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Artificial Respiration in the Dog by Percutaneous, Bilateral, Phrenic Nerve Stimulation

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Artificial respiration was produced in 11 anesthetized dogs using trains of short duration stimuli (1 msec with a frequency of 35/sec), applied to needle electrodes placed bilaterally at the base of the neck. The tips of the needles were in close proximity to the phrenic nerves. In all cases, the inspired volume increased with an increase in stimulus intensity. Typically, it required 5 to 10 volts (peak) to produce an inspired volume equal to spontaneous tidal volume. The maximum inspired volumes ranged from 1.27 to 4.31 times the tidal volume. (Am J Emerg Med 1991;9:527-529. Copyright © 1991 by W.B. Saunders Company)

Ever since Waud[1] demonstrated in the rabbit that direct, bilateral phrenic nerve stimulation contracted the diaphragm and produced a substantial inspired volume, it became obvious that this technique could be used to provide artificial respiration. Sarnoff et al[2] confirmed these results and Glenn et al[3] developed an externally energized, implanted stimulator for phrenic nerve stimulation. Glenn[4] and his colleagues developed a fully implantable unit for human use. The method is now used clinically and is called diaphragm pacing. There have been many studies in which the inspiratory motor nerves were stimulated with body surface electrodes.[5] However this technique has not been adopted clinically for two reasons: (1) it is difficult to locate the optimum skin sites for the electrodes, and (2) there is often a rather unpleasant skin sensation due to the stimulating current. If the electrodes are not exactly over the proper sites the stimulating current has to be high, which makes the skin sensation painful. Therefore it occurred to us that percutaneous needle electrodes could be used to deliver stimuli directly to the phrenic nerves and provide an easy means of applying artificial respiration and avoiding the stimulation of skin receptors. To the best of our knowledge, there has been no prior report of phrenic nerve stimulation with percutaneous needle electrodes. The present report describes the use of bilateral needle electrodes inserted into the base of the neck of the dog to stimulate both phrenic nerves to investigate the relationship between inspired volume and stimulus intensity.

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METHODS AND MATERIALS

All studies described herein were performed in accordance with US Department of Health, Education, and Welfare standards.[6] In addition, this study was approved by the Purdue University Animal Care and Use Committee.

To cause inspiration, the diaphragm must be contracted tetanically by the delivery of a train of stimuli to the phrenic nerves. The duration of the train of stimuli determines the duration of inspiration. Figure 1 illustrates schematically the essential features of phrenic nerve stimulation.

In this study 11 dogs were used; the weights ranged from 9 to 12 kg. Each animal was first sedated with thiopental (20 mg/kg given intravenously) and a cuffed endotracheal tube was inserted. Anesthesia was maintained with a mixture of methoxyflurane in oxygen. Anesthesia depth was stage III, planes 1 and 2. Respiration was recorded by temporarily disconnecting the anesthesia machine and connecting the endotracheal tube to a 5-L, air-filled recording spirometer containing a carbon dioxide absorber.

The stimulating electrodes were made from straight surgical cutting needles, 8 cm long and 0.033 in in diameter in the manner described by Geddes et al.[7] The bare end of a flexible, stranded, insulated wire was passed through the eye of

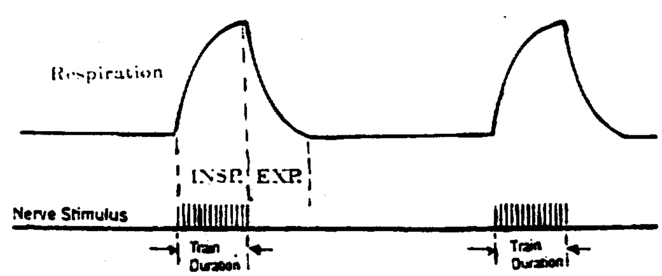

FIGURE 1. The essential requirement for providing artificial respiration by phrenic nerve stimulation. The upper recording represents the volume of air breathed. The lower recording represents the stimuli. A train of short-duration stimuli delivered to the phrenic nerves causes the diaphragm to contract tetanically which produces inspiration. Expiration is passive by elastic recoil after cessation of the train of stimuli.

the needle and soldered. A small rubber stopper was passed over the needle tip and advanced so that it covered the soldered connection, thereby providing insulation as well as a handle for manipulation. Each needle electrode was insulated to within 5 mm of its tip by placing a cork over the cutting tip to cover about 5 mm. Then the needle was sprayed with Krylon insulating plastic. When the plastic was dry, the cork was removed, thereby exposing the 5-mm uninsulated tip.

The needle electrodes were inserted in the neck dorsal to the external jugular vein, below the angle of the jaw, and advanced toward the thoracic inlet to bring the tip close to the cervical phrenic trunk, ie, caudal to C5.

Contraction of the diaphragm requires the delivery of a train of stimuli to the phrenic nerves. The duration of each stimulus is not critical, but for typical motor nerves, a duration of 1 msec or less is satisfactory. The frequency of the stimuli in the train need only be high enough to produce a fused tetanic contraction. In a previous study[8] we determined that a frequency of above 25/sec is adequate. The duration of the stimulus train need only be long enough to produce a full inspiration, which requires about 0.5 to 0.7 seconds. The number of stimulus trains/min is the artificial respiratory rate.

A Mark V Physiograph stimulator (Narco Bio-Systems, Houston, TX) was used. The stimulus frequency was 35/sec and the pulse duration was 1 msec. The duration of inspiration was controlled by turning the stimulator output on and off manually.

After about 1 hour of anesthesia the tidal volume of each animal was first measured while breathing spontaneously. Next the depth of anesthesia was increased slightly to depress respiration, and then intermittent phrenic nerve stimulation was applied by turning the output of the stimulator on and off. The stimulus voltage was increased incrementally from 5 V, and the resulting inspired volume was recorded and measured. The voltage was increased until little additional inspired volume was obtained for a further increase in voltage.

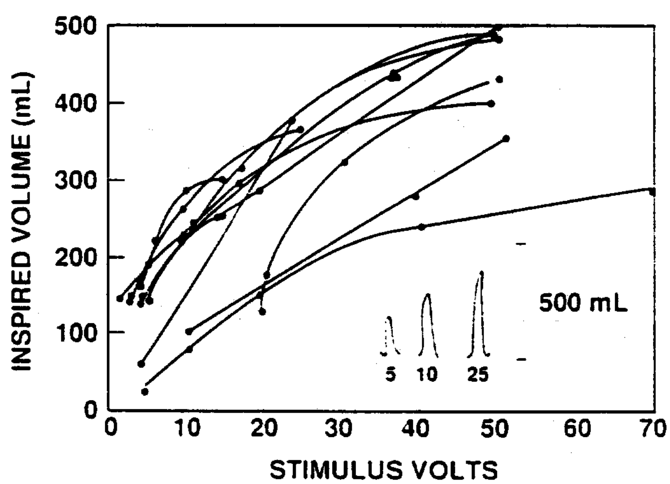

FIGURE 2. Inspired volume (mL) versus stimulus output (volts peak) for bilateral, cervical, phrenic nerve stimulation in the dog with needle electrodes. The inset shows typical inspired volumes for 5, 10, and 25 V along with a 500-mL calibration for a 10-kg dog.

TABLE 1. Respiratory Volumes

Dog No.	Weight (kg)	Tidal Volume	Max Volume	Ratio Max/Tidal
11.29	10	171	366	2.14
11.28	9	175	482	2.75
11.13	11	153	489	3.20
12.3	12	148	407	2.75
12.4	11	135	488	3.61
12.6	10	85	366	4.31
12.14	10	191	500	2.62
12.19a	11	203	392	1.93
12.19b	11	128	162	1.27
12.20	10	119	476	4.0
1.3	12	225	288	1.28

RESULTS

Figure 2 illustrates the inspired volume versus peak stimulus voltage for all of the animals. The inset in the lower right of the figure shows typical inspired volumes for stimuli of 5, 10, and 25 V, along with a 500-mL calibration. Table 1 summarizes the spontaneous tidal volumes obtained during anesthesia just prior to applying the bilateral phrenic nerve stimulation, and the maximum inspired volume. Also shown are the ratios of maximum inspired volume to the tidal volume.

DISCUSSION

In all cases, the maximum inspired volume was larger than the spontaneous tidal volume. The quality of electrode application, ie, the proximity of the electrode tips to the phrenic nerves, is revealed by the voltage required to produce one tidal volume. The lower this voltage, the closer the electrode tips were to the phrenic nerve trunks. Typically it required 5 to 10 V to produce one tidal volume.

It was surprising to discover in a few animals that the ratio of maximum inspired volume to spontaneous tidal volume was only slightly higher than 1.0. In these animals, there was considerable neck-muscle contraction, an event that was minimal when the electrodes were placed close to the phrenic nerves.

A different percutaneous approach to the phrenic nerves was reported by Daggett et al.[9,10] In those studies a bipolar pacing electrode was passed down a jugular vein until the electrode came in proximity to the phrenic nerve trunk and the stimulating current spread adequately to intercept the phrenic nerve. The same technique was used by Silver et al[11] to provide artificial respiration to enable measurement of Fick blood flow during cardiopulmonary resuscitation in a dog with ventricular fibrillation. Peterson et al[12] used stimuli applied to subdiaphragm monopolar electrodes to provide artificial respiration in the anesthetized dog.

To the best of our knowledge, this is the first report to describe the use of needle electrodes to access the cervical phrenic nerves. The attractive features of percutaneous phrenic nerve stimulation are its ease of application and the simple equipment needed. The use of needle electrodes bypasses the skin receptors, and it is expected that if the technique is applied to man there will be little sensation with properly applied electrodes. The volume of air inspired can be in excess of spontaneous tidal volume. Therefore large minute volumes can be achieved if desired by the use of a high artificial respiration rate. Although cutting needles were used in this study, long, slender hypodermic needles, insulated to within a few mm of the tip, can be used. The same stimulator can be used to provide artificial respiration in small and large subjects.

The technique described herein requires functioning myoneural junctions. Therefore, it may be useful in situations when sudden respiratory arrest is detected early. It may be useful in cardiopulmonary resuscitation if the period of circulatory arrest has not been present for many minutes. However, even in such cases, after a few minutes of conventional cardiopulmonary resuscitation which has restored the flow of some oxygenated blood, phrenic nerve stimulation is likely to be effective. Another area of application is provision of respiration during anesthesia. Clinical studies are needed in these areas. The contraindications for using the method are the presence of a pneumothorax or the use of myoneural blocking agents.

Finally, it should be noted that with phrenic nerve stimulation, inspiration is produced by negative intrathoracic pressure, as occurs when breathing normally. Therefore the use of this technique avoids the intermittent reduction in pulmonary blood flow that occurs with positive-pressure ventilation.

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