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RESPIRATORY ACTIVATION OF THE FACIAL NERVE AND ALAR MUSCLES IN ANAESTHETIZED DOGS

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SUMMARY

1. Comparisons were made of the activities of the dorsal buccal branch (d.b.b.) of the facial nerve which innervates the alae nasi and of the alar muscles themselves (alae nasi) with the activity of the phrenic nerve in eight anaesthetized, spontaneously breathing dogs during hypercapnia, end-expiratory airway occlusion, and chest wall compression, before and after vagotomy. Nerve and muscle activities were recorded from bipolar cuff or wire electrodes respectively and processed by a moving average technique.

2. Peak facial d.b.b., alae nasi, and phrenic activity all increased linearly with hypercapnia.

3. Airway occlusion prolonged the duration of phrenic as well as facial d.b.b. and alae nasi activity. A comparison of electrical activity during unoccluded and occluded inspirations indicated a facilitation of phrenic activity but an inhibition of both facial d.b.b. and alae nasi activities associated with volume feed-back. These volume-related feed-back effects were abolished by vagotomy.

4. After vagotomy, peak facial d.b.b., alae nasi and phrenic activities increased during lower chest wall compression and decreased with upper chest wall compression when compared to the preceding control breath.

5. Alae nasi and facial nerve activities, like that of the phrenic nerve, respond to respiratory chemical and reflex influences.

INTRODUCTION

Contraction of the alar muscles flare the external nares. In humans and anaesthetized animals as well, alae nasi activation results in a decrease in nasal and total respiratory resistance (von Dishoeck, 1937; McCaffrey & Kern, 1979; Carlo, Martin, Bruce, Strohl & Fanaroff, 1983; Mathew, 1984).

Since the external nares are the first inspiratory resistance element during nasal breathing, the results of an increase in nasal resistance are that negative pressures in the pharynx are larger with inspiration than when nasal resistance is low. Negative pressures in the pharynx can act to collapse the upper airway (Brouillette & Thach, 1979) and have recently been shown to change respiratory drive and rhythm (Mathew, 1984; van Lunteren, van de Graaff, Haxhiu, Strohl & Cherniack,

1984*b*). Therefore, the respiratory chemical and reflex regulation of alar muscle activation is important because of its interaction in the regulation of total respiratory resistance and the maintenance of upper airway patency.

Alae nasi electromyographic (e.m.g.) activity is a measure of upper airway muscle activity in human subjects (von Dishoeck, 1937; Strohl, Hensley, Hallett, Saunders & Ingram, 1980; Strohl, O'Cain & Slutsky, 1982). It is known that alae nasi activation can correlate with the tidal volume response to CO_2 and will occur before the onset of inspiratory flow (Strohl *et al.* 1982). In anaesthetized animals, where voluntary factors are eliminated, alae nasi e.m.g. activity responds to certain non-chemical respiratory stimuli, such as augmented breaths (van Lunteren, van de Graaff, Parker, Strohl, Mitra, Salamone & Cherniack, 1983), negative pressure applied to the isolated upper airway (Mathew, 1984; van Lunteren *et al.* 1984*b*) and stimulation of oesophageal afferents (Cherniack, Haxhiu, Mitra, Strohl & van Lunteren, 1979). These studies suggest that qualitative similarities are present between alae nasi, genioglossal, and posterior cricoarytenoid activity in response to various respiratory non-chemical reflexes. Quantitative differences exist between the alae nasi response and that of the other upper airway muscles and the diaphragm or phrenic nerve in the response to phasic vagal reflex mechanisms (van Lunteren, Strohl, Parker, Bruce, van de Graaff & Cherniack, 1984*a*). There are no studies, however, which have localized facial nerve activity or measured alae nasi muscle responses to increased chemical drive or chest wall reflexes.

The purpose of this study was to examine the pattern of e.m.g. activation of the alar muscles of the external nares (the alae nasi) in anaesthetized dogs in response to chemical and non-chemical respiratory stimuli. Facial nerve activity was monitored, in addition to alae nasi e.m.g. activity, in order to compare the time course of its response to phrenic nerve activity. Our results showed that the response of facial neurogram and the alae nasi e.m.g. to changes in hypercapnic, vagal and chest wall stimuli were similar.

METHODS

Eight mongrel dogs weighing 8·5–14·1 kg were anaesthetized with thiopentone (10–20 mg/kg) and α-chloralose (50 mg/kg), both given intravenously. Supplemental anaesthesia with chloralose was given every 30–60 min to maintain a stable level of anaesthesia as judged from corneal reflex and response to pain. All animals were studied in the supine position, orally intubated with a No. 9 or 10 endotracheal tube. A one-way valve was mounted on the endotracheal tube. Airflow was measured with a pneumotachograph placed on the inspiratory side of the one-way valve. In five animals, airflow was electronically integrated to determine inspiratory tidal volume.

The alae nasi e.m.g. was determined from a pair of dermal needle electrodes (Grass Instruments, Waltham, MA) inserted percutaneously into the alar muscles just behind the lateral wall of the nasal aperture (Fig. 1). Placement of the recording electrodes was facilitated by inspecting the alar folds during occlusion of the inspiratory line for two or three breaths. This manoeuvre increased respiratory output, resulting in easily discernible movement of the alar muscles.

Recordings were also made from the dorsal buccal branches (d.b.b.s) of the facial nerve leading to the alae nasi (Fig. 1). To expose the facial nerve, a skin incision was made from the external nares extending to the angle of the jaw. The branches of the facial nerve were identified and nerve rootlets, branches of the d.b.b. of the facial nerve, leading into the alae muscles were dissected free. Most often there was one small (1–2 mm) nerve which branched as it inserted into the alar muscles. Section of both branches of this nerve was necessary to abolish ipsilateral alae nasi activity. To facilitate recording of neural activity, the facial d.b.b. nerve was desheathed proximal to its branch point. The cut end was placed in a tunnel electrode, and covered with petroleum jelly to prevent

drying. The electrical activity recorded from this branch of the facial nerve was recorded simultaneously with e.m.g. activity from the contralateral alar muscles. Phrenic nerve activity was recorded from the desheathed cut-end of the C5 root of the left phrenic nerve, exposed by a lower cervical incision, and prepared for recording in a manner similar to that for the facial d.b.b. nerve. Electrical activities of nerves and muscles were amplified and filtered to record activities of 30–1000 Hz (Grass Instruments Inc., Waltham, MA). In all instances raw electrical activities were displayed on an oscilloscope to observe the quality of the recordings. The alae nasi e.m.g. was also monitored by a loudspeaker. Nerve and muscle activities were full-wave rectified and a moving average technique used to allow better quantification of action potentials from e.m.g. or neural

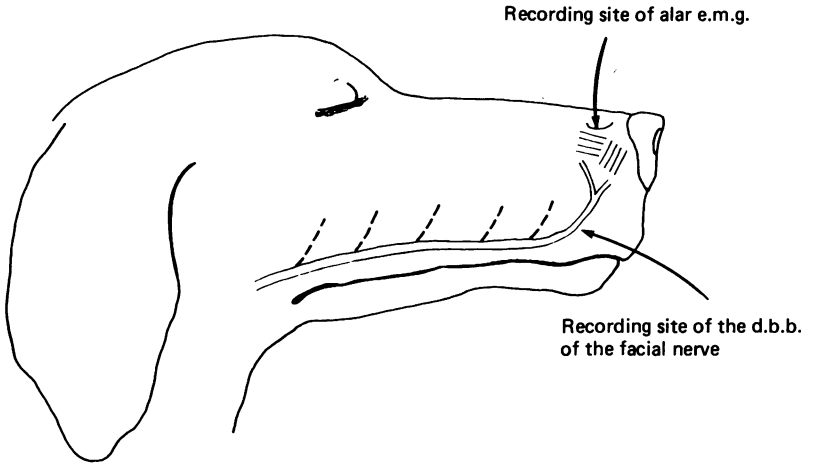

Fig. 1. This sketch of the preparation shows the regions from where the alae nasi e.m.g. and facial nerve (d.b.b.) were recorded.

signals (Evanich, Lopata & Lourenco, 1976). The moving average of activity was measured for height (mm) and rate of rise of inspiratory activity (height divided by the time between onset and peak inspiratory activity) for neural and muscle recordings.

Measurements were performed during spontaneous breathing and during rebreathing tests, using the progressive hyperoxic hypercapnia technique of Read (1966). To assess the effect of changes in lung volume, alae nasi e.m.g. and facial and phrenic neural activities were compared before and after the inspiratory line was occluded for a single breath. Occlusion was accomplished by turning a three-way stopcock to a closed position during the previous expiration. Airway occlusion was performed every ten to twelve breaths during progressive hypercapnic tests. Traces of the tidal volume and moving average of e.m.g. or neural activity during the occluded effort and the average of activity from the five preceding inspirations were superimposed to facilitate comparison.

In six animals bilateral cervical vagotomy was performed. After vagotomy, tests of progressive hypercapnia were repeated. In addition, after vagotomy the effect of stimulation of the chest wall was assessed by manually creating an abrupt, bilateral inward motion of the ribcage at or near the onset of inspiration. *Upper* chest wall compression was performed by squeezing the ribcage at the level of the fourth rib (Bradley, 1977; Remmers, 1979); *lower* chest wall compression was performed by squeezing the ribcage at the lower costal margin (Decima & von Euler, 1969). Comparisons were made of airflow and/or tidal volume and e.m.g. activity between the preceding inspiration and the subsequent effort during which the chest wall reflex was elicited.

Respiratory frequency before and after vagotomy was calculated from 2 min portions of the records during resting breathing and from 30 s periods during progressive hypercapnia. Frequency was determined from peak phasic activity present in the alae nasi or in the phrenic nerve during these times.

Statistical analysis was performed using the least-squares regression analysis (progressive hypercapnia) or by the Wilcoxon signed rank test.

RESULTS

Records of the moving average of alae nasi, e.m.g. and facial d.b.b. and phrenic neural electrical activities are shown in Fig. 2 at two levels of hypercapnia during progressive hyperoxic hypercapnia in each of two dogs prior to vagotomy. Each tracing is an average of five successive breaths. The time of onset and pattern of activation of the facial nerve and alae nasi are different from that of the diaphragm.

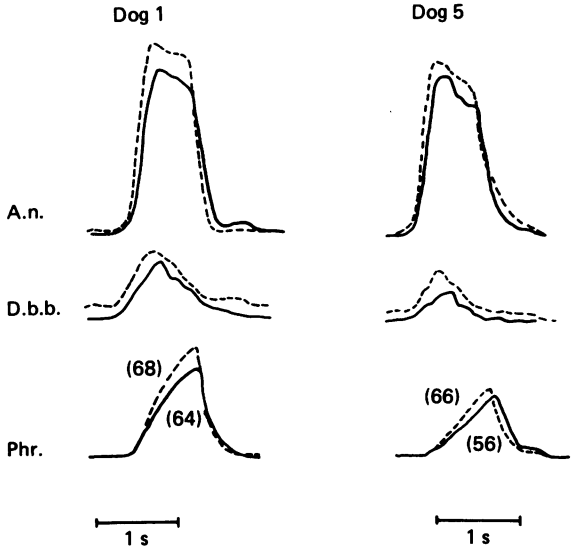

Fig. 2. Tracings of the moving average of alae nasi (a.n.), the d.b.b. of the facial nerve, and phrenic (phr.) nerve activity are shown for two animals at two levels of chemical drive. Continuous lines indicate the average of five breaths at lower end-tidal CO_2 levels (dog 1: 64 torr; dog 5: 56 torr); dashed lines indicate the average of five breaths at a higher CO_2 level (dog 1: 68 torr; dog 5: 66 torr).

The alae nasi e.m.g. and facial d.b.b. neurogram show an earlier onset, a steeper rate of rise, and sustained activity during inspiration when compared to phrenic nerve activity which shows a ramp-like activation, beginning after the onset of alae nasi and facial nerve activity and increasing in activity throughout inspiration. With increasing levels of chemical drive the general patterns of activation were qualitatively similar; however, like phrenic nerve activity, the peak level and the rate of rise of activation of the alae nasi and facial d.b.b. nerve increased with increasing drive.

Peak alae nasi e.m.g. activity is plotted against peak activity of the phrenic nerve and the facial nerve d.b.b. for each animal. The peak facial d.b.b. nerve activity was linearly related to peak alae nasi activity in each animal. This is shown graphically in Fig. 3. Compared to the slope of the line of identity, the slope of the alae nasi–facial relationship was statistically equal. Also shown in Fig. 3 is the relationship between peak alae nasi e.m.g. activity and phrenic nerve activity in each animal. Increases in peak alae nasi activity were linearly related to increases in phrenic nerve activity; however, for any given change in alae nasi activity there appeared a larger increase in phrenic activity.

Comparisons of the rate of rise of inspiratory activation of the alae nasi, facial nerve d.b.b. and phrenic nerve during progressive hypercapnia for each of the six dogs are shown in Table 1. In all animals the slope of the relationship between CO_2 levels and the rate of rise of inspiratory activity were positive and adequately fitted using linear regression analysis in the phrenic nerve, alae nasi muscle and facial d.b.b. nerve. Similar results were found when comparisons of the peak height of activity were made.

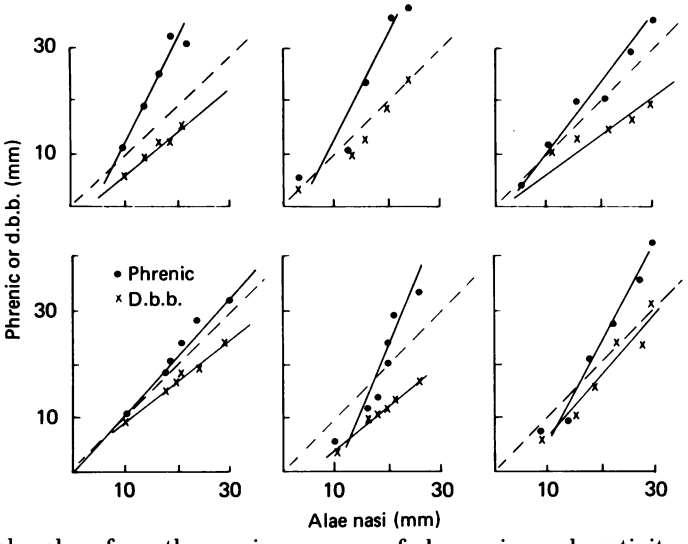

Fig. 3. Peak values from the moving average of alae nasi muscle activity (X-axis) are plotted against peak values of phrenic (●) or d.b.b. (×) nerve activity for each of six animals. The dashed line is a line of identity. Continuous lines represent the linear regression through values during a CO_2 rebreathing trial.

TABLE 1. Hypercapnic responses (change in rate of rise/CO_2 mmHg)

Dog	Phrenic nerve	Alae nasi muscle	Facial d.b.b. nerve
1	1·52 (0·96)*	0·79 (0·99)	0·65 (0·98)
2	7·17 (0·98)	3·25 (0·99)	3·59 (0·99)
3	2·91 (0·98)	1·18 (0·96)	0·65 (0·90)
4	0·93 (0·99)	0·65 (0·98)	0·58 (0·96)
5	1·80 (0·94)	0·49 (0·94)	0·81 (0·90)
6	4·91 (0·99)	2·08 (0·98)	1·33 (0·96)

* (r value).

The relationship between tidal volume and peak alae nasi activity is shown for five animals in Fig. 4*A* and *B*. In Fig. 4*A*, tidal volume is plotted against peak alae nasi activity. In each animal as tidal volume increased during progressive hypercapnia, the peak activity of the alae nasi e.m.g. also increased. In order to control for the varying gain of the e.m.g. signal in the different animals and for their different size peak alae nasi e.m.g. and tidal volume were plotted as a percentage of maximal values (Fig. 4*B*). All points except four fell within $\pm 10\%$ of a line of identity.

Extrapolation of the curves in Fig. 4*A* to the X-intercept gave a mean value of $6{\cdot}8 \pm$ S.D. 2·5 ml which was not statistically different from zero. To test the assumption

that the threshold of activation of alae nasi e.m.g. activity and tidal volume was indeed similar, records were analysed for presence of periodic breathing or for periods of rapid decreases in respiratory drive leading to apnoea of greater than 15 s. Four animals (Nos. 1, 2, 4 and 6) spontaneously exhibited apnoeas under these conditions. An example of periodic breathing occurring in one animal is shown in Fig. 5. Records suggested that the threshold of activation of the alae nasi and tidal volume, and in

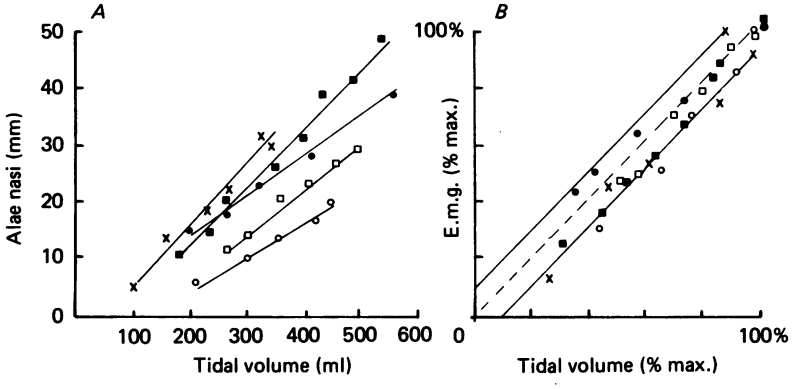

Fig. 4. *A* shows absolute values of the peak alae nasi e.m.g. and tidal volume during a CO_2 rebreathing trial; the continuous line indicates the line for linear regression for each animal. *B* shows the same values expressed as a percentage of the maximal value; the dashed line is a line of identity and the continuous lines represent a range of $\pm 10\%$ around the line of identity. Each symbol represents an individual animal.

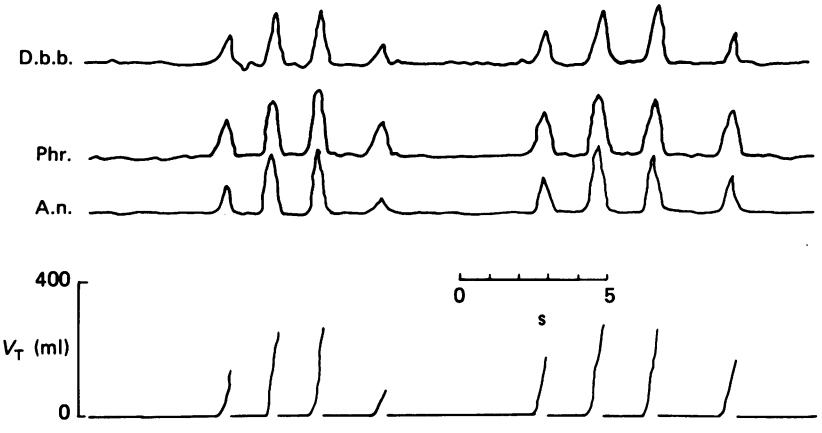

Fig. 5. The moving average of facial d.b.b., phrenic (phr.) and alae nasi (a.n.) activity follows patterns of tidal volume (V_T) changes during periodic breathing with apnoea. A five second (s) time marker is shown.

addition the phrenic nerve and facial d.b.b. nerve were similar. Records from the other animals demonstrated this phenomenon.

If lung volume was prevented from changing during an inspiratory effort initiated at functional residual capacity (airway occlusion), consistent changes in the pattern of facial (d.b.b.), phrenic and alae nasi activities occurred. Changes observed in a representative animal are shown in Fig. 6 in which the occluded and unoccluded

trajectories are superimposed at two levels of chemical drive. With airway occlusion, the moving average of phrenic nerve activity showed few changes in its pattern until near the end of the unoccluded trajection at which point comparison of the two trajections showed facilitation of phrenic activity. Most striking in the alae nasi and facial d.b.b. activities is a volume-dependent inhibition in the latter part of inspiration, shown in Fig. 6 as a shaded area. This effect of volume feed-back on alae nasi and facial d.b.b. nerve activities was apparent at each level of chemical drive.

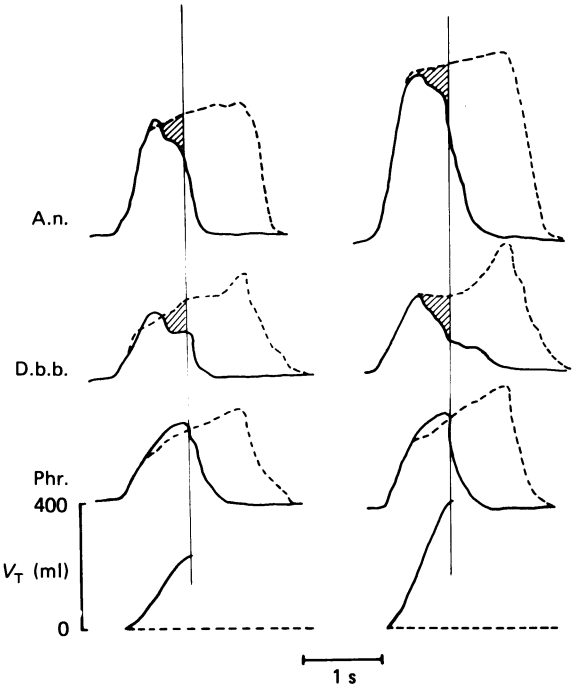

Fig. 6. The moving average of activity of the alae nasi (a.n.), facial d.b.b. branch and phrenic (phr.) during one breath (continuous line) followed by an effort where the trachea was occluded at end-expiration and a change in tidal volume (V_T) prevented (dashed lines). Tracings are from a CO_2 rebreathing trial in one animal (end-tidal P_{CO_2}, left: 52 torr; right: 58 torr). The vertical lines indicate the end of inspiration as judged from the peak phrenic nerve activity.

Vagotomy resulted in changes in the pattern of alae nasi e.m.g. and facial d.b.b. nerve activities. Peak activation of both alae nasi and facial d.b.b. activity now occurred later in inspiration, closer to time-to-peak phrenic activity (see Fig. 7, control tracing). This pattern of activity in the alae nasi and facial d.b.b. was similar to that seen with airway occlusion before vagotomy (see Fig. 6). Following vagotomy, changes in e.m.g. activation due to chest wall compression were clearly seen. Fig. 7 shows the different effects of upper and lower chest wall compression on facial d.b.b., alae nasi e.m.g. and phrenic activities in one animal. The trajectories recorded before and during chest wall compression are superimposed. Compression of the upper ribcage resulted in a reduction of phrenic and facial d.b.b. activity; the effect on the alae nasi was not readily apparent in this example. On the other hand, compression

of the lower chest wall resulted in facilitation of activity. With either upper or lower chest wall compression, inspiration was terminated earlier. Results in other animals were similar.

Respiratory frequency was calculated independently from the frequency of alae nasi or phrenic nerve bursts during resting breathing and progressive hypercapnia, before and after vagotomy. In each animal calculations of respiratory frequency using either of the two signals were identical.

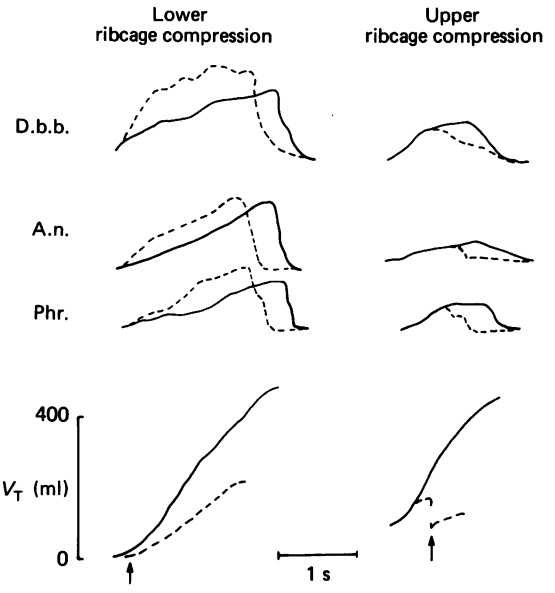

Fig. 7. The different effects of lower ribcage (left) and upper ribcage (right) compression on the moving average of facial d.b.b., alae nasi (a.n.), and phrenic (phr.) activity are shown. Manual compression was performed at the time of the arrow. Continuous lines: control, post-vagotomy; dashed lines: after compression.

DISCUSSION

Results of this study showed that in the anaesthetized dog e.m.g. activity of the alae nasi was an indication of changing respiratory drive during hypercapnia or with vagal or chest wall reflexes. The pattern of activation in the alar muscles was similar to that seen in the d.b.b. of the facial nerve. Both facial d.b.b. nerve and alae nasi e.m.g. activity showed a proportionate increase in activation to hypercapnia and to increases in the phrenic nerve. The thresholds of activation of alae nasi activation were similar to facial d.b.b. and phrenic nerve activation. Alae nasi activation was predictably present with inspiration and could be used as an index of respiratory output.

Differences in the onset and pattern of activation between the upper airway and chest wall muscles have been described previously (Strohl *et al.* 1980, 1982; Carlo *et al.* 1983; van Lunteren *et al.* 1983, 1984*a*, *b*; Mathew, 1984). The alae nasi e.m.g. showed patterns of activation present in most records of upper airway muscles. Unlike most upper airway muscles, however, the alar muscles are easily accessible and

measurement of their e.m.g. activity is relatively simple. In contrast the genioglossal e.m.g. requires fine wire electrodes and a transoral approach to a muscle which interdigitates with the geniohyoid and palatoglossus muscles (Brouillette & Thach, 1979, 1980; Weiner, Mitra, Salamone & Cherniack 1982). E.m.g. activation recorded from these electrodes, therefore, may reflect not only genioglossal activation but could also record more distant activity from muscles which move the tongue in directions opposing the genioglossus. These anatomical features may be one reason that the genioglossal e.m.g. signal obtained showed differences from the diaphragm in response to progressive increase in chemical drive (Brouillette & Thach, 1980; Weiner *et al.* 1982). Alternatively, it may be that there are distinct differences between the pattern of recruitment in the genioglossus muscle and the diaphragm. Our results showed that the activation of the alae nasi and phrenic nerve were more alike than that reported for the genioglossus and diaphragm in response to increased chemical drive. Furthermore, when periodic breathing is produced in the animal, thresholds for activation in the alae nasi and the phrenic were similar. In contrast, the threshold for activation of the genioglossus is known to be different (Brouillette & Thach, 1980; Weiner *et al.* 1982). Perhaps the alae nasi e.m.g. gives a more distinct and uniform record of muscle activity than the fine wire recordings of the genioglossal e.m.g. In any event, recruitment of facial d.b.b. nerve/alae nasi respiratory activity with changing chemical drive is more like the phrenic nerve/diaphragm than like the hypoglossal/genioglossus.

Alar muscles and the facial nerve were subject to reflexes initiated from the lungs and chest wall. Airway occlusion at end-expiration prevented lung expansion and resulted in a prolongation of inspiration in the phrenic nerve and diaphragm and in an increase in the amount and duration of alae nasi and facial nerve activity. This study confirmed previous reports that upper airway muscles were subject to phasic vagal influences (Brouillette & Thach, 1980; van Lunteren *et al.* 1984*a*).

During airway occlusion the alae nasi and facial d.b.b. activity showed similar patterns of response. Commonly at all levels of chemical drive, a volume-mediated inhibition of activity was apparent in the latter half of inspiration. Other investigators have noted similar responses in recurrent laryngeal and hypoglossal nerve recordings (Cohen, 1975; Weiner *et al.* 1982). Occasionally, before the volume inhibition and at lower levels of chemical drive, there was a brief period early in inspiration where volume facilitation of activity occurred. In contrast the phrenic nerve responses showed a volume facilitation starting in mid-to-late inspiration (Bartoli, Cross, Guz, Huszczuk & Jeffries, 1975; DiMarco, von Euler, Romaniuk & Yamamoto, 1981). In a previous study where alae nasi activity alone was compared to genioglossal and diaphragm/phrenic activity, differences were found between animals and in the same animal between the extent of vagally mediated volume-dependent effects in the different muscles (van Lunteren *et al.* 1984*a*). The implications of these different patterns of muscle response in the central organization of vagal reflexes remain to be determined.

After vagotomy, we showed that the alar muscles will show reflex activation or inhibition depending on where the chest wall is compressed. Previous descriptions of the influence of regional chest wall distortion have focused on intercostal-to-phrenic reflexes (Decima & von Euler, 1969; Remmers, 1979). In this report it is demonstrated

that chest wall distortion also results in changes in cranial nerve and upper airway muscle activities. An intercostal–bulbar reflex pathway must exist to explain the phenomenon of upper airway responses to chest wall compression. Inward distortion of part or all of the chest wall may occur during airway occlusion, such as during snoring or obstructive apnoea in sleep. Intercostal–bulbar pathways could act as a feed-back mechanism to preserve the balance of forces between upper airway and chest wall activation in the face of respiratory loads and maintain or restore upper airway patency (Brouillette & Thach, 1979). In the face of airway obstruction, the shortening of inspiration with chest wall distortion would act in a way opposite to vagal stretch reflexes which in animals will prolong inspiratory time to maintain tidal volume (Clark & von Euler, 1972; Bartoli *et al.* 1975; DiMarco *et al.* 1981; van Lunteren *et al.* 1984*a*). It is a curious finding that in humans airway occlusion experimentally produced during sleep results in either no change in inspiratory time (Iber, Berssenbrugge, Skatrud & Dempsey, 1982) or occasionally in rapid shallow efforts (Issa & Sullivan, 1983). The reflex effects of chest wall distortion could be a factor to consider in understanding this phenomenon.

It is probable that activation of the alae nasi acts to change nasal resistance in the anaesthetized dog. With increased respiratory output with chemical or reflex stimulation, the lateral walls of the external nares were observed to flare outward. In human adults and infants, alae nasi activation is associated with nasal flaring and a fall in nasal resistance (Strohl *et al.* 1982; Carlo *et al.* 1983). Paralysis of the facial nerve in humans results in an ipsilateral decrease in nasal flow (von Dishoeck, 1937). A fall in nasal resistance has been shown to occur in anaesthetized dogs exposed to hypoxia and hypercapnia and is attributed to vascular factors in the nose (McCaffrey & Kern, 1979). It is evident from our data that neuromuscular activity occurs regularly with inspiration in the anaesthetized animal and we would predict that some portion of the fall in nasal resistance during inspiration with increased drive could be accounted for by alae nasi activation.

The alae nasi and facial nerve have an onset of activation and a response to vagal and chest wall reflexes prior to the phrenic nerve. Further studies are required before the precise mechanisms for these temporal differences in activation are known; however, the observations imply that respiratory output is projected in a co-ordinated, timely fashion to many respiratory muscles. These results imply a problem of defining the onset of inspiration and the phases of the respiratory cycle from measurement of upper airway muscle activity alone. Conventionally, phrenic nerve or diaphragm e.m.g. records are employed to define inspiratory time and expiratory time. Airflow or tidal volume records can correlate well with neuromuscular activity unless there occurs a significant increase in the mechanical time constant of the lungs or chest wall (Miserocchi & Milic-Emili, 1976). With the vagus intact, peak neuromuscular activation in the alar and other upper airway muscles occurs well before peak tidal volume and phrenic activity; therefore, upper airway muscle activation cannot be used in the conventional measurement of phases within the respiratory cycle.

Phasic changes in the alae nasi e.m.g. gave an estimate of respiratory frequency, similar to that obtained from the phrenic neurogram. Measurement of the alae nasi could be useful during procedures or studies in which a qualitative measure of respiratory rate or depth would be helpful. For example, we used the auditory output

of alae nasi e.m.g. as a way of monitoring respiration during induction of anaesthesia and surgical preparation of the animal. While hearing the alae nasi e.m.g. did not replace careful observation of the animal, the auditory signal, like the auditory signal for heart rate, gave useful information specifically regarding respiratory rate and depth during surgery.

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