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ABSTRACT

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- 1. Preparing Institution: University of Pittsburgh School of Medicine, Department of Anesthesiology, Pittsburgh 13, Pennsylvania.
- 2. Title of Report: A Study of Artificial Respiration and Resuscitation.
- 3. Principal Investigator: Peter Safar, M. D.
- 4. Dates: January 1 to December 31, 1962. 80 pg. (7 enclosures) 9 tables.
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- I. Cardio-pulmonary Resuscitation. (A) In dogs with ventricular fibrillation, various combinations of external cardiac compressions (ECC) and lung inflations were studied. Artificial arterial pressures and flows were slightly better in most dogs when lung inflations were simultaneous with ECC as compared to interposed lung inflations. Arterial O₂, CO₂ and pH values were closer to normal with interposed inflations (same tidal volumes and rates). ECC for periods longer than 15 seconds without ventilation led to a fall in arterial O₂ saturation when air was used for ventilation. These data and clinical experience with over 100 resuscitation attempts made us recommend a lung inflation/ECC ratio of approximately 3/15 for the not intubated patient. This ratio was also used by a single operator. (B) Constant manual pressure over the abdomen during ECC increased carotid and femoral artery flows and pressures. (C) Epinephrine 2 mg. given subcutaneously over the sternum during ECC did not significantly increase artificial arterial pressures and flows. Epinephrine 0.25 - 0.5 mg. given intravenously during ECC raised artificial arterial pressures, but not arterial flows. Epinephrine or nor-epinephrine given intravenously immediately before or after defibrillation increased greatly, spontaneous arterial pressures and flows. (D) Dextrane (20 % of estimated blood volume) given intravenously raised artificial arterial flows and pressures during ECC, the same as given intra-arterially (normovolemic dogs). (E) The respirator of the Beck-Rand ECC machine was modified and evaluated for laboratory use in intubated dogs. (F) Clinical trial of a 24-hour resuscitation service in the Presbyterian-University Hospital of Pittsburgh.
- II. Acute Anemia with Normovolemia. In dogs, the treatment of exsanguinating hemorrhage (30-60 min.) with plasma expanders alone was studied.
- III. Prolonged Artificial Ventilation and Tracheotomy Care. Testing of equipment and clinical trials led to modifications of equipment and to simplified clinical routines.
- IV. Laboratory. Establishment by Dr. Galla of a reliable biochemistry laboratory for future research.
- V. Symposium Discussions of controversial topics with other investigators.
- VI. Training Medical and Lay Personnel in Heart-Lung Resuscitation. New First Aid Training Film.

Body of Army Progress Report

Annual Research Contract
DA-49-193-MD-2160

Principal Investigator: Peter Safar, M. D.

Associate Investigator: Leroy Harris, M. D.

University of Pittsburgh, School of Medicine,
Department of Anesthesiology

I. CARDIO-PULMONARY RESUSCITATION.

GENERAL EXPERIMENTAL METHODS.

Unselected healthy mongrel dogs were given Nembutal 25 mg./Kg. intravenously and tracheal intubation was performed with a cuffed tube. Forty-five minutes following the administration of the anesthetic, ventricular fibrillation was produced by an external electric shock. During these 45 minutes, preparations were made for some or all of the following measurements:

- (1.) Carotid blood flow (bubble flow meter or rotameter).
- (2.) Carotid and femoral blood pressures (strain gauges).
- (3.) Cannulation of femoral artery for taking arterial blood samples.
- (4.) Cannulation of femoral vein for administration of drugs.
- (5.) Connection of electrodes for EKG.
- (6.) Tracheal pressure (strain gauge).
- (7.) Tidal volumes of ventilation (Wright meter).

At 40 minutes following the administration of the anesthetic, with the dog breathing spontaneously room air, control measurements were made and an arterial blood sample drawn for the analysis of oxygen, CO₂ and pH values. At 45 minutes, ventricular fibrillation was produced and external cardiac compressions (ECC) started with the Beck-Rand machine (see I-E). The machine was adjusted to produce the best possible artificial arterial pressures and carotid flows. After one minute of cardiac arrest following ventricular fibrillation a repeat blood sample was drawn to serve as control before the institution of resuscitative efforts; preliminary to the drawing of this sample ECC was performed briefly in order to circulate desaturated peripheral blood into the arterial system. At one minute following ventricular fibrillation ventilation with room air was started, using the techniques and tidal volumes described subsequently.

I. CARDIO-PULMONARY RESUSCITATION.

(A) STUDY OF VENTILATION-CARDIAC COMPRESSION RATIOS.

(1) Comparison of interposed and simultaneous lung inflations.

Method. Ventilation with room air was performed by means of the piston respirator designed for the Beck-Rand machine (see I, E) or by manual compression of a Ruben bag. Tidal volumes of 15 ml/Kg. were kept constant by monitoring inflations with a Wright ventilation meter. The lung inflations were either interposed between every second ECC or performed simultaneously with every second ECC. (The 1/4 ratios were tested in pilot experiments only). A period of three minutes of either interposed or simultaneous ventilation was carried out and at the end of each period the various measurements were made. The other type of ventilation was then performed for three minutes and the measurements repeated. The entire procedure was repeated until three comparisons of each type of ventilation were obtained in each animal.

Result. Table 1 gives the results on carotid flows, arterial oxygen saturations, and pH values during ECC with interposed and simultaneous lung inflations. The difference of the effects on carotid flows and pressures by the two types of lung inflations was not striking and was quite inconsistent. There was a slight tendency for the carotid flow to be increased with the simultaneous type of inflation. With simultaneous inflations, carotid flows were increased in 7/15, markedly increased in only five of these seven; in 5/15 there was no difference in carotid flows and in 3/15 there was a slight decrease with simultaneous inflations.

This generally agrees with the findings of Dr. Wilder although he found a greater increase of carotid flows with simultaneous lung inflations.

All artificial arterial flows were approximately 15-30 % of the control spontaneous blood flows. This is in agreement with previous studies in connection with this contract performed by Redding.

The adequacy of ventilation is definitely superior with the interposed type of lung inflation. Table 2 gives a summary of the arterial O₂ saturations and pH values with the two types of ventilation. This superiority of the interposed lung inflation increased with longer periods of resuscitation. Simultaneous lung inflations with the same tidal volumes as interposed lung inflations required approximately twice the peak airway pressures of the latter.

(2) Comparison of 3/15 and 6/30 ratios of ventilation and external cardiac compression.

Method. Observations on the comparative effectiveness of three rapid lung inflations followed by 15 ECC, vs. six rapid lung inflations followed by 30 ECC were made, because in actual resuscitations these ratios could be performed by a single operator. Ventilation with room air was performed by manual compression of a Ruben bag. Tidal volumes of three times the normal spontaneous tidal volume of the dog (measured by a Wright ventilation meter). Three times the spontaneous tidal volume was chosen in an attempt to simulate volumes recommended for field resuscitation. The tracheal tube was clamped during ECC to simulate the soft tissue obstruction which occurs in almost all instances of cardio-pulmonary resuscitation on not intubated patients in whom the head is not supported. A period of six minutes of one or the other ratio of ventilation/ECC was carried out and arterial blood samples were taken for analysis at the end of the last period of ECC. The other ratio of ventilation /ECC was then performed for six minutes and again blood taken for analysis. The entire procedure was repeated until at least three comparisons of 12 minutes each were made in each animal.

Result. The results shown in Table 3 indicate clear superiority of the 3/15 ratio. The 3/15 ratio gave better oxygen saturations in every instance, oxygen saturation averaging 93 % at the end of six minutes and 90 % at the end of 18 minutes. The 6/30 ratio gave oxygen saturations of approximately 90 % at the

end of six minutes and only 74 % at the end of 18 minutes (average). The 6/30 ratio did not provide satisfactory ventilation, this becoming more apparent with the duration of ECC.

SUMMARY.

On the basis of the above-mentioned data we believe that our clinical recommendation of the 3/15 ratio is a reasonable compromise between uninterrupted circulation and adequate ventilation.

In actual resuscitation attempts in humans we found it difficult in the not intubated subject to interpose adequate tidal volumes by mouth-to-mouth or bag-mask ventilation in the one second which is available for lung inflation, because of leakage at the mask or mouth, gastric insufflation and slow air flow due to airway obstruction. The airway pressures required to inflate the lungs with the interposed method - and even more so to inflate the lungs simultaneously with ECC - always exceeded esophageal opening pressures reported by Ruben. When the patient's trachea was intubated, however, two experienced operators could interpose easily lung inflations without interruption of sternal compressions. Uninterrupted ECC with interposed inflations, therefore, is recommended for the intubated patient.

I. CARDIO-PULMONARY RESUSCITATION.

(B) THE EFFECT OF COMPRESSION OF THE ABDOMEN DURING RESUSCITATION.

Method. Ventilation was 15 ml/Kg. of room air using the piston respirator of the Beck-Rand machine with the 1/2 interposed technique. Carotid flows and arterial pressures were measured. Three minute periods with and without constant manual compression of the upper abdomen were alternated.

Result. Abdominal pressure during ECC gave constantly better carotid flows as shown in Table 4. The carotid flows increased in 17/18 comparisons. The carotid pressures were increased during abdominal compression in all 18 comparisons. The increased arterial flows and pressures with constant manual pressure over the abdomen is not due to compression of the abdominal aorta, since the flows and pressures were increased in both the femoral and carotid arteries. Simultaneous recording of inferior vena cava pressure and right auricular pressure during resuscitation suggests that abdominal compression prevents back-flow of blood from the right heart into the inferior vena cava during ECC, thus causing more effective filling of the right heart. In addition, probably the beneficial effect of abdominal compression may be due to splinting of the diaphragm and thus confining the entire force of sternal compression to the intra-thoracic structures.

I. CARDIO-PULMONARY RESUSCITATION.

(C) EFFECT OF EPINEPHRINE ON ARTIFICIAL CIRCULATION.

Method. Again, dogs in ventricular fibrillation were ventilated with tidal volumes of 15 ml./kg.. E. C. C. was performed with the Beck-Rand machine at a ratio of 1/2 with interposed inflations. Control tracings of the artificial arterial pressures and carotid blood flows were obtained during artificial circulation with E. C. C.. After a base-line of these values was observed, epinephrine 0.25 or 0.5 mg. was given intravenously and the recordings of arterial pressure and carotid flows were continued. After the pressure and flow returned to the pre-epinephrine level and had remained stable for 5 minutes, the intravenous injection of epinephrine was repeated. At least 3 comparisons of pressures and flows before and after intravenous epinephrine were obtained in each animal.

Similar studies were performed with the subcutaneous injection of epinephrine-- since a significant increase in artificial circulation by subcutaneous epinephrine may justify its use in the hands of para-medical personnel in cases of cardiopulmonary resuscitation outside of hospitals. After recording the artificial pressure and carotid flow for a control period, 2 mg. of epinephrine was injected subcutaneously over the sternum (where it could be massaged into the circulation by E. C. C.) and the arterial pressure and carotid flow tracings continued for 20 minutes. **Whenever** any change of pressure or flow occurred, the observations were continued until pre-epinephrine levels had returned. A second subcutaneous injection of epinephrine was then given and again the pressures and flows observed.

Results. Table 5 shows the effects of intravenous epinephrine on the carotid flow and arterial pressure during E. C. C.. Intravenous epinephrine always caused a marked increase in the artificial arterial pressure--but the artificial carotid flow remained essentially unchanged. In only one animal (dog 5) was there a moderate increase of flow. The increase in arterial pressure caused by intravenous epinephrine occurred 15-30-seconds after the intravenous injection and lasted for 2-3 minutes. In pilot experiments a similar rise in arterial

pressure and no rise in arterial flow was observed with the use of nor-epinephrine.

Table 6 shows the effect of subcutaneous epinephrine during E. C. C.. The effects on the arterial pressure were minimal. In only 4/9 observations was there an increasing pressure produced by subcutaneous epinephrine.

Never was an increase in carotid flow observed. Blood flow to the subcutaneous tissues during E. C. C. does not seem to be adequate to cause absorption of effective amounts of epinephrine.

Pilot experiments with epinephrine or nor-epinephrine given immediately before defibrillation or immediately following defibrillation, indicate that with a spontaneously beating heart not only pressures but also blood flows are greatly increased.

Conclusion. Epinephrine should be given intravenously (or directly into the heart chamber if a vein is not accessible) as soon as possible, after the start of external cardiac compression and ventilation. This cannot be expected to increase artificial circulation, but the beneficial effects are as follows: Possibility of re-starting the heart which had stopped in asystole; possibility of enhancing the chance of successful defibrillation of the heart in ventricular fibrillation; and markedly better spontaneous circulation immediately following successful restoration of spontaneous cardiac contractions.

I. CARDIO-PULMONARY RESUSCITATION.

(D) EFFECT OF PLASMA EXPANDER IN NORMO-VOLEMIC DOGS.

Method. Since catecholamines did not increase artificial blood flow during E. C. C., we studied the effect of increased blood volume on artificial blood flows. Dextrane was chosen, as it is more readily available than blood. At the same time the intravenous and intra-arterial routes were compared in normo-volemic dogs.

The method of artificial ventilation and circulation was the same as in the previous experiments. A base-line of artificial arterial pressures and flows was recorded during E. C. C.. Dextrane (20% of the estimated blood volume; blood volume estimated as 10% of body weight) was given intravenously (5 dogs) or intra-arterially (another 5 dogs), within a period of 5 minutes. Artificial arterial pressures and flows were observed during and following the administration of the dextrane.

Results. Table 7 shows the effect of intravenous and intra-arterial dextrane during E. C. C.. Both routes of administration caused a moderate increase in carotid flow in all animals except for 1/5 in the intravenous series and 1/5 in the intra-arterial series. Arterial pressures increased in 2/5 in the intravenous series and in all 5 of the intra-arterial series. There was no striking difference in the increase in blood flow caused by the 2 routes of administration.

Conclusion. In the normo-volemic dogs treated with E. C. C. and ventilation, increase of blood volume with intravenously or intra-arterially administered plasma expander causes a greater increase in artificial circulation than the use of catecholamines. The intra-arterial route is not indicated since, it is clinically more difficult to use. This is in contrast to the observation of Negovsky and others in exsanguinated animals, in which the intra-arterial route proved far superior to the intravenous route as supportive measure of artificial manual systole.

I. CARDIO-PULMONARY RESUSCITATION.

(E) MODIFICATION AND TESTING OF THE BECK-RAND EXTERNAL CARDIAC COMPRESSION MACHINE.

The Beck-Rand machine was found to be a useful tool for the laboratory as it can provide external cardiac compression with a constant force and rate. The machine was used for cardio-pulmonary resuscitation in over 60 dogs with cessation of circulation. The constancy of external cardiac compression was provided satisfactorily with this machine.

Although the wide anterior-posterior diameter of the dog's thorax is less suitable for mechanical chest compression than is the human thorax, it was possible to use the Beck-Rand machine in dogs satisfactorily when the upper part of the sternum and the abdomen were fastened to the V-shaped animal board with broad strips of adhesive tape. When this was not done the dog's thorax tended to tilt over to the sides during chest compressions. Sandbags or other supports for the dog's thorax proved less satisfactory.

The experiments carried out with the use of this machine are listed under I. (A-D).

Artificial arterial blood pressures and blood flows (measured with a rotameter) in dogs with ventricular fibrillation could be maintained higher with manual external cardiac compression than with mechanical external cardiac compression with the Beck-Rand machine. Nevertheless, the constancy of performance of the Beck-Rand machine made us choose this apparatus for all cardio-pulmonary resuscitation experiments on dogs.

Modification of the ventilator of the Beck-Rand machine:

The original air intake valve in the back of the piston respirator was closed permanently since it did not allow addition of oxygen. A new one-way intake valve was placed in front of the piston housing. This allowed for ventilation with any gas mixture, since a large reservoir bag with the desired mixture

could be attached to the intake valve if necessary. Oxygen enrichment of air by merely blowing oxygen around the opening of the intake valve is possible. A non-distensible plastic tubing was used to connect the T piece of the intake valve and piston with the Ruben non-rebreathing valve, which in turn was connected to the dog's tracheal tube. A Wright ventilation meter was placed between the Ruben non-rebreathing valve and the cuffed tracheal tube to measure continuously inflation tidal volumes. The tidal volumes were adjusted according to the readings of the Wright ventilation meter, by opening or closing partially or completely a deliberate leak at the piston housing. The rate and timing of inflations could be set by changing the position of the knob at the cog-wheel gearshift, which connects the ventilator with the sternal compression machine, which is electrically driven. Ratios of 1 inflation to 2 sternal compressions or 1 inflation to 4 sternal compressions could be set, inflations either simultaneously with sternal compressions or interposed between sternal compressions. An airway pressure gauge (reading 0-60 cm H₂O pressure) was connected to the T tube at the piston outlet. Next to it was placed a safety pop-off valve which could be adjusted to prevent exceeding of a pre-determined peak airway pressure. The pop-off valve was of the magnetic type (Anesthesia Associates).

Thus, the respirator designed is volume readable, pressure readable,(almost) volume set, time cycled, without rebreathing, and permitted a safety pop-off airway pressure setting and the use of air, air-oxygen mixtures, or pure oxygen.

Clinical use of external cardiac compression machines:

We have not used the Beck-Rand machine in patients, since our clinical cases of cardio-pulmonary resuscitation required usually only limited periods of external cardiac compression, which was easily performed by the manual method. We were afraid that by trying to place a patient into an external cardiac compression machine we may cause un-necessary interruptions of manual artificial circulation. Our clinical experience with over 150 cases of manual external cardiac

compression suggests that machines for this purpose in ambulances and hospitals should not be used at this time, since they would distract from the greatest advantage of external cardiac compression, namely simplicity, immediate availability, and no need for equipment. In hospitals, external cardiac compression machines may possibly prove to have a place in the future in selected patients with cardio-pulmonary collapse who need prolonged assisted circulation.

Mechanical respirators of external cardiac compression machines (like the one we designed for laboratory use of the Beck-Rand machine) should not be used in the not intubated subject. Such mechanical respirators do not compensate for mask leakage, may cause gastric insufflation because of the high airway pressures sometimes required for ventilation during external cardiac compression, and do not allow immediate recognition of airway obstruction. Airway obstruction and efficacy of ventilation can readily be recognized during bag-mask or exhaled air ventilation. In the subject with a cuffed tracheal tube, certainly, the synchronized ventilator of an external cardiac compression machine will produce adequate ventilation, if properly set.

ANALYSIS OF ARTERIAL PRESSURE CURVE DURING ARTIFICIAL SYSTOLE. The diastolic pressure during external or internal cardiac compression is close to 0 in most dogs and man studied--in spite of high systolic pressures and blood flows of up to 40% of control. Excessively low flows or low peripheral resistance cannot be the cause. We expect that the heart in ventricular fibrillation or stand-still has leaking aortic (and maybe other) valves. Bubble flow meter and simultaneous pressure tracings from heart chambers and arteries seem to prove this. Testing is still being carried out. Suspicion of valve leak was first pointed out to me by Wilder.

I. CARDIO-PULMONARY RESUSCITATION.

(F) CLINICAL TRIAL OF 24-HOUR RESUSCITATION SERVICE AT THE PRESBYTERIAN-UNIVERSITY HOSPITAL OF PITTSBURGH.

Before considering external cardiac compression and mouth-to-mouth resuscitation a field method for cardio-pulmonary resuscitation (i.e. a first-aid maneuver) it is essential to provide 24-hour coverage by skilled personnel in hospitals to which resuscitation cases may be brought.

With the organization of the new Department of Anesthesiology at the University of Pittsburgh Health Center an emergency resuscitation service was first organized at the Presbyterian-University Hospital. Subsequently, long-term resuscitation methods were introduced and applied in the newly organized Intensive Care Unit of that hospital.

For constant availability of emergency resuscitation services an in-service training program for nurses, house staff and attending staff was introduced, teaching phase I of cardio-pulmonary resuscitation (see enclosure 1). In addition, specially trained anesthesiologists and other personnel were made available on a 24-hour resuscitation call service at all times. A "stat" resuscitation call service was established (see enclosure 2).

The resuscitation service outlined in enclosure (2), including the telephone answering service, made it possible to have any patient in acute difficulty treated immediately by mouth-to-mouth or bag-mask ventilation and, if pulseless, by external cardiac compression, started by a trained by-stander (usually a nurse or intern). In addition, the telephone paging system summons usually within 60 seconds the entire resuscitation team with the resuscitation cart to the scene. The team consists of at least one anesthesiology resident (and/or staff anesthesiologist), one inhalation therapist, sometimes one surgical house officer, and sometimes one nurse anesthetist.

The resuscitation cart (essential for phase II and parts of phase III of resuscitation, see enclosure 1), which was first designed empirically, was later modified as added needs became apparent. The final design of the resuscitation cart in use now is described and illustrated in enclosure (2). Also, the step-by-step resuscitation efforts applied in most cases of inadequate ventilation and pulselessness are listed in enclosure (1), Table.

Although most of the over 100 resuscitation attempts made outside of the operating rooms during the period of July, 1961 to July, 1962 seemed futile, as many patients proved to have been in a not reversible agonal state, the approximately 10 lives saved made this a worthwhile project. In approximately 25 patients with sudden death from coronary disease outside the operating rooms, two patients with proven ventricular fibrillation due to heart attacks were restored to pre-arrest status and were discharged in good condition. The unsuccessful resuscitation attempts had an instructional value for the personnel involved. With expanded in-service education of house staff and nurses and expanded accident room activities at the Presbyterian-University Hospital of Pittsburgh, we expect the salvage rate to be improved in the future.

Enclosure (2): Resuscitation policy of the Presbyterian-University Hospital of Pittsburgh.

Enclosure (1): Paper on Resuscitation in "Current Medical Digest."

Enclosure (1-A): Paper in German: Frey, Jude and Safar, External Cardiac Resuscitation.

Enclosure (1-B): Film abstract "Introduction to Respiratory and Cardiac Resuscitation" PMF 5349.

MODIFICATION OF COMMERCIALY AVAILABLE EMERGENCY ARTIFICIAL VENTILATION EQUIPMENT.

- (1) Ruben (Air Shields) Bag-Mask Unit. Already 3 to 4 years ago we strongly recommended to the Air Shields Company and to Dr. Ruben to increase the volume of the Ambu-Ruben self-inflating foam rubber bag from 1 liter to 2-3 liters. With the commercially available 1 liter bag, we found sometimes inability to compensate for mask leakage with this relatively inadequate reserve volume. This recommendation, apparently, was followed by Air Shields, who in connection with Dr. Elam, increased the size of this bag.
- (2) To-and-Fro O₂ Anesthesia Bag-Mask Unit. This unit should be used with a high flow (over 10 to 15 L/min. flow of O₂) with over-flow providing CO₂ washout. The regular adaptor with O₂ inlet nipple between bag and mask (without CO₂ absorption cannister) was modified for us by Anesthesia Associates. The Universal adaptor fits into standard rubber masks and also takes 15 mm endo-tracheal slip joints. The pop-off valve is closed for I. P. P. V. with a mask, allowing leakage of excess O₂ flow at the mask for better controllability of bag filling and inflation volumes. For I. P. P. V. with a tracheal tube, the pop-off is open and with each bag pressure ^{pop-off} is shut by pushing a button with the thumb. This is possible with tracheal tube ventilation since the second hand is not tied up with support of head, jaw and mask. For spontaneous breathing the pop-off is open and can be adjusted to any intermittent or continuous ^{positive} airway pressure desired.
- (3) Kreisselman (Ohio) Manual I. P. P. B. Resuscitator. Disadvantages of the commercially available model: Lever for initiating inflation is removed from the face so that the hand operating the lever cannot be used to hold mask and jaw as well; too low inflation flow rate; too low peak pressure; too high resistance for exhalation.
Modifications recommended ^{by us} and made by Ohio: Lever for inflation moved to the chin part of the mask so that both hands can be used for mask support during inflation;

peak flow rate of 60 L/min. for inflation; peak pressure as desired up to 60 cm. H₂O; less resistance to exhalation; Universal adaptor for standard Ohio masks and 15 mm endo-tracheal slip joints.

All 3 units listed here proved satisfactory for emergency I. P. P. V. during actual resuscitations throughout the Presbyterian-University Hospital of Pittsburgh.

II. ACUTE ANEMIA WITH NORMO-VOLEMIA.

Background. Recent developments in hematology and blood banking have led to the recognition of many blood sub-groups and thus to the need for more complex typing and cross-matching of blood. This inevitably means a longer waiting period for safely matched blood for those patients who are acutely in need of replacement of large amounts of lost blood. For instance, in our institution at the present time, 60 minutes is considered the minimal safe time for a complete cross-match. Experts discourage the use of O Rh negative blood without cross matching in patients in need of acute transfusion. Although it proved impossible so far to assess the true "risk" of any given blood transfusion, it is obvious that the increasing number of sub-groups and the increasing number of people who have received transfusions have increased the "risk" of transfusion and decreased the number of "safe" bottles of blood available for each patient.

Much experimental work has been done on hemorrhage leading to oligemic shock. We are not aware of any studies done on hemorrhage treated without transfusion but rather with maintenance of a near-normal blood volume by plasma or plasma expanders--with experiments designed to answer the questions listed below. Clinically, we attempt to treat hemorrhage as soon as it is recognized, by hemostasis and replacement of lost volume. How far can we go replacing lost blood with substances not containing red cells?

Experiments were started in an attempt to answer the following questions:

- (1) What degree of exsanguination can an animal withstand--and how long-- if volume replacement is carried out with, for instance, dextrane, before reversible and irreversible deterioration of physiologic parameters occur?
- (2) What is the role of hypotension per se vs. hemoglobin deficiency in this deterioration?
- (3) What is the mechanism of death in acute severe anemia leading to complete loss of hemoglobin--with normal circulating volume. Does failure of the heart or failure of the brain occur first?

- (4) What is the role of high vs. normal concentrations of inhaled O₂ in this deterioration?
- (5) Can hyperventilation with O₂ by controlled ventilation prevent or minimize the development of metabolic acidosis?
- (6) At what point of exsanguination and dextrane replacement does red cell replacement become essential for survival?
- (7) Does any particular plasma expander have advantages over another (e. g. regular dextrane vs. low molecular weight dextrane)?
- (8) What is the pattern of dying in exsanguinating hemorrhage without hypovolemia, in conscious spontaneously breathing dogs as compared to anesthetized dogs with or without artificial ventilation, with or without O₂ inhalation?
- (9) What is the pattern of dying under these conditions and anesthesia with different types of anesthetic agents and techniques?

Methods. This work is in progress and so far the following experiment was carried out.

Healthy dogs were very lightly anesthetized with pentobarbital 15 mg./kg. and paralyzed with succinylcholine 20 mg./I. V. as needed. Trachea was intubated with a cuffed tube and controlled ventilation (I. P. P. V.) carried out with 100% O₂, tidal volumes 15 ml./kg., rate 30/min. with a piston respirator.

Each dog was prepared for measurement of the following parameters: (1) carotid blood flow; (2) intra-arterial blood pressure; (3) inferior vena cava pressure; (4) E. K. G.; (5) E. E. G.; (6) arterial pO₂; (7) arterial pCO₂; (8) arterial pH; (9) arterial hemoglobin and hematocrit.

60 minutes following the induction of anesthesia control measurements were made and an arterial blood sample was drawn. The following procedure then followed:

- (1) Rapid hemorrhage of 20% of estimated blood volume (estimated blood volume

- to the 10% of body weight).
- (2) Rapid intravenous replacement of the blood withdrawn by the same amount of clinical (regular) dextrane.
 - (3) Repeated withdrawals of 10% of blood volume with replacement of the same volume by dextrane, approximately every 10 minutes, until the arterial hemoglobin was reduced to 3 gram %.
 - (4) Continuous observation of the parameters mentioned above.
 - (5) Arterial blood samples were drawn at 5/30 and 60 minutes.
 - (6) When the hemoglobin reached 3 gram % the animal was left at that level until 60 minutes after the initial bleeding. Then again hemorrhage and replacement were started. When the first significant changes of E. K. G. or E. E. G. occurred during this terminal hemorrhage, another arterial blood sample was taken for analysis.
 - (7) Hemorrhage and replacement were continued until asystole or ventricular fibrillation occurred, at which time the last arterial sample was taken.

Tentative Results.

5 dogs. 60 minutes after the start of hemorrhage the hemoglobin values were 20-25% of the control values (2.7 to 3.9 grams %) to that point (approximately 3 gm. % hemoglobin) no significant abnormalities of E. K. G. or E. E. G. were observed. The pupils remained small and reacted to light. The arterial pressure dropped to 85-90% of the control value 5 minutes following the first hemorrhage and later on only to 75-90% of the control values until one hour after the start of hemorrhage. The carotid blood flow likewise dropped only slightly, parallel with the slight arterial pressure drop.

The arterial pH remained above control values even when the arterial pressure terminally (after 1 hour) dropped to very low levels and when the hemoglobin dropped to below 3 gm. %. This is probably due to the extreme hyperventilation with pure oxygen used in these experiments.

When the hemoglobin was reduced below 3 gm. %, the heart stopped in 4 dogs in asystole and in 1 dog in ventricular fibrillation at hemoglobin values of 0.5 to 2 gm. %. Upon crude examination it appeared that the E. K. G. changes preceded significant changes of the E. E. G. Also the E. K. G. changes were more related to hypotention than to low hemoglobin values. A more detailed analysis of the bio-chemical aspects of dying under these conditions will follow. Low molecular weight dextrane will be used. Determination of lactic acid and pyruvic acid and capillary microscopy in search for plugging of the terminal circulation, will be added to the above mentioned measurements.

III. PROLONGED ARTIFICIAL VENTILATION AND TRACHEOTOMY CARE.

In military medicine prolonged artificial ventilation (prolonged assisted or controlled ventilation) is applicable in patients with severe chest injury, pulmonary burns, nerve gas poisoning, etc.

Clinical experience with over 100 cases of prolonged assisted or controlled ventilation at the Baltimore City Hospitals and during the past year at the University of Pittsburgh Health Center, led to the establishment of simplified, effective routines. Some conclusions drawn from this experience are summarized in enclosure 3 (paper "Cuffed Tracheotomy Tube vs. Tank Respirator"); enclosure 4 (training and documentary film "Prolonged Artificial Ventilation" PMF 5348); and enclosure 5 (tracheotomy care procedure introduced at the University of Pittsburgh). Other conclusions will be published later.

A copy of the film script "Prolonged Artificial Ventilation" may be obtained from Mr. Dixon, Walter Reed Army Institute of Research, Walter Reed Hospital, Washington, D. C..

III. (A) SOME OF THE CONCLUSIONS:

(a) Intra-tracheal intermittent positive pressure ventilation or positive negative pressure ventilation, via cuffed tracheotomy tubes, was found superior to the use of the iron lung (tank respirator). The tank respirator should be reserved for the occasional patient who is in need of prolonged artificial ventilation and does not require a tracheotomy (conscious, dry and compliant lungs, intact upper airway innervation). I. P. P. V. via a mouth piece or oro-nasal mask (without tracheotomy or tracheal tube) is not practical because it often leads to gastric distention, leakage and laryngospasm. The chest respirator and the raincoat respirator work on the same principle as the iron lung but produce less ventilation. The raincoat respirator makes patients feel too hot to be suitable for long-term artificial ventilation.

(b) A negative phase for exhalation caused worse ventilation in asthmatics

(because of air trapping due to bronchial collapse), but added occasionally a beneficial effect on patients with intracranial lesions, who may benefit from the lowering of the jugular vein pressure caused by lowering of the mean intrathoracic pressure below that obtainable by intermittent positive pressure methods alone.

(c) Assisted ventilation (patient cycled) is rarely necessary. Controlled ventilation could easily be induced in most patients with coaching and, if necessary, in addition with the use of opiates or muscle relaxants. Controlled ventilation has the great advantage over assisted ventilation in that it abolishes all work of breathing.

(d) The respirator must deliver room air or air/oxygen mixtures up to 100% O₂. It should not rely upon compressed gases.

(e) The respirator must deliver into the patient's tracheotomy tube air (or air-oxygen mixtures) at body temperature and with a relative humidity of between 90-100%. This was possible with the use of heated mid-stream nebulizers.

(f) Volume-set respirators are preferred to pressure-set respirators. Pressure-set respirators should at least be modified to indicate the tidal volumes moved into the patient ("pressure-set, volume-readable respirators").

(g) The use of cuffed tracheotomy tubes offers many advantages over the use of uncuffed tubes. The advantages of the cuffed tube include (1) constant ventilation after initial adjustments are made; (2) less drying of the mucosa; and (3) avoidance of inhalation of vomitus and other foreign matter from the pharynx. With the leaking technique (uncuffed tubes) recommended by Moersch, drying of the mucous membranes, uncontrollable ventilation volumes and inhalation of gastric content were seen. With the use of cuffed tubes necrosis of the trachea mucosa was avoided when either the "no leak" technique was used (cuff inflated just to the point of abolishing audible leaks and slight, brief deflation at intervals); or when the "minimal leak" technique was used. In spite of the "minimal leak" constancy of ventilation could be maintained fairly well and the conscious patient could talk. With the "no leak" technique or the

"minimal leak" technique and adequate humidification, as outlined in enclosure 5, the continuous use of cuffed tubes, even for periods of over 1/2 year, proved safe.

Several cuffed tracheotomy tubes were tested. The rubber tubes with built-in cuffs (polio tube of Ruesch) and the spiral-latex tracheotomy tube (Anesthesia Associates) both have no inner cannula and have too thick walls. This led to a higher incidence of plugging of the tip of the tube. We, therefore, preferred to use the regular Jackson silver cannula (with inner cannula), with the Moersch swivel adaptor for easy connection to any respirator. This Moersch modification of the Jackson cannula was equipped with a "slip-on cuff." The cuff should be short and have a long sleeve. The short cuffs without long sleeves occasionally slipped off the tip of the tube and caused partial obstruction. This, apparently, can be avoided with the use of the long sleeved Ruesch type cuff distributed by the Schick Company (Chicago). The cuff should be 1 size smaller than the size of the tube, to avoid slipping.

(h) Monitoring of Ventilation. Spot checks of arterial pCO_2 and pH indicated that mild hyperventilation can be carried out safely for weeks without blood gas monitoring in patients with fairly healthy lungs. We maintained controlled ventilation with 1 1/2 to 2 times the ventilation recommended by the Radford nomogram. This maintained arterial pCO_2 values between 25 and 35 mm Hg. In patients with very severe pulmonary disease blood gas monitoring is advantageous. We are in the process of comparing arterial pH and pCO_2 values with those obtained from capillary blood of various sites, as measured by the ASTRUP micro technique.

III. (B) TESTING OF NON-REBREATHING VALVES.

We noticed that the Moersch ball valve and the Ruben valve, when used with the Moersch piston respirator, did not prevent rebreathing. As the piston moved back slowly (particularly at slow cycling rates of the respirator), the ball or bobbin of these valves moved also slowly into the expiratory position during the expiratory phase. This permitted exhaled air to leak back into the tubing between piston and valve. There is also back-leak with the Rudolph and the Emerson non-rebreathing valves. All these valves had forward leak as well. The Beaver valve had least back leak and was, therefore, chosen.

A test rubber lung was ventilated with a cycling rate of 20 per minute and a piston stroke volume of 1.5 liters. Several valves were tested.

Wright ventilation meters were attached to all 3 ports of the non-rebreathing valves (one between piston and valve, one between valve and test lung, one at the expiratory port of the valve). The results are summarized in table 8.

The valve chosen for use with the Moersch respirator, therefore, was the Beaver valve, which has the advantage of minimal back-leak, easy collection of exhaled air through an expiratory port (with a Wright ventilation meter attached for monitoring), simplicity, and easy servicing.

III. (C) MODIFICATION OF MOERCH PISTON RESPIRATOR.

The Moerch piston respirator was used in over 50 patients for prolonged controlled ventilation. Although the commercial model is simple and reliable, it offered certain hazards for the patients. Therefore, modifications were made, which resulted in a safe, satisfactory ventilator.

Advantages of the commercially available Moerch piston respirator:

- (a) Reliable motor for long-term use.
- (b) Useable without compressed gases.
- (c) Simplicity.
- (d) Tidal volumes constant, if used with cuffed tracheal tube.
- (e) Large piston reserve volume available to compensate for leakage, if necessary.

Disadvantages of the commercially available Moerch piston respirator:

- (a) Inadequate cold humidifier, which delivered measured relative humidity of only 30-40% at room temperature.
- (b) Unreliable non-rebreathing valve. The ball valve sticks often. Even without sticking, sometimes large volumes of exhaled air leak back into the piston because of a slow fall of the ball when the piston moves backward. There is also a forward leak during inflation.
- (c) Absence of an airway pressure gauge.
- (d) Absence of a tidal volume meter. Although the piston stroke volume is indicated crudely at the piston, it has no relation to the actual tidal volumes the patient receives, because of leaks between piston and tracheotomy tube (particularly in the ball valve).
- (e) Absence of safety pop-off pressure valve, which should prevent excessively high airway pressures.
- (f) Designed for use with a leaking non-cuffed tracheotomy tube.
- (g) Inability to give aerosol therapy during artificial ventilation.

Modifications were made to correct all the above-mentioned disadvantages:

- (a) A heated mid-stream nebulizer (Puritan) was placed between piston and non-rebreathing valve. With an oxygen flow of 10 liters per minute it delivered 90-100% relative humidity at body temperature into the tracheotomy tube. This at the same time increased the oxygen concentration to between 30 and 50%, depending on the minute volume. This and other humidifiers were evaluated. This is also listed in table 9.
- (b) The Moersch ball valve was replaced by the Beaver valve (British Oxygen Company) as the result of the tests outlined under "III (B)". Among the various non-rebreathing valves tested, the Beaver valve showed least back-leak, simplicity and has an easily exchangeable valve leaflet and an expiratory port, which permits easy monitoring of exhaled tidal volumes. The disadvantage of the Beaver valve is its great resistance to spontaneous breathing in case the respirator fails in a patient who can breathe spontaneously.
- (c) An airway pressure gauge was attached to the tubing between non-rebreathing valve and tracheotomy tube to continuously monitor airway pressures.
- (d) A Wright ventilation meter was attached (intermittently, as needed,) to the expiratory port of the Beaver valve. With the use of the minimal leak technique measuring the expiratory tidal volumes is more reliable than measuring the inspiratory tidal volume, since the expiratory tidal volume is measured while the system is not under pressure and, therefore, leaks less.
- (e) A magnetic pop-off valve (Anesthesia Associates) was provided at the piston, in place of the standard inadequate pop-off valve commercially available with the respirator.
- (f) In adults, the respirator was used preferably with a cuffed tracheotomy tube for the reasons mentioned above.
- (g) For aerosol therapy during artificial ventilation a large-bore Y-tube was inserted proximal to the Beaver valve, with an aerosol

nebulizer attached to the side arm of the Y. When the oxygen flow into the aerosol nebulizer was turned on, the oxygen through the heated mid-stream nebulizer was turned off.

III. (D) TESTING AND MODIFICATION OF OTHER RESPIRATORS.

- (1) A Radcliffe respirator was obtained from England. The Radcliffe respirator is a time cycled, volume readable, pressure set respirator which delivers air or air oxygen mixtures at a relative humidity of 90-100% at body temperature. It also provides, if necessary, a negative phase during exhalation. Its main advantage over the Moersch respirator is the mechanical valves, which are less likely to stick than any of the pneumatic non-rebreathing valves used with the Moersch respirator.

Modifications of the Radcliffe respirator were made or suggested by us:

- (a) Increase of the maximal bellows stroke volume from 1 liter to 2 1/2 liters, by increasing the cam.
 - (b) Attachment of an aerosol nebulizer via a large-bore Y-tube in the inspiratory tubing.
 - (c) Modification for use as anesthesia machine, which would require wider breathing tubes and a larger canister for CO₂ absorption.
- (2) The pressure-set respirators of the Bennet and Bird type were equipped with Wright ventilation meters at the expiratory ports of the non-rebreathing valves. This proved satisfactory with the Bennett respirator. The new Bird Circle-type respirator, which also provides a negative phase, cannot be adjusted for indicating tidal volumes, unless the ventilation meter is placed between the Y-tube and the tracheotomy tube. This would increase the dead space and lead to accumulation of secretions and moisture in the Wright ventilation meter. The ventilation meter in the expiratory tubing of the Bird circle would read the excess venturi flow of the negative phase system and gave wrong values. The Bird respirator proved to be excellent for I. P. P. B. treatments as an assistor. It was not satisfactory for prolonged controlled ventilation, as it is not "nurse proof" and does not provide an indication of tidal exchange. The Engstrom respirator was not tested since its price is unrealistic.

III. (E) TRACHEOTOMY ROUTINE.

Much time was spent in designing the sterile atraumatic tracheotomy routine outline in enclosure 5. After many trials and errors we became convinced that non-adherence to this or a similar routine leads to iatrogenic pulmonary complications, such as infections, trauma, drying of the mucous membranes and plugging of the bronchioles.

Enclosure 3: Paper on respirator care

Enclosure 4: Abstract of movie "Prolonged Artificial Ventilation" PMF5348

Enclosure 5: Outline of tracheotomy routine introduced at Presbyterian-University Hospital, Pittsburgh

IV. LABORATORY.

Under the guidance of Dr. Galla during the past year the anesthesia laboratory was developed to the point of providing reliable determinations for the various parameters listed below. Much new equipment was secured and set up and laboratory technicians were trained - including those supported by this Army contract. A considerable amount of time, energy and money was spent in developing this biochemistry laboratory in order to enable research to be carried out in connection with this Army contract.

The determinations available now include the following:

- (a) Multichannel electronic recording of vascular pressures, air pressures, blood flows (rotameter), EEG, EKG, pneumotachogram, and end-tidal CO₂ analysis with infrared analyzer.
- (b) Instrumentation Laboratories set-up for measuring PCO₂, pO₂ and pH.
- (c) Gas chromatography for measuring contents of gases and volatile anesthetics in blood and air.
- (d) Spectrophotometry for the determination of lactate, pyruvate, glucose, phosphorus, hemoglobin and citrates.
- (e) Methods for measuring un-esterified fatty acids in blood.
- (f) Flame photometry for determination of serum electrolytes.
- (g) Van Slyke's procedure for oxygen content and CO₂ content.
- (h) ASTRUP micro pH analysis of blood.

Frequent change of personnel delayed the development of certain techniques.

V. STUDIES AND DISCUSSIONS.

The senior investigator and some associate investigators participated in lectures and symposium discussions with other investigators outside of Pittsburgh to learn about the present status of controversial points in the field of resuscitation under investigation.

Symposium on Resuscitation. International Congress of Anesthesiology, Vienna, Austria, September, 1962. Chairman: Peter Safar. Participants included ^{Dr. Harris and} various international authorities including Drs. Negovsky from Russia and Dr. Keszler from Prague, who both have done original work on intra-arterial transfusion, the use of oxygen vs. air in artificial ventilation, hypothermia, and external and internal defibrillation. This symposium will be published in the near future.

Symposium on Cardio-Pulmonary Collapse. A.M.A. convention, Chicago, June, 1962 (American College of Chest Physicians). Chairman: Peter Safar. Participants- Drs. Elam, Wilder, Zoll and Jude. (Published in Diseases of the Chest)

Meeting of the Neuro-Anesthesia section of the World Association of Anesthetists at the National Institutes of Health, Washington, D. C. Drs. Rosomoff and Safar attended.

Symposium Discussion on "Shock" of the National Academy of Sciences, National Research Council, Washington, D.C. in November, 1962. Attended by Dr. Harris.

VI. TRAINING MEDICAL AND LAY PERSONNEL IN HEART-LUNG RESUSCITATION.

Experience was gained in in-service training programs of physicians, nurses and lay personnel at the University of Pittsburgh Medical Center in cardio-pulmonary resuscitation courses.

- (1) The film "Introduction to Respiratory and Cardiac Resuscitation", made in 1961 in connection with this contract, was translated by Dr. Yvonne Noviant in Summer, 1962. Dr. Noviant was visiting Instructor at the University of Pittsburgh, Department of Anesthesiology in June and July, 1962.

There is a great demand for such training films in French speaking parts of the world.

- (2) Making of the new First-Aid film "First Things First" by Johnson and Johnson. Dr. Safar rewrote the script and acted as medical advisor. Many of the fundamentals shown in this film evolved from research performed in connection with various Army resuscitation-research contracts.

TABLE #1

EFFECT of INTERPOSED and SIMULTANEOUS LUNG INFLATIONS DURING E.C.C.

| | Control Intact | Lung Inflation/E.C.C. Ratios 1/2 | | | | | |
|-----------------------|-------------------|----------------------------------|------------|---------|------------|---------|------------|
| | | Circul. | Interposed | Simult. | Interposed | Simult. | Interposed |
| Dog #1 | | | | | | | |
| Car. Flow ml./min. | 72 | 18 | 16 | 18 | 18 | 18 | 17 |
| % O ₂ Sat. | 92 | 98 | 92 | | | 99 | 55 |
| pH | 7.40 | 7.54 | 7.48 | | | 7.13 | 7.05 |
| Dog #2 | | | | | | | |
| Car. Flow ml./min. | 64 | 19 | 48 | 43 | 38 | 44 | 44 |
| % O ₂ Sat. | 92 | 89 | 77 | | | 89 | 80 |
| pH | 7.34 | 7.32 | 7.19 | | | 7.15 | 7.15 |
| Dog #3 | | | | | | | |
| Car. Flow ml./min. | 100 | 12 | 16 | 14 | 15 | 12 | 13 |
| % O ₂ Sat. | 96 | 90 | 82 | | | 87 | 54 |
| pH | 7.33 | 7.54 | 7.38 | | | 7.41 | 7.18 |
| Dog #4 | | | | | | | |
| Car. Flow ml./min. | 100 | 12 | 18 | 15 | 15 | 13 | 13 |
| % O ₂ Sat. | 96 | 97 | 95 | | | 85 | 62 |
| pH | 7.34 | 7.31 | 7.32 | | | 7.23 | 7.10 |
| Dog #5 | | | | | | | |
| Car. Flow ml./min. | 60 | 6 | 7 | 6 | 7 | 6 | 6 |
| % O ₂ Sat. | 93 | 99 | 82 | | | 99 | 85 |
| pH | 7.30 | 7.62 | 7.30 | | | 7.53 | 7.29 |

TABLE #2

SUMMARY of EFFECT of INTERPOSED and SIMULTANEOUS LUNG INFLATIONS ON ARTERIAL OXYGEN SATURATIONS and pH VALUE

| | Intact Circul. | 3 Minutes Interposed Vent. | 3 Minutes Simult. Vent. | 18 Minutes Interposed Vent. | 18 Minutes Simult. Vent. |
|---------------------|-------------------|----------------------------|-------------------------|-----------------------------|--------------------------|
| O ₂ Sat. | 94% (92-96%) | 94% (89-99%) | 86% (77-95%) | 91% (85-99%) | 67% (54-85%) |
| pH | 7.34 (7.3-7.4) | 7.46 (7.3-7.6) | 7.26 (7.2-7.3) | 7.30 (7.2-7.5) | 7.15 (7.0-7.22) |

TABLE # 3

O₂ SATURATION & CO₂ CONTENT DURING EXTERNAL CARDIAC COMPRESSION
COMPARISON OF 3 INFLATIONS/15 ECC & 6 INFLATIONS/30 ECC

| | CONTROL | V. F. 1 min. ECC | 3/15 6 min. | 6/30 6 min. | 3/15 18 min. | 6/30 18 min. |
|-----------------------|-----------------|---------------------|-----------------|-----------------|-----------------|-----------------|
| O ₂ SAT. | 93 % 86-97 % | 65 % 50-79 % | 93 % 85-99 % | 90 % 81-99 % | 90 % 85-95 % | 74 % 70-80 % |
| CO ₂ CONT. | 42.5 31-49 | 44.0 36-53 | 26.0 21-31 | 26.0 25-35 | 16.5 8-21 | 24.5 21-28 |

TABLE #4

COMPARISON OF CAROTID FLOW DURING E.C.C. WITHOUT AND WITH ABDOMINAL COMPRESSION

| Dog # | No abd. press. | Abd. press. | No abd. press. | Abd. press. | No abd. press. | Abd. press. |
|----------------------------|----------------|----------------------|----------------|-----------------------|----------------|-----------------------|
| Dog # 1 Carotid Flow | 13 cc. min. | 23 cc. min. (+77) | 20 cc. min. | 27 cc. min. (+35) | 19 cc. min. | 23 cc. min. (+21) |
| Dog # 2 Carotid Flow | 22 cc. min. | 40 cc. min. (+92) | 22 cc. min. | 40 cc. min. (+82) | 20 cc. min. | 40 cc. min. (+100) |
| Dog # 3 Carotid Flow | 9 cc. min. | 15 cc. min. (+40) | 9 cc. min. | 15 cc. min. (+40) | 8 cc. min. | 11 cc. min. (+38) |
| Dog # 4 Carotid Flow | 26 cc. min. | 36 cc. min. (+38) | 10 cc. min. | 24 cc. min. (+120) | 4 cc. min. | 17 cc. min. (+300) |
| Dog # 5 Carotid Flow | 8 cc. min. | 15 cc. min. (+87) | 6 cc. min. | 8 cc. min. (+33) | 12 cc. min. | 12 cc. min. (0) |
| Dog # 6 Carotid Flow | 15 cc. min. | 24 cc. min. (+60) | 8 cc. min. | 24 cc. min. (+200) | 8 cc. min. | 20 cc. min. (+150) |

(change in parentheses)

TABLE #5
EFFECT OF I. V. EPINEPHRINE DURING E.C.C.

| Dog # | Intact Circulation | MCC Before Epinephrine | MCC after Epinephrine | MCC before Epinephrine | MCC after Epinephrine | MCC before Epinephrine | MCC AFTER Epinephrine |
|---------------|-----------------------|---------------------------|--------------------------|---------------------------|--------------------------|---------------------------|--------------------------|
| Dog # 1 | | | | | | | |
| Food Pressure | 175/125 | 70/25 | 160/65 | 90/25 | 160/50 | 80/20 | 125/40 |
| Carotid Flow | 64 cc./min. | 22 cc./min. | 15 cc./min. | 12 cc./min. | 13 cc./min. | 12 cc./min. | 21 cc./min. |
| Dog # 2 | | | | | | | |
| Food Pressure | 175/130 | 55/15 | 95/25 | 75/15 | 95/25 | 55/10 | 90/20 |
| Carotid Flow | 58 cc./min. | 11 cc./min. | 11 cc./min. | 11 cc./min. | 11 cc./min. | 14 cc./min. | 14 cc./min. |
| Dog # 3 | | | | | | | |
| Food Pressure | 100/65 | 70/10 | 150/25 | 75/10 | 175/30 | | |
| Carotid Flow | 65 cc./min. | 15 cc./min. | 7 cc./min. | 11 cc./min. | 11 cc./min. | | |
| Dog # 4 | | | | | | | |
| Food Pressure | 155/100 | 70/10 (20) | 150/20 (45) | 55/10 (20) | 125/15 (45) | 65/10 (20) | 160/35 (60) |
| Carotid Flow | 70 cc./min. | 22 cc./min. | 18 cc./min. | 27 cc./min. | 16 cc./min. | 22 cc./min. | 16 cc./min. |
| Dog # 5 | | | | | | | |
| Food Pressure | 160/130 (140) | 95/35 (45) | 115/50 (65) | 80/25 (35) | 115/50 (50) | 95/30 (40) | 140/45 (55) |
| Carotid Flow | 75 cc./min. | 10 cc./min. | 60 cc./min. | 13 cc./min. | 28 cc./min. | 6 cc./min. | 15 cc./min. |

TABLE #6
EFFECT OF SUBCUTANEOUS EPINEPHRINE DURING E.C.C

| Dog # | Intact Circulation | BCC before Epinephrine | BCC after 2 mg. Epinephrine subcut. | BCC before Epinephrine | BCC after 2 mg. Epinephrine subcut. |
|----------------|--------------------|------------------------|-------------------------------------|------------------------|-------------------------------------|
| Dog # 1 | 165 135 (145) | 55 10 (25) | 55 10 (25) | 85 10 (25) | 125/25 (40) |
| Blood Pressure | 68 cc./min. | 12 cc./min | 12 cc./min. | 14 cc./min. | 12 cc./min. |
| Flow | | | | | |
| Dog # 2 | 165 110 (125) | 60 30 (40) | 60 30 (40) | | |
| Blood Pressure | 85 cc./min. | 15 cc./min | 15 cc./min. | | |
| Flow | | | | | |
| Dog # 3 | 165 130 (140) | 85 20 (30) | 85 20 (30) | 65 10 (15) | 65/10 (15) |
| Blood Pressure | 34 cc./min | 9 cc./min | 9 cc./min. | 11 cc./min | 11 cc./min. |
| Flow | | | | | |
| Dog # 4 | 200 170 (175) | 80 25 (40) | 90 30 (40) | 80 25 (35) | 100/35 (45) |
| Blood Pressure | 66 cc./min | 11 cc./min. | 11 cc./min. | 8 cc./min. | 8 cc./min. |
| Flow | | | | | |
| Dog # 5 | 225 175 (195) | 110 45 (55) | 160 75 (95) | 100 35 (45) | 100/35 (45) |
| Blood Pressure | 60 cc./min. | 8 cc./min. | 8 cc./min. | 9 cc./min | 9 cc./min. |
| Flow | | | | | |

TABLE #7

EFFECT OF I. V. DEXTRANE DURING M-L-R

| Dog # | Carotid Flow ml./min. | | Blood Pressure | |
|-------|-----------------------|----------------|-----------------|----------------|
| | Before dextrane | After dextrane | Before dextrane | After dextrane |
| 1 | 14 | 14 | 90/35 | 90/35 |
| 2 | 14 | 20 | 150/50 | 170/50 |
| 3 | 13 | 18 | 110/30 | 110/30 |
| 4 | 9 | 12 | 95/25 | 125/30 |
| 5 | 35 | 48 | 130/45 | 120/40 |

EFFECT OF I. V. DEXTRANE DURING M-L-R

| Dog # | Carotid flow ml./min. | | Blood Pressure | |
|-------|-----------------------|----------------|-----------------|----------------|
| | Before dextrane | After dextrane | Before dextrane | After dextrane |
| 1 | 22 | 26 | 45/25 | 65/30 |
| 2 | 24 | 35 | 90/25 | 160/40 |
| 3 | 16 | 20 | 75/30 | 95/30 |
| 4 | 16 | 24 | 50/25 | 65/25 |
| 5 | 18 | 18 | 55/25 | 100/45 |

Table 8

TESTING OF NON-REBREATHING VALVES
for use with Moerch Respirator

| Valve | Vol.setting at Piston ml | A p p r o x i m a t e V o l u m e s , m l | | | | |
|------------------|--------------------------------|--|---|--|---|---|
| | | going into valve inlet during INFLATION | leaking out of expir.port during INFLATION | going in and out of test lung | leaking back through valve inlet during EXHALATION** | leaving exp.port during EXHALATION |
| MOERCH noll | 1500 | 1250 | 100 | 1150 | 400 | 750 |
| MOERCH no.2 | 1500 | 1250 | 100 | 1150 | 400 | 750 |
| MOERCH no.3 | 1500 | 1200 | 100 | 1100 | 400 | 700 |
| RUBEN ANES. | 1500 | 1250 | 0(?) | 1250 | 500 | 750 |
| RUDOLPH(Puritan) | 1500 | 1300 | 300 | 1000 | 200 | 800 |
| EMERSON | 1500 | 1300 | 0(?)* | 1300 | 800 | 500* |
| BEAVER (B.O.C.) | 1500 | 1300 | 0 | 1300 | 50 | 1250 |

volumes measured by 3 Wright ventilation meters simultaneously, 1 at valve inlet, 1 at expiratory port and 1 between valve and test lung. (5 L rubber bag). Test lung pressures approx. 15/0 cm H₂O.

* calculated , not measured, since Emerson valve has no expiratory port.

** this back leak is less in patient use than with test lung, as in patients pressure drop is usually more rapid. Nevertheless even in patients back leak occurs and relative back leak volumes are valid.

Table 9

HUMIDITY
DELIVERED BY RESPIRATORS

| RESPIRATOR | HUMIDIFIER | Tidal vol. or Piston stroke vol. Rate 20/min. | RELATIVE HUMIDITY delivered into tracheotomy approx. * | Air TEMPERATURE delivered into tracheotomy approx. |
|---------------|--|---|---|---|
| MOERCH-PISTON | <u>Mueller-Moerch, old commercial type, midstream, cold water, surface</u> | 2 L | 30 - 45 % | 20° C |
| | <u>Walton, to piston intake, cold water, atomizer</u> | 2 L | 50 - 60 % | 20° C |
| | <u>Mueller-Safar-Moerch, experimental type; midstream, warm water, surface</u> | 2 L | 80 - 90 % | 30° C |
| | <u>Hopkins, experimental type, midstream, hot water, surface, copper mesh</u> | 3 L | 90% (15min) 55% (3 hrs) | 28° C 24-27° C |
| | | 1 L | 75 - 80 % | 27° C |
| | | 1 L | 78 - 83 % | 27° C |
| | | 1 L | | 32° C regular heater |
| | | 1 L | | 37° C special heater |
| | | | | |
| | | | | |

Fl & cont.

| | | | | |
|-------------------------------------|--|-------------------------------|--------|-----------------------------|
| BENNETT PR-1A | Puritan Nebulizer midstream, warm water, atomizer by added O2 flow | P (P. setting 20 cmH2O) | 97 % * | 27 - 37°C regular heater |
| BIRD MARK 7 | Bird side stream, cold water or aerosol atomizer | P (P. setting 20 cmH2O) | 40 % | 20° C |
| RADCLIFFE-EAST (Oxford, England) | Radcliffe midstream, hot water, surface | 1 L | 98 % * | 37° C |

* measured with ABBSON calibrated hygrometer in box, into which delivery tube of respirator was inserted.
 ** this relative humidity was maintained for unlimited periods of time

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