Anesthesiology
V 37, No 1, July 1972

Bilateral Phrenic-nerve Block in Man:

Technical Problems and Respiratory Effects

John H. Eisele, M.D., M. I. M. Noble, M.D.,† Jordan Katz, M.D.,‡*
Dennis L. Fung, M.D.,§ Robert F. Hickey, M.D.¶

Attempts were made to produce bilateral phrenic-nerve blocks in 11 normal volunteers in order to evaluate the respiratory effects. The study demonstrated that selective bilateral block of the phrenic nerves is difficult to achieve, even with the use of a nerve stimulator, because the sympathetic, vagus, and recurrent laryngeal nerves may be blocked inadvertently. The results in three subjects with evidence of pure bilateral phrenic-nerve blocks indicated that in the sitting position ventilation is not impaired, inspiratory capacity is reduced 25 per cent, and there is an altered sensation in breathing as well as breath-holding. The subjects became acutely aware of their breathing, which was deeper and slower. The feeling of discomfort during breath-holding was less intense, and thus more tolerable, during phrenic-nerve block. (Key words: Nerve block; Phrenic nerve; Vagus; Sympathetic nervous system; Inspiratory capacity; CO_2–ventilatory response; Respiratory sensations.)

MOORE[1] indicates that phrenic-nerve block can be used to arrest diaphragmatic action during surgical operations, or for alleviation of persistent hiccups. It has also been employed to predict the effect of phrenic crush or section in tuberculosis. Phrenic-nerve block is reportedly a simple procedure, and bilateral phrenic-nerve blocks have been performed for intractable hiccups without respiratory problems.[2] There is no information concerning respiratory changes in healthy subjects during diaphragmatic paralysis. It was the purpose of this study to produce bilateral phrenic-nerve blockade in normal subjects without involving other nerves in the neck, and to examine the diaphragm's contribution to respiration and respiratory sensations.

Method

TECHNIQUE

To locate the phrenic nerve, we used the method described by Sarnoff,[3] in which a stimulating needle placed on the cervical portion of the phrenic nerve elicits diaphragmatic contractions that are easily observed and are experienced as painless hiccups. Phrenic-nerve block can then be achieved with a small volume (2–5 ml) of concentrated local anesthetic (lidocaine, 2–4 per cent) in order to avoid blocking other nerves in the neck.

CRITERIA OF SUCCESSFUL BLOCK

Evidence of altered diaphragmatic motion appears on a fluoroscope as asynchronous contractions. Bilateral phrenic-nerve block results in paradoxical diaphragmatic movements, which are not entirely passive since the lateral portions of the diaphragm receive innervation from the lower intercostal nerves. This makes complete phrenic motor-nerve blockade difficult to evaluate on the fluoroscope, since the muscle's innervation does not get entirely blocked.

Loss of the ability to stimulate the diaphragm with as much as 30 volts applied to the phrenic nerve can be used as supplemental

* Associate Professor, Department of Anesthesiology, University of California, School of Medicine, Davis, California 95616.
† Lecturer, Department of Medicine, Charing Cross Hospital Medical School, Fulham Hospital, London, W. 6, England.
‡ Associate Professor, Department of Anesthesia, University of Miami, Miami, Florida 33152.
§ Major, USAF, Keesler Medical Center, Biloxi, Mississippi 39531.
¶ Assistant Professor in Residence, Anesthesia, University of California Medical Center, San Francisco, California 94122.
Accepted for publication January 18, 1972. Supported in part by the John A. Hartford Foundation.
Address reprint requests to John H. Eisele, M.D.

TABLE 1. Results of Nerve Block Attempts in 11 Subjects, Showing the Changes in Vital and Inspiratory Capacities Measured with the Subjects Seated

	Age (Years), Sex	Nerve Block Achieved	Vital Capacity (l)		Inspiratory Capacity (l)	
			Before → After	Per Cent Change	Before → After	Per Cent Change
Subject 1	32, M	Bilateral phrenic	5.20 → 3.90	−25	3.00 → 2.25	−25
Subject 2	35, M	Bilateral phrenic	4.80 → 4.00	−20	3.30 → 2.60	−27
Subject 3	19, M	Bilateral phrenic	4.50 → 3.60	−20	3.00 → 2.40	−20
Subject 4	30, M	Bilateral phrenic and vagal	4.30 → 3.70	−14	3.00 → 2.40	−20
Subject 5	25, M	Bilateral phrenic and vagal	4.80 → 3.90	−19	3.25 → 2.15	−34
Subject 6	23, M	Unilateral phrenic and sympathetic	5.40 → 4.60	−15	3.40 → 2.80	−18
Subject 7	22, M	Unilateral phrenic	3.90 → 3.30	−15	2.60 → 2.30	−12
Subject 8	21, M	Recurrent laryngeal	4.00 → 4.00	0	2.75 → 2.75	0
Subject 9	23, F	Recurrent laryngeal	3.40 → 3.50	+3	1.80 → 2.20	+22
Subject 10	26, M	None	5.00 → 4.60	−8	3.60 → 3.40	−0.5
Subject 11	23, M	None	4.00 → 4.00	0	2.30 → 2.20	−4

evidence of nerve block if the needle tip has not moved.

A Horner's syndrome, indicative of sympathetic block, could interfere with respiratory studies. More important in terms of respiration is evidence of vagus nerve involvement. Block of vagal sensory fibers leads to a decreased ventilatory response to CO_2,[4] especially, to a failure of the respiratory rate to increase with increasing CO_2. Blockade of the recurrent laryngeal nerve causes a voice change and possible airway obstruction, while block of the main vagus nerve leads to tachycardia (increase in heart rate of more than 20 beats/min).

MATERIAL AND PROCEDURE

Eleven normal subjects (ten men, one woman; ages 19 to 35 years) volunteered for bilateral phrenic-nerve blocks. They were informed of the risks and the possibility of altered sensations. Two of the subjects were familiar with respiratory physiology. The sitting position was used since diaphragmatic paralysis in the supine position can produce orthopnea owing to the passive elevation of the diaphragm and the decrease in lung compliance.[5, 6] The nerve blocks were not painful, and anxiety was minimal after careful explanations and assurances as to the safety of the procedures. Injections were made on one side and then the other except that in Subjects 2 and 6 both phrenic nerves were injected simultaneously with the aid of two nerve stimulators, in an effort to insure a longer-lasting block.

Respiratory studies were carried out immediately before and after the phrenic-nerve-block attempts. These included inspiratory-capacity and vital-capacity measurements, which were performed a minimum of three times and recorded on a spirometer. The largest values were taken for the inspiratory and vital capacities. The ability to detect inspiratory resistive loads was tested by random addition of various-sized filters to a tube connected to the mouthpiece, increasing resistance 0.3 to 2.2 cm H_2O/l/sec. The subjects were blindfolded, and detection of the load was signaled with a hand button. The ventilatory response to CO_2 was determined by a rebreathing method,[7] using a mixture of 7 per cent CO_2, 30 per cent O_2, and 63 per cent N_2, while measuring end-tidal P_{CO_2} with a Godart capnograph. The ventilatory CO_2-response slope was measured over the initial steep rise which was reasonably linear. The last test was the breath-hold maneuver, which was done at end-expiration (functional residual capacity) after washing out N_2 with O_2. Care-

ful attention was given to the end-tidal P_{CO_2} before the breath-hold, which was repeated numerous times before the block and at least three times after the block.

Results

Success of the Block

The results of the phrenic-nerve-block attempts are summarized in table 1. Although the diaphragm was unresponsive to maximal phrenic-nerve stimulation in Subjects 1, 2, 3, 4, and 5, some movement was still seen on the fluoroscope. Subjects 6 and 7 had unilateral phrenic-nerve blocks and smaller alterations in breathing. Subject 6 also developed a complete unilateral Horner's syndrome. Four subjects (4, 5, 8, and 9) showed evidence of vagal block: two had decreases in CO_2 responsiveness, and two became hoarse. The last two subjects (10 and 11) had no evidence of any nerve block, and since they had received approximately the same amounts of lidocaine as the other subjects, they served as controls.

Respiratory Studies

In the sitting position, Subjects 1, 2, and 3 had decreases in inspiratory capacity of 25, 27, and 20 per cent after bilateral phrenic block (table 1). Subjects 4 and 5, who showed evidence of vagal block, had reduced inspiratory capacities (20 and 34 per cent, respectively). In these five subjects there were definite paradoxical respirations, and they had an altered breathing sensation, in that inspiration felt different and looked jerky. The tidal volumes and respiratory frequencies were irregular at first, and within minutes breathing became deeper and slower. The reductions in inspiratory capacity of 18 and 12 per cent in Subjects 6 and 7 helped confirm unilateral phrenic-nerve block, although it is possible that these subjects had partial bilateral phrenic-nerve blockade that could not be detected by the fluoroscope. The per cent reductions in inspiratory capacity following phrenic-nerve block were larger than the per cent changes in vital capacity, since inspiration contributes only a portion to the vital capacity, which is an expiratory maneuver. Subjects 8, 10, and 11 had no change or small reductions in lung capacities, while only Subject 9 (with recurrent laryngeal block) had an increase in lung capacity.

In the three phrenic-nerve-blocked subjects, breath-holding times were prolonged (table 2). In each case end-tidal P_{CO_2}'s at the starts of the breath-holds during the control period and during the block were similar. The increased breath-holding time during phrenic-nerve block, therefore, was not the result of hyperventilation before breath-holding. At the same time, the breath-holding sensation was markedly attenuated or altered. It was described as less intense and was felt in the upper chest rather than in the epigastric area, which is the usual site of distress. The breath-hold was also prolonged in the subjects with vagal involvement, 4 and 5, an expected result of vagal block.[4] Of the remaining subjects, 6 and 7 had smaller increases in breath-holding times, while 8, 10, and 11 had no appreciable changes in breath-holding at comparable P_{CO_2}'s.

Rebreathing of CO_2 by the phrenic-nerve-blocked subjects produced no change in the ventilatory responses except in Subject 1, who became more sensitive to CO_2 for no apparent reason. That is, the CO_2–ventilation slopes were similar to those before the block (see table 3). Also, the breakpoint, which is the time when rebreathing cannot be tolerated longer, occurred at about the same P_{CO_2} in these subjects before and after phrenic-nerve block. Subjects 4 and 5 had reduced responses to CO_2 rebreathing and an altered CO_2 sensation, which is part of the evidence of vagal block. None of the remaining subjects (6, 8, 9, 10, and 11) showed any change in their responses to CO_2 rebreathing after the block procedure.

The detection of added airway resistance was unaltered by phrenic-nerve-block attempts in the seven subjects tested, and the sensation of breathing with an increased load was likewise not influenced by phrenic-nerve-block attempts (see table 3).

Discussion

Phrenic-nerve block is an uncommon procedure in medicine; therefore, it is not surprising that little has been written on the subject, especially on the concomitant block of vagus,

TABLE 2. Breath-holding Time and Sensation*

	Before Block		After Block		Sensation
	P_{CO_2} (mm Hg)	Time (Sec)	P_{CO_2} (mm Hg)	Time (Sec)	
Subject 1	32.0	59	35.4	150	Less intense
Subject 2	28.0	40	27.0	80	Less intense
Subject 3	37.5	76	38.5	113	No change
Subject 4	35.5	108	35.0	118	Almost absent
Subject 5	34.2	37	34.2	70	Felt vague
Subject 6	39.0	42	39.1	55	Felt different
Subject 7	37.5	59	37.5	72	No change
Subject 8	28.0	46	29.5	52	Felt easier
Subject 9	(No comparable values for P_{CO_2})				No change
Subject 10	39.2	59	36.0	72	No change
Subject 11	33.2	104	32.2	106	No change

* Breath-holding time in subjects before and after phrenic-block attempts. Several breath-holds were performed but only those done at approximately the same end-tidal P_{CO_2}'s are recorded since the starting P_{CO_2} is a critical determinant of the breath-hold. Note the prolongation of BHT in Subjects 1 through 7, all of whom had some phrenic or vagal block. Subjects 10 and 11 (no block) had small changes in BHT, which would be expected since therir P_{CO_2} values were lower after the block attempt.

TABLE 3. Ventilatory Responses to CO_2* and Thresholds of Load Detection before and after Phrenic Block Attempts†

	CO_2 response Slope $\Delta V_E/\Delta CO_2$ (l/Min/mm Hg)		CO_2 Sensation	Threshold of Load Detection (cm H_2O/l/Sec)		Loading Sensation
	Before	After		Before	After	
Subject 1	2.5	4.0	No change	0.7	0.7	No change
Subject 2	0.9	0.8	No change	Incomplete		Incomplete
Subject 3	2.8	2.8	No change	0.6	0.6	No change
Subject 4	2.4	1.2	Felt no drive	0.6	0.6	No change
Subject 5	1.6	1.0	Felt vague	0.3	0.3	No change
Subject 6	2.0	1.8	No change	Incomplete		Incomplete
Subject 7	Incomplete		Incomplete	Incomplete		Incomplete
Subject 8	1.8	1.8	No change	0.5	0.3	No change
Subject 9	0.7	0.8	Felt easier	Incomplete		Incomplete
Subject 10	2.5	2.5	No change	0.5	0.5	No change
Subject 11	2.0	2.5	No change	0.3	0.3	No change

* Expressed as change in ventilation per increment of change in CO_2.
† Subjective responses are also indicated.

sympathetic, or other cervical nerves. It is not evident in the literature whether the diaphragm can be completely paralyzed with local anesthetic injected in or about the phrenic nerve. Minimal respiratory changes have been observed during cervical epidural anesthetic blocks employing 20 ml or more of 2 per cent lidocaine.[8] Deep cervical plexus block (C3, C4, C5) is likewise not associated with respiratory complications unless the subarachnoid space is entered. This suggests that the peripheral motor fibers of the phrenic nerve are difficult to block completely, which is one reason large volumes of anesthetic have been recommended. The completeness of phrenic-nerve block could not be determined by fluoroscopy or by the inability to elicit a diaphragmatic contraction with maximal stimulation of the phrenic nerve. Electromyographic recording of the diaphragm could have aided considerably, but this was not chosen because surface electrodes are too imprecise and the placement of diaphragm needles incurs a high risk of pneumothorax.

Nevertheless, with careful placement of the stimulating needles, we were able to produce substantial phrenic motor-nerve blocks in three subjects without involving other nerves or structures. The effects on ventilation were not surprising in view of previous estimations. Bergofsky,[9] using a body plethysmograph in normal subjects breathing with their diaphragms only, observed that the diaphragm contributes 26 per cent of the tidal volume in the upright position. In studies of unilateral phrenic crush in young male tuberculosis patients there were 15 to 18 per cent decreases in vital capacity.[10, 11] Bilateral phrenic-nerve block, then, might be expected to decrease vital capacity 30 per cent or more. It should be pointed out, however, that no lung-capacity measurement is a perfect index of muscle integrity since it also depends on patient motivation and cooperation.

The ventilatory responses to CO_2 were not changed by the phrenic-nerve blocks despite an altered breathing pattern. That is, at normocapnia breathing appeared to be somewhat labored, and we thought that the intercostal muscles might fatigue when stressed with elevated CO_2. Sant'Ambrogio[12] found a ventilatory response to CO_2 in phrenicotomized cats but not in phrenicotomized rabbits; hence, the respiratory contribution of the diaphragm appears to differ among species.

Detection of added inspiratory loads in the range of 0.3 to 2.2 cm $H_2O/l/sec$ was unimpaired by phrenic-nerve blockade. These results are in keeping with normal threshold values for loads to breathing reported by Bennett and Campbell.[13] These authors feel that muscle spindles play an important role in detection of respiratory loads. However, it has been shown that the intercostal muscles, which are rich in spindles, can be blocked without influencing the detection of inspiratory or expiratory loads.[14] This suggests that the upper airway or the pharynx is the area where added external respiratory resistance is felt.[15]

Breath-holding tolerance was greatly prolonged by the phrenic-nerve block, which indicates the diaphragm is involved in this sensation. It is known that diaphragmatic contractions occur early during a breath-hold and increase in intensity until the breakpoint.[16] Abolition or reduction of this activity, therefore, may lessen the concomitant urgency to breathe. Prolongation of the breath-hold can also be seen following curarization of all muscles including the diaphragm[17] and during bilateral vagal block.[18] Hyperventilation, motivation, and practice also may influence breath-holding, which is why in our study the maneuver was repeated several times to minimize these factors.

The effect of phrenic-nerve block on breath-holding may be the result of partial paralysis of the diaphragm muscle, the contractions of which may distort lung tissue and thereby stimulate receptors with vagal afferents. On the other hand, tendon and/or pain receptors in the diaphragm may be activated during a breath-hold, and their afferent path would be interrupted by even a partial phrenic-nerve block. It is likely that in this study most of the sensory fibers were blocked, since they are more susceptible to local anesthesia than motor fibers.

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Drugs and Their Actions

MAGNESIUM, DIGITALIS AND CARDIAC RHYTHMICITY Although the roles of potassium and calcium in the genesis of digitalis-induced arrhythmias are well-known, magnesium, too, is important. Magnesium depresses cardiac conduction and spontaneous rhythm, perhaps by activation of membrane ATPase, in turn increasing potassium transport into the cell. Digitalis inhibits membrane ATPase, causing a loss of cellular potassium. This reciprocal action of magnesium and digitalis was studied in a series of dogs. Those made hypomagnesemic by extracorporeal dialysis had cardiac arrhythmias after smaller doses of digitalis than normomagnesemic dogs; the arrhythmias could be reversed with magnesium sulfate. Administration of magnesium decreased plasma potassium, presumably owing to intracellular movement of K^+. The digitalis-induced myocardial potassium loss was blocked by simultaneous administration of magnesium. However, digitalis-induced arrhythmias were not always associated with myocardial potassium loss, indicating that other factors were also responsible for the arrhythmia. If it is necessary to administer magnesium during digitalis-induced arrhythmia, 7 to 15 ml of 25 per cent $MgSO_4$ should be given slowly intravenously with ECG monitoring. Measurement of plasma magnesium and potassium levels is recommended. (*Seller, R. H.: The Role of Magnesium in Digitalis Toxicity, Am. Heart J. 82: 551–556, 1971.*)