

Role of the Anesthesiologist. Many Intensive Care Units were established primarily for the convenience of nursing care. The primary purpose of such a unit, however, is intensive MEDICAL care, with specially-trained nurses as helpers. Some patients require the constant attendance of a physician who is experienced in emergency and long-term resuscitation techniques. This is the area in which the Anesthesiologist can contribute most to patient care outside the operating room. One staff physician should be the coordinator of the unit and he also would be the logical choice for Chairman of the Intensive Care Unit Committee. Although in some hospitals, the Anesthesiologist may qualify best for this role, the coordinator should be selected not on the basis of specialty affiliation, but rather on the basis of interest, personal clinical experience and availability. He should be responsible for respirator care and inhalation therapy and for the teaching of nurses and house staff in tracheostomy care, resuscitation and other procedures.

In Intensive Care Unit work, one staff Anesthesiologist is assigned fulltime to the unit to maintain continuity of special treatments. He sees, in consultation, all patients admitted. Each anesthesia resident is assigned to the unit for 1–2 months. The Anesthesiologists make rounds several times a day, preferably jointly with the physicians of the other specialties. During nights and weekends the resident "on call" for anesthesia is immediately available for Intensive Care Unit work, while the Intensive Care Unit staff Anesthesiologist is available by phone. Residents providing night coverage for the Intensive Care Unit should have had prior experience under supervision. Ideally, when several new respirator patients are admitted, a resident and staff Anesthesiologist should be available in the hospital for Intensive Care Unit work alone, also during nights and weekends.

Providing around the clock coverage with Anesthesiologists experienced in Intensive Care Unit work is difficult. We found it possible only by utilizing extensively the help of nurse anesthetists in the operating rooms and inhalation therapists outside the operating rooms. Since many long-term resuscitation techniques are still in the pioneering stage, their acceptance may be hampered by inexperienced "consultants."

Dr. Safar then discussed the physical set-up of an Intensive Care Unit and showed plans for the new unit at Pittsburgh.

It was found advisable to establish simple and precise routines for the nursing staff concerning the following procedures: (a) general unconscious patient care; (b) continuous intravenous administration of potent drugs; (c) asepsis; (d) emergency cardiopulmonary resuscitation; (e) prolonged assisted and controlled ventilation; (f) tracheotomy care; and, (g) prolonged hypothermia. (a)–(d) should be part of the training of house staff and Intensive Care Unit/Recovery Room nurses and will not be discussed here.

Prolonged Assisted and Controlled Ventilation. During a 5-year period over 250 patients received assisted or controlled ventilation for periods from 1 day to 4½ months.

The following conditions were considered indications for prolonged artificial ventilation: (a) respiratory paralysis from any cause; (b) severe pulmonary disease; (c) severe chest wall trauma; (d) restriction of breathing.
movements (for instance, after major abdominal surgery with abdominal distension or in obese patients); (e) metabolic acidosis (for instance, after open heart surgery, prolonged hypoxia or severe shock); and (f) "exhaustion" (for instance, following extensive surgery in patients in poor physical status). In several of these indications the temporary abolishment of the work of breathing (and thus the reduction of oxygen consumption and acidosis) seems to be the primary reason for the beneficial effects of prolonged controlled ventilation.

The Tank Respirator. The Scandinavian experience with poliomyelitis patients during the early 1950's established the superiority of intratracheal positive pressure ventilation over the use of the tank respirator (iron lung) without tracheostomy. Our experience showed that this superiority exists also when the tank respirator patients are tracheotomized. The principal advantages of intratracheal positive pressure ventilation over the use of the tank respirator are: greater accessibility and mobility of the patient, greater simplicity, greater ventilatory reserve which is essential in patients with reduced lung-thorax compliance or increased airway resistance, and easier synchronization with spontaneous breathing.

From 1958 to 1960 a simple routine of prolonged controlled ventilation was established. This routine includes: the use of large bore cuffed tracheotomy tubes, warm mist, artificial "sighing"-coughing, change of position, passive hyperventilation with approximately 50 per cent oxygen, and aseptic, atraumatic tracheostomy care.

Cuffed Tracheotomy Tube. Simple "plumbing" errors, i.e., difficulties with the tracheostomy or the connectors between tracheostomy tube and nonrebreathing valve, are the most common causes of life-threatening emergencies in respirator cases. "Plumbing" is of greater practical importance than the choice of a particular respirator or the exact monitoring of blood gases. The swivel adapter of the Mörch-Jackson silver cannula, connected to the valve via a flexible non-kinking rubber tube, provides a movable connection which is necessary to avoid injury. A tight-fitting, narrow, double-walled, low-pressure rubber cuff is mounted on all adult tubes (fig. 7). The cuffed tube (in contrast to the uncuffed tube) facilitates constant volume ventilation, protects against inhalation of foreign matter, facilitates humidification, and makes patient-triggered (assisted) respiration possible.

Great care is necessary for the safe use of cuffed tubes. The following cuff technique was used continuously for periods up to 4½ months without the development of tracheal necrosis as checked by tracheoscopy:

No leak technique (for aspiration risks)—Inflate the cuff slowly while inflating the lungs with positive pressure until all audible air leakage through the mouth or nose is abolished—but no more. DEFLATE the cuff every 2 hours for about 1–2 minutes, and re-inflate cautiously as described above.

Minimal leak technique (for conscious respirator patients)—Inflate the cuff slowly until all audible leakage is abolished, and then deflate the cuff slightly merely to allow the patient to talk without losing large inflation volumes. Deflation of the cuff at regular intervals (as recommended for the no-leak technique) is not necessary with the minimal leak technique.

When controlled ventilation is not expected to exceed 24 hours (e.g., immediate postoperative support), an orotracheal tube is used. Small amounts of opiates or relaxants are given if the patient is reacting on the tube. Continuous ventilation via mouthpiece or mask proved unsatisfactory.

Humidification. With the upper respiratory mucosa bypassed, the goal is to deliver into the tracheostomy tube air-oxygen mixtures saturated with water vapor at body temperature. With the use of specially heated midstream humidifiers or atomizers, it proved pos-
sible to deliver a humidity of over 90 per cent at approximately 35° C. Spot checking of the delivered gas temperature is desirable, since we have seen hyperthermia caused by failure of the humidifier thermostat.

_**Sighing and coughing.**_ The need for intermittent deep lung inflations to counteract miliary atelectasis was suspected as early as 1957 on the basis of crude compliance measurements in man. Therefore, artificial sighing with a 3-liter self-inflating rubber bag was introduced as a routine procedure in paralyzed respirator cases (fig. 8). More recently, the soundness of this practice has been established scientifically by the work of Bernstein, Mead, Bendixen and others. A respirator which automatically produces periodic overinflation would be desirable but is as yet unavailable.

When patients have difficulty clearing secretions in spite of adequate humidification, sighing should be combined with artificial coughing. This consists of simultaneously releasing the airway pressure at peak inflation and externally compressing the thorax. In addition, various postures (depending upon the lung area to be drained) and pounding ("cupping") of the thorax may be utilized.

_**Positioning.**_ Change of posture every 1–2 hours to counteract pulmonary hypostasis and the development of bed sores, as well as active or passive limb motions are part of intensive nursing care in unconscious or paralyzed patients.

_**Ventilation.**_ In patients without chronic cardiopulmonary disease mild mechanical hyperventilation without blood gas monitoring proved simple and safe. Approximately 1 1/2–2 times the ventilation recommended by the Radford nomogram, utilizing approximately 50 per cent oxygen was used. Oxygen enrichment proved essential in spite of sighing because some venous admixture invariably develops in respirator cases. In poliomyelitis patients, the above routine carried out for several months stabilized the arterial $P_{CO_2}$ between 25 and 35 mm of mercury. Neither was consciousness disturbed, nor did signs of tetany develop. In patients with cardiopulmo-
nary disease, however, ventilation and inhaled $P_{O_2}$ concentration must be guided by arterial $pH$, $P_{CO_2}$, and $P_{O_2}$ values.

It is especially important in patients with chronic hypoxia and hypercarbia to avoid a rapid lowering of the $P_{CO_2}$. In six patients with emphysema and $CO_2$ narcosis, when vigorous assisted or controlled ventilation restored consciousness and rapidly lowered the arterial $P_{CO_2}$ to normal or slightly below normal values, subsequent coma and convulsions occurred. Intracellular alkalosis is thought to be the basis of the phenomenon (Robin). In patients with long-standing respiratory acidosis, therefore, re-oxygenation should be prompt, but the $P_{CO_2}$ should be lowered gradually to levels the patient is accustomed to. If the pulmonary respiratory drive is too great to allow the "assister" or "controller" to ventilate with low volumes, intravenous narcotics are used.

**Assisted Versus Controlled Ventilation.** Controlled ventilation proved simpler and safer for maintenance. In patients with flail chest and when it is desirable to reduce the work of breathing, controlled ventilation is the choice. If the patient "fights" the respirator, hyperventilation preferably by manual bag compression should be tried first. Conscious patients may be coached to let the machine take over. If all this fails, "softening" doses of narcotics or relaxants are used.

**Choice of Respirator.** All respirators, even the pressure-cycled ones, should be adapted for the monitoring of exhaled tidal volumes (e.g., by a Wright ventilation meter) and of airway pressures. Intermittent positive pressure ventilation with a modified Mörch piston respirator or a Bennett PRIA unit proved satisfactory. A negative phase seems indicated only in patients with cerebral lesions in whom the mean jugular venous pressure should be kept as low as possible. For this purpose we have used an East-Radcliffe respirator. A Ruben bag-valve assembly should always be at the bedside for transportation, interval ventilation, for sighing, and when the respirator fails.

**Tracheostomy Care.** Tracheotomies performed too low have caused hemorrhage, pneumothorax, slipping-out of the tracheostomy tube and difficulty with tube change. Tracheotomies for respirator cases should be performed just below the first tracheal ring. Control over the tracheal opening should be retained for at least 48 hours, either by suturing a V-shaped flap to the skin or by placing a loop of silk around the lower edge of the tracheal opening. In tracheostomy care one should always consider the following basic requirements: (a) airway patency, (b) sterility, (c) maximal humidification of the inhaled air, and (d) avoidance of trauma to the tracheobronchial tree.

**Equipment the Nurse Should Have Ready.** Sterile suction catheters (straight and curved tip), towels, cup with water and forceps—all should be sterile. Sterile cup with N.P. solution (neomycin 1 mg./ml. plus polymyxin B 0.1 mg./ml.) for storage of adapters and introducer at patient's bedside. Solution and cup should be changed daily. Suction machine with Y-tube. Sterile gauze and Kleenex. Spare sterile tracheotomy tube of the same size.

**Recommended Suctioning Procedure.** The tracheotomy tube should be suctioned only when presence of phlegm is audible. Routine suctioning at regular intervals should be performed only when specifically ordered by the physician. Too frequent suctioning causes trauma and infection. Wash the hands and use a freshly sterilized (autoclaved or boiled) suction catheter, cup and sterile water for each suctioning procedure. Place a sterile towel over the patient's chest, close to the tracheostomy tube. The suctioning procedure may consist of several successive insertions of the catheter if contamination of the catheter between insertions is avoided. Moisten the catheter tip with sterile water before insertion. Handle with sterile forceps the part of the catheter which is to be inserted.

Insert the catheter with the Y-tube open and apply suction while slowly withdrawing the catheter. Avoid repeated "poking." Suction the right and the left lung separately. Use curved tip catheters for the left lung. This deep suctioning may be performed by graduate nurses of the Intensive Care Unit and the Recovery Room who are trained in this procedure. Rinse the catheter with sterile water between insertions. If one touches anything outside the lumen of the tracheostomy
tube with the catheter, it is contaminated and
a new one must be used.

Make certain that the patient is well-
oxigenated before suctioning and avoid pro-
longed suctioning as it may produce hypoxia
and cardiac arrest. In apneic, respirator pa-
tients, do not interrupt ventilation for more
than 30 seconds at a time for suctioning. You
may suction through the swivel connector
without disconnecting the respirator. Isotonic
saline solution may be injected into the
trachea, but only by a physician.

Change of Tracheostomy Tube. The inner
cannula should be cleaned thoroughly with
soap and hot water and sterilized by boiling
for 5 minutes at least every 12 hours. Ventila-
tion should be continued via a spare inner
cannula. The change of the outer tracheostomy
tube must be performed by a physician. The
anesthetist should be called when difficulty is
anticipated and for the change in all respira-
tor cases. Sterile equipment which the nurse
should have ready for change of the tube in-
cludes: tracheal hook, cuff-spreader, gloves,
one replacement tube the same size (check
cuff before insertion) and one spare tracheo-
stomy tube one size smaller, an extra tracheo-
stomy tape and water soluble lubricating
jelly; suitable lighting equipment should be
available.

For the first change and when difficulty is
anticipated, there must also be a bag mask
unit and orotracheal intubation equipment
ready for use as ventilation via mouth or nose
may prove necessary. Apneic respirator pa-
tients should be hyperoxygenated before
changing the tube.

Prolonged Hypothermia. Hypothermia re-
duces the reaction of the brain to both traum-
atic and ischemic injury. Prolonged hypo-
thermia is indicated in any patient who has
sustained brain damage severe enough to alter
consciousness regardless of the etiology.
Cooling is particularly desirable in problems
in which the temperature may rise, as in
third ventricle surgery, bacterial or viral in-
fecion of the brain, head injury and basilar
artery occlusion syndrome.

In dogs, 25° C. for 1 hour is protective
if started within 1 hour after injury. Since
treatment can rarely be started that early and
since it is dangerous to lower the tempera-
ture that much, we substitute hypothermia of
30-32° C., until the patient begins to awaken,
for a maximum of 3 weeks. Edema following
injury may last up to 3 weeks.

The technique consists of (a) anesthesia
and curarization for blockage of shivering
during the induction of hypothermia; (b)
external application of cold (blanket or ice
bags); (c) control of shivering, convulsions
and restlessness during maintenance by the
intermittent intravenous infusion of "lytic"
drugs (e.g., a mixture of meperidine 100 mg.,
promethazine 100 mg. and phenobarbital 100
mg.); and (d) tracheostomy only in selected
cases (50 per cent of Rosomoff's series). The
type of drugs used is less important than the
technique used to block shivering without
producing respiratory depression. Blood gas
monitoring seems desirable, since even mild
hypercarbia may be harmful in patients with
cerebral lesions. In some cases, therefore,
artificial respiration may be required.

Hypothermia without undue drug depres-
sion does not mask the signs of a mass lesion,
since hypothermia per se (at 30° C.) does
not produce unconsciousness. The pupils
react and since hemiparesis, bradycardia and
respiratory depression are recognizable.

Prolonged hypothermia is a very difficult
technique to carry out optimally. The main
deterrent to its use seems to be the lack of
adequately controlled intensive medical and
nursing care.

Training of Personnel. Nurses and house
officers of all departments involved can learn
the procedures outlined by daily contact with
patients. This is best done under the super-
vision of a staff Anesthesiologist and other
staff physicians experienced and interested in
Intensive Care Unit work.

The inhalation therapist's role in the Inten-
sive Care Unit is to help physicians and nurses
by maintaining and checking respirators and
other equipment; helping in emergencies; and,
administering intermittent positive pressure
and aerosol treatments.

The chief Anesthesiologist conducts a simple
and practical 2-week course every 6 months in
inhalation therapy, respirator care and resuscita-
tion. This course is attended by new anes-
thesia residents, inhalation therapists, present
and prospective Intensive Care Unit-Recovery
Room nurses, and other interested personnel. Since the special nurses require additional knowledge, this course is expanded to 4 weeks for them. The mornings are devoted to seminars and demonstrations, 2 weeks for the above-mentioned inhalation therapy course and 2 weeks for other topics. The latter seminars and demonstrations are conducted by staff physicians of various departments and by nurses with Intensive Care Unit experience. It is imperative that physicians assume the responsibility for the nurses’ training.

This discussion has merely attempted to convey some of our concepts in the field of intensive care. No attempt was made to present a bibliography or to discuss all techniques in detail.

Discussion

Dr. Kinney stressed the importance of the increased water requirements in febrile patients who are controlled by respirators. Thus added humidification to the airway is necessary to prevent drying of secretions. Dr. Severinghaus questioned the importance of droplet nuclei in infections in the types of patients usually cared for in intensive care units. Dr. Kinney replied that the infection rate dropped if the airborne droplet nuclei are controlled. Dr. Seeley commented that the problem of ultraviolet radiation on the control of wound infection has been investigated by the Committee on Trauma of the National Research Council. The report of this committee will appear in Annals of Surgery. Dr. Holaday suggested that technicians ought to be able to perform blood gas analyses as well as take care of ventilators. Dr. Cherniak, however, suggested that the person responsible for the patient should do the analyses and adjust the ventilation parameters. The problem of monitoring these patients was discussed. Dr. Bates suggested that a blood lactate level is one of the better indices of the adequacy of tissue oxygenation and circulation. Dr. Holaday reiterated the importance of bedside measurement rather than distant monitoring. The committee displayed a lack of enthusiasm for central or distant monitoring. Dr. Severinghaus mentioned two new techniques for monitoring. They include the determination of mixed venous oxygen tension which adequately reflects low tissue oxygenation. Continuous blood pressure monitoring may be done by attaching the pressure line from an indwelling arterial catheter to a suitably arranged aneroid manometer.

The place of telemonitoring in the future of intensive care units was briefly discussed without significant conclusions being drawn.

Twenty-Fifth Anniversary Symposium

The Annual Symposium to appear in the July–August issue will commemorate the twenty-fifth anniversary of the founding of this Journal. The theme begins on an historical note and broadens into an examination of the human, environmental, and scientific substance of anesthesiology today. Life among the early anesthetists, the scientific milieu, inherent hazards in apparatus, air pollution and radiation, the psychology of pediatric anesthesia, and an indictment of antiexplosion practices are just a few of the essays that have been prepared by men well known for their work in these fields. This is a new perspective that should provide food for thought for some time to come.