METHODS OF ARTIFICIAL RESPIRATION

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PART I

CRITERIA OF EFFICIENCY OF DIFFERENT METHODS

Recent articles in the *British Medical Journal* (Gibbens, 1942) and the *Lancet* (1943) raise the much-discussed problem of the efficiency of different methods of artificial respiration. After an examination of Table I in the article by Gibbens it seems necessary to restate the present knowledge of this subject; otherwise it is hardly possible to explain the great variations in his figures. In any case it seems better to try to give a physiological explanation than to admit that "the almost ideological frenzy in the attacks of the opposing advocates leaves the impression that it is the nationality of the promoter which determines the choice of method" (Gibbens).

General Principles

All methods must, theoretically, obey the following requirements: (1) give sufficient pulmonary ventilation—i.e., as nearly as possible the ventilation of a normal subject at rest; (2) stimulate the heart and circulation to help respiratory exchanges and transport of oxygen to tissues; (3) be harmless in themselves, easy of execution, and rapid in attaining results.

To judge the physiological efficiency of the methods various tests have been used, the most important of which are: (1) determination of pulmonary ventilation and respiratory exchange; (2) radioscopic and radiographic control; (3) manometric values of cardiac pressures during inspiration and expiration; (4) control of blood movement in the circulatory system. In this paper I deal only with the test of ventilation, the theme of recent discussions.

Nearly all investigators have held the determination of pulmonary ventilation to be a test of the utmost importance. In the table given by Gibbens the results have been obtained by quite different experimental techniques—some on subjects who had voluntarily suspended their breathing, others on subjects in apnoea, first produced by voluntarily forced breathing, and others, again, on subjects who had just died and in whom rigidity had not yet taken place.

Determinations in Voluntary Suspension of Breathing

The first part of Table I shows the widely varying results obtained by various experimenters on subjects who have voluntarily suspended their breathing while artificial respiration is applied. It was the British "Suspended Animation" Committee which, in 1903, decided that Silvester's method would produce a larger ventilation than Schäfer's. Schäfer did not believe that the techniques made it possible to judge the efficiency of the different methods. He considered it evident "that it is possible by nearly all the methods investigated to obtain an exchange of air per respiration as great as that of the tidal air." Schäfer's conclusions retain their value. Physiologists who have carefully studied respiration know that normal subjects, even when accustomed to respiratory tests, are completely incapable of neutralizing their breathing during the experiment and cannot be entirely passive all the time. This is the fundamental reason which explains the great difference in the results obtained as shown in part 1 of the table.

Determinations on Subjects in Apnoea

In order to obtain more passivity in the subjects certain experimenters applied artificial respiration during the short period of apnoea which follows a carefully studied period of voluntary forced breathing. In these conditions the quantity of air which enters the chest at each artificial respiration is

TABLE I

Experimental Conditions	Author	Lung Ventilation in c.cm.	
		Schäfer's Method	Silvester's Method
1. Subjects having voluntarily suspended their breathing ●	"Suspended Animation" Committee (1903) Schäfer (1904) Burton-Opitz (1922) Ploman (1906) Hamburger (1909) Liljestrand <i>et al.</i> (1913) Eve (1932) Killick and Eve (1933)	366 -- 520 504 (average) 500-600 616 500 1,000 350-550	458 178 — 1,200-2,000 454 540 — 200
2. Subjects in apnoea	Liljestrand <i>et al.</i> (1913) Héderer (1934)	170 100-150	190 250-280
3. Non-rigid cadaver	Héderer (1934) Bruns (1927) Bruns and Thiel (1930)	40-50 20 20	200 200 200
4. Apnoeic patients in moderately deep anaesthesia	Waters and Bennett (1936)	2 females, 180 (average) 2 males, 662 (average)	214 (average) 933 (average)

shown to be much less than during artificial respiration when the subject has voluntarily suspended his breathing. Details concerning the Hering-Breuer reflex and "chemical" control of breathing can be found in the excellent work on *Respiration* by J. S. Haldane and J. B. Priestley (1935; Clarendon Press, Oxford).

The important point is that after a carefully studied period of voluntary forced breathing the passivity of the subject is much greater than when the subject voluntarily suspends his breathing. This is shown by the fact that the volume of air entering the chest at each artificial respiration is independent of the frequency of the artificial breathing, while with voluntary suspension of natural breathing the entering volume of air varies inversely with the frequency. In these conditions the results shown in part 2 of the table indicate that Silvester's method ensures a greater ventilation than Schäfer's. The technique gives better and more constant results than that which utilizes the subject who voluntarily suspends his breathing. The "Suspended Animation" Committee forty years ago observed:

"It occurred to the Committee that it might be feasible to carry out the inquiry upon the living subject, the conditions necessary being that the subject should remain completely passive for the short period of time during which the experiment might last, and that he should not, by involuntary closure of the glottis, prevent the free passage of air into or out of the lungs. The first of these conditions can be readily fulfilled if the subject immediately prior to the experiments makes several deep respirations and the *besoin de respirer* is absent. Under these circumstances it is by no means difficult to perform artificial respiration for a short time without any resistance on the part of the subject, and without his making any spontaneous movements of respiration."

Determinations on the Cadaver and in Anaesthesia

In 1908 Schäfer summed up the position with regard to artificial respiration on the cadaver by stating that the experiments were mostly futile by reason of post-mortem rigidity. Other causes besides rigidity may interfere with the results; these include pre-mortem circulatory stasis, pulmonary or non-pulmonary origin of death, abdominal meteorism, and age and corpulence of the subject. By operating on non-rigid cadavers after tracheal intubation, Bruns, Bruns and Thiel, and Héderer obtained greater ventilation with Silvester's method than with Schäfer's, as shown in part 3 of the table.

In 1936 Waters and Bennett made a comparative study of different methods of artificial respiration on males and females. They used patients brought into apnoea by exaggerated minute-volume respiratory exchange while in moderately deep anaesthesia. The low carbon dioxide content resulting from such a procedure sufficed to prevent voluntary respiratory movements while the skeletal muscles were completely relaxed. These workers obtained a greater ventilation with Silvester's technique than with Schäfer's (part 4 of table), and they believe their findings to be a definite contribution because "an apnoeic patient under deep anaesthesia . . . exactly simulates the candidate for resuscitation by artificial respiration."

Conclusions

Taking into account the different techniques which may be relied upon for the comparative study of manual methods of artificial respiration, it seems justifiable to say that all experimenters agree that Silvester's method introduces in the respiratory tract of the apparently dead subject the biggest volume of air. But it is necessary to emphasize again that the determination of ventilation is only one criterion in judging the efficiency of these methods. The choice of a method depends also on the causes of asphyxia. In previous papers I have insisted on the advantages and disadvantages of Silvester's and Schäfer's methods and their possible improvements.

PART II

TILTING STRETCHERS VERSUS MANUAL METHODS OF ARTIFICIAL RESPIRATION

In 1932 F. C. Eve published an article on a new method of artificial respiration in which the patient lay on a rocking stretcher and the weight of the abdominal contents pushed the diaphragm alternately up and down. He believed that this movement of the diaphragm was sufficient to ensure lung ventilation of normal value. More recently articles have appeared suggesting the great superiority of Eve's method over other methods of artificial respiration. Gibbens (1942) writes:

"Many otherwise uninjured men are rescued after only a short immersion and yet do not survive. This is undoubtedly because the normal methods of artificial respiration are not very efficient, need many skilled men, and are so tiring that they are not carried out thoroughly or for long enough. It was a relief to read of Eve's rocking method, which can be practised by unskilled men, efficiently and with little fatigue . . . Killick and Eve have given detailed figures which show the rocking stretcher's superiority over other methods, and it is eminently practicable at sea."

It is true that there are certain practical advantages in Eve's method, but its physiological superiority remains to be proved. The experiments so far made to demonstrate its efficiency are very few, and in my opinion fall short of proof.

Experimental Results with Eve's Rocking Method

In his article in 1932 Eve studied experimentally the effect of his rocking method on the lung ventilation of a subject voluntarily suspending his breathing. He found that each see-saw movement of the stretcher produced a lung ventilation of 1,500 c.cm. Schäfer's method applied to the same subject produced a ventilation of 1,000 c.cm. per respiration. The radiographic control of the chest in the subject voluntarily suspending his breathing during rocking showed a diaphragmatic excursion of 5 cm., which, according to Eve, indicates roughly a movement of 1,800 c.cm. of air. In the following year Killick and Eve, again experimenting on subjects voluntarily suspending their breathing, found much smaller values of lung ventilation. Using the rocking method at rates approximating to the normal respiratory rate, the tidal air was 450 to 600 c.cm. They also

found Schäfer's method less efficient than had been shown by Eve a year before, and wrote that it produced a tidal air varying in different subjects from 350 to 550 c.cm.

These very different results obtained by the author of the method are no more surprising than the similarly different results obtained by other experimenters who have studied the efficiency of the various manual methods of artificial respiration on subjects voluntarily suspending their breathing. This technique of investigation is inconclusive because normal subjects, even when accustomed to respiratory tests, are completely incapable of neutralizing their breathing during the experiments and cannot be passive all the time. The lack of passivity in the subjects experimented upon by Killick and Eve is shown by the fact that the volume of air entering the chest at each artificial respiration varies inversely to the frequency, as is brought out in Table II, drawn from the experimental results of these investigators.

TABLE II

Rate of Rocking (R) per min.	Volume of Ventilation per min. (litres)	Tidal Air in c.cm. per See-saw
Without (R)	5.2	
6-7 (Rs)	5.4	830
10 "	6.1	610
14-15 "	6.6	450
20-22 "	8.5	400

Table III shows that results comparable to those of Killick and Eve are obtained when the rhythm of the respiratory movements is varied during artificial respiration produced by manual methods in a subject voluntarily suspending his breathing. Moreover, the volume of tidal air is practically the same as that observed in normal breathing.

TABLE III

Respiratory Rate per min.	Schäfer's Method		Tidal Air (c.cm.) Normal Breathing (Ventral Position)	Silvester's Method		Tidal Air (c.cm.) Normal Breathing (Dorsal Position)
	Vol. of Vent. per min. (litres)	Tidal Air per Movement (c.cm.)		Vol. of Vent. per min. (litres)	Tidal Air per Movement (c.cm.)	
6	—	—	—	4.9	810	830
10	6.25	630	660	6.15	610	590
15	7.50	500	510	8.15	540	450
20	8.60	430	430	10.25	340	390

A glance at these tables shows that the experimental basis on which Gibbens relies as proof that the rocking method is superior to the other methods of artificial respiration is insufficient.

In 1936 Waters and Bennett studied comparatively the efficiency of the methods promoted by Eve, Schäfer, and Silvester on patients brought into apnoea by exaggerated respiratory exchange while in moderately deep anaesthesia. They stated: "An apnoeic patient under deep anaesthesia, we believe, exactly simulates the candidate for resuscitation by artificial respiration." Unfortunately, their experiments were carried out only on four subjects, and one single experiment was made to compare Eve's method with those of Schäfer and Silvester. This experiment was made on a woman, 47 years of age, whose vital capacity was 2,200 c.cm., and in this subject rocking through an angle of 60 degrees (the angle of tilt in the work of Killick and Eve was 50 degrees) produced a lung ventilation of 100 c.cm. In the same subject Schäfer's and Silvester's methods produced respectively a lung ventilation of 160 and 140 c.cm. That single experiment during which small ventilations were obtained does not suggest the superiority of Eve's method, and should be repeated on various subjects. Nor do the results obtained by Eve and Killick on subjects voluntarily suspending their breathing permit us to state definitely that the rocking method is the best. Eve's method may be physiologically excellent, and certainly it deserves thorough study. What are the experimental criteria which enable us to judge its comparative efficiency?

Criteria of Efficiency of the Rocking Method

In judging the efficiency of Eve's method very important information can be obtained by studying lung ventilation on subjects in apnoea, on apnoeic patients in moderately deep anaesthesia, and on the non-rigid cadaver. A comparative study is necessary on each subject, using in turn the methods of Eve,

Schäfer, and Silvester; and these studies, made on man, ought to be completed by experiments made on large monkeys after curarization. The comparative study of the various methods could be made (1) when the animal's breathing is stopped but cardiac activity remains, and (2) when breathing and heartbeats have stopped. The study of lung ventilation, chemical composition of expired air, gaseous exchanges, and percentage saturation of haemoglobin with oxygen in arterial and mixed venous blood would give very important indications of the efficiency of alveolar ventilation. It seems also absolutely necessary to study the influence of the angle of tilt on lung ventilation. If the weight of the abdominal contents actuates the diaphragm we may deduce that the volume of lung ventilation must be in relation with the angle of tilt.

A second criterion derives from radioscopic and radiographic study of the chest. This study must be made in the same experimental conditions as those used for the measurement of lung ventilation (subjects in apnoea, apnoeic patients in moderately deep anaesthesia, non-rigid cadaver).

One of the aims of artificial respiration is to stimulate the heart and circulation in order to produce oxygenation of the blood and to supply oxygen to the tissues. Artificial respiration creates an indirect massage of the heart, the intensity of which is shown by differences of pressure in the cardiac cavities during inspiratory and expiratory movements. The measurement of intracardiac pressure made on the non-rigid cadaver indicates that a quick see-saw flow of the blood takes place in the heart cavities, producing a true endocardiac massage. This mechanical stimulation certainly plays an important part in the restarting of the heart's activity. The various manual methods of artificial respiration are far from having the same efficiency on the cardiovascular system. Table IV shows the differences of pressure produced in the left ventricle of the non-rigid cadaver by various methods during inspiration and expiration.

TABLE IV

Method	Lung Ventilation in c.cm. (Non-rigid Cadaver)	Pressure in Left Ventricle (cm. Water)		Difference (cm. Water)
		Inspiration	Expiration	
Silvester (without expiratory compression) ..	200	-8	+1	9
Silvester (with expiratory compression)	280	-8	+18	26
Schäfer	20	+9	+13	4
Combined method: Schäfer's method with raising of elbows	210	-7	+15	22

A study of Table IV shows that the manœuvres of artificial respiration which mobilize the thoracic framework above and below its position of equilibrium—i.e., which provoke an active inspiratory enlargement of the chest and then an expiratory compression—are the most efficient, both on the cardiovascular and on the respiratory system. Silvester's method with expiratory compression and Schäfer's method improved by the addition of an active inspiratory movement (raising the elbows) fulfil these conditions.

The feeble action of Schäfer's method on respiration and circulation can be explained by the conditions of the respiratory system. In the cadaver (and in the apparently dead body) all the reflexes have disappeared, the muscles are slack, and the loss of tonus in the respiratory muscles brings the chest into the complete expiratory position; the diaphragm is relaxed and arches into the thorax.

As a result of these changes the lungs are almost entirely emptied of air and the capacity of the thoracic cavity is much diminished. Therefore the conditions of the respiratory system in the apparently dead body do not lend themselves to methods of artificial respiration which use only expiratory pressure on the thorax and abdomen, since the respiratory system is already in the greatest possible state of expiration. The ventral position in Schäfer's method further exaggerates the diminution of the capacity of the thoracic cavity, because the weight of the spine, shoulder, and back muscles contributes also to the collapse of the thorax. The strong pressure (+9 cm. water) registered in the left ventricle of the non-rigid cadaver lying on the abdomen and the slight manometric oscillations resulting from the manœuvres of Schäfer's method show the complete collapse

of the chest and the resulting compression of the heart. The state of collapse of the respiratory system of the apparently dead body explains completely why Schäfer's method, which compresses the abdominal viscera in the chest, utilizing the piston-like action of the diaphragm to expel the lung contents, has such a slight result on ventilation and circulation. As the rocking method is based on the same principle of stimulation of the inert diaphragm (by the weight of abdominal contents instead of abdominal compression as used in Schäfer's method), and the subject lies on the stretcher in the ventral position, it seems to me necessary to study the efficiency of Eve's method on the cardiovascular system of the apparently dead body.

The measurement of intracardiac pressure on the non-rigid cadaver during rocking and a complete study of the physiology of the circulatory system in large monkeys after curarization (measurement of arterial and venous blood pressure, circulation time, output of heart) under the same conditions as to rocking should yield information of great practical value.

Conclusions

Eve's rocking method certainly has great practical advantages, but the experimental criteria so far employed to study its physiological efficiency seem to me insufficient to prove its superiority to other methods of artificial respiration. A more complete experimental study is necessary before its efficiency can be determined.

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MANAGEMENT OF ACUTE PLEURAL EMPYEMA

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The treatment of pleural empyema, whether it be acute or chronic, is simple drainage, and the drainage must remain adequate for as long as there is an abscess cavity. This is a surgical principle which applies to collections of pus anywhere in the body, but it is a principle which, in the case of intrathoracic pus, is in danger of being submerged by a constant flood of new-fangled drainage tubes, new irrigation apparatus, water pumps, and electric suction. The time at which an empyema should be drained is a matter for clinical judgment. The wise surgeon does not incise an infected area until the inflammation is well localized, and this too is applicable to pleural infections. Considerations of cardio-respiratory physiology may call for relief of pressure within the chest before drainage is advisable, and in such circumstances repeated aspiration of an infected pleural effusion may be necessary. Aspiration should be performed frequently, slowly, and without air replacement. In certain cases the same conditions may call for a water-sealed intercostal drain. When an empyema is ready for draining a liberal incision should be made, at least 2 in. of rib removed subperiosteally, and a tube inserted. Only the skin should be sutured. At operation