Glottal Patency during Experimental Seizures in Piglets

THOMAS E. TERNDROP, ALAN KADISON, AND PEAK WOO

Department of Emergency Medicine, State University of New York Health Science Center at Syracuse,
Syracuse, New York 13210

ABSTRACT

Tracheostomized cats and piglets demonstrate respiratory stimulation during experimental seizures, whereas airway intact piglets demonstrate hypoventilation and increased subglottic resistances. The purpose of this study was to characterize the role of the vocal folds in contributing to these increased subglottic resistances during experimental seizures. A controlled animal study was performed in six anesthetized, spontaneously breathing, hyperoxic piglets who had subglottic pressure and airflow measured. A fiberoptic video scope directed into the cephalad trachea recorded subglottic images of the vocal folds. Glottal area patency (GAP) was evaluated at inspiratory onset (I_o), peak inspiratory pressure (I_p), and expiratory onset (E_o) for four to five consecutive breaths under baseline control, ictal, interictal, and anticonvulsant conditions. Seizures were induced with i.v. pentylenetetrazol or bicuculline. Normalized GAP was greatest at I_p under all conditions, except anticonvulsant. During ictal periods, piglets demonstrated significant reductions in mean GAP throughout the respiratory cycle (I_o , 98%; I_p , 78%; E_o , 98%), compared with baseline ($p < 0.001$, repeat measures analysis of variance). During ictal discharges, hypoventilation and glottal obstruction resulted in significant reductions in mean arterial pH (-0.35) and Pao_2 (-39 kPa) and elevations in $Paco_2$ ($+8.1$ kPa),

compared with baseline conditions. During interictal conditions mean GAP at I_p was increased, whereas at E_o (-66%) GAP was reduced, compared with control. These data demonstrate that the vocal folds are tonically adducted throughout the respiratory cycle during ictal phases and have increased expiratory adduction during interictal phases of seizures induced with standard i.v. convulsants in hyperoxic piglets. (*Pediatr Res* 38: 932-937, 1995)

Abbreviations

GAP, glottal area patency
ECoG, electrocorticogram
Ve, minute ventilation
PTZ, pentylenetetrazol
BIC, bicuculline
ANOVA, analysis of variance
 Pao_2 , arterial O_2 pressure
 $Paco_2$, arterial CO_2 pressure
 I_o , inspiratory onset
 I_p , inspiratory pressure
 E_o , expiratory onset

All patients with ongoing seizure activity require temporary respiratory support during treatment, whereas an important subset will undergo endotracheal intubation (1-3). Recent data from cats and piglets demonstrate that respiration is centrally stimulated during both cortically and systemically induced seizures (4-6). These data are at odds with the frequent clinical observation of patients who often develop cyanosis, apnea, and impaired respiration during seizures (7, 8). Data from an airway-intact piglet seizure model demonstrates that subglottic airway resistances and obstruction are important determinants of respiratory responses during seizures (9).

Thus, an improved understanding of the mechanisms of upper airway obstruction during seizures is important to improve current management strategies.

Human subjects with unprotected upper airways demonstrate respiratory acidosis during seizures (7). Although there are no human data on upper airway behavior during seizures, preliminary data from paralyzed, ventilated cats demonstrates increased thyroarytenoid motor nerve activities during ictal-interictal transitions (10). These data indicate the potential role of the larynx in contributing to upper airway obstruction during seizures, possibly by tonic adduction of the vocal folds and reduction of the glottal airway.

The purpose of the present study was to characterize glottal patency, ventilation, and blood gas changes during seizures. Baseline control, hypoxic-hypercapnic rebreathing, ictal, interictal, and anticonvulsant conditions were tested in a hyperoxic, lightly anesthetized, piglet seizure model. Rebreathing experiments were performed to simulate respiratory stimulation,

Received December 8, 1994; accepted June 28, 1995.

Correspondence: Thomas E. Terndrup, M.D., Department of Emergency Medicine, SUNY Health Science Center, 750 E. Adams St., Syracuse, NY, 13210.

Supported by a Research Grant from the Central New York Children's Telethon and the Emergency Medicine Foundation (T.E.T.).

Presented at the Society for Neuroscience Annual Meeting, November 14, 1994, Miami Beach, FL.

whereas anticonvulsant conditions were included to compare glottal behavior associated with seizure termination. Digitized video frames of the glottis were evaluated at the onset of inspiration, peak of inspiratory pressure, and onset of expiration during the stated conditions. We hypothesized that the glottis is tonically adducted during seizures induced with i.v. chemoconvulsants, resulting in upper airway obstruction.

METHODS

Animal preparation. This protocol was approved by the Committee for the Humane Use of Animals. Healthy, mixed-breed, domestic piglets underwent an overnight fast and were anesthetized with alphaxalone-alphadolone (Saffan; Pittman-Moore, Washington Crossing, NJ), 10 mg/kg intramuscularly, approximately 20 min after glycopyrolate, 0.5 mg. They were placed supine on a V-shaped board and their extremities were restrained. An infusion of alphaxalone-alphadolone, 5–6 mg/kg/h, was provided for maintenance anesthesia. During surgical preparation, additional small i.v. boluses of alphaxalone-alphadolone, 0.05–0.1 mg/kg, were occasionally administered to ensure adequate anesthesia. The infusion rate was adjusted to provide light anesthesia with intact gag responses during laryngoscopy.

Through a lateral neck incision, an external jugular vein and common carotid artery were isolated and cannulated using polyethylene catheters. After elevation of a scalp flap, small, paired temporal craniotomies allowed placement of silver wire electrodes to contact the dura for recording electrocortical activity (ECoG). The ECoG wires were sutured to the scalp. Through a midline neck incision, a low tracheostomy allowed insertion of a short, Y-shaped tube (7-mm internal diameter) which was secured in both the caudal and rostral trachea with umbilical tape in four piglets. Two or three rings of the trachea were excised to maintain the original length of the trachea in each piglet, taking care to avoid injury to the recurrent laryngeal nerves. A puncturable membrane was placed over the remaining arm of the Y-tube, allowing the airtight introduction of a flexible, fiberoptic endoscope (2.7-mm external diameter; Olympus, New Hyde Park, NY) which was directed caudad from the subglottic trachea. In two piglets, a shortened endotracheal tube (4.5-mm internal diameter) was placed through a tracheostomy, and no airflow passed through the upper airway.

Ventilation was measured by standardizing airflow through the nasal cavities in four piglets. To demonstrate nasal patency, a soft suction catheter was passed through both nares into the larynx and subsequently removed. After suturing the lips closed, a round mask (Laerdal no. 1) was secured to the snout along the edges of the mask with a rapid drying silicone sealant. In two piglets, no airflow occurred above the tracheostomy, and airflow was measured at the tracheostomy, which was connected to the respiratory circuit via a shortened endotracheal tube. One-way inspiratory and expiratory valves (no. 2230B; Hans-Rudolph, Kansas City, MO) were attached to the mask or tracheostomy tube. The total *in vitro* respiratory dead space of the mask and respiratory apparatus was 8.5 mL, and the resistance was 1.1 cm H₂O/L/min at 0.5–5 L/min flow. Proximal airway pressure was measured in the subglottic tra-

chea with an in-line transducer (model P50; Gould Electronics, Cleveland, OH). Inspiratory flow was measured with a pneumotachograph (Fleisch no. 0) with output to a differential pressure transducer (no. DP45-16; Gould). The ECoG was amplified (no. 13-4615-58; Gould) and filtered (1–10 kHz). The rectal temperature was monitored and servo controlled between 37 and 39°C with a warming blanket and cooling mechanism. Arterial pressure and end-tidal carbon dioxide were monitored during experiments.

PTZ (Sigma Chemical Co., St. Louis, MO) was dissolved in sterile water and brought to a concentration of 100 mg/mL. After new baseline recordings, seizures were induced with PTZ in five piglets, 100 mg/kg, i.v., followed by 2–3 mg/kg, as i.v. injections at 5–7-min intervals as required to induce recurrent, vigorous tonic-clonic seizures. BIC (Sigma Chemical Co.) was dissolved in 0.1 N HCl, brought to a pH of 4–5 with 0.1 N NaOH, and to a final concentration of 100 mg/mL. Seizures were induced in two piglets with 1.5 and 4 mg/kg of i.v. BIC, respectively, the former in a piglet who failed to respond to PTZ. Seizures were judged to occur when tonic-clonic activity was present in two or more extremities associated with a sudden increase in the amplitude and synchronization of ECoG waveforms (*i.e.* large amplitude, spike, and wave type). Electrocerebral activity was discriminated from muscle and movement artifact by several means: 1) procedural methods (using a shielded cable, a silver-tipped electrode bared at only the distal 1 mm, securing the ECoG wire by suturing it to the scalp flap, cable grounding, and signal filtering); 2) our experience at ECoG and electromyographic recordings during seizures in moving, anesthetized piglets; 3) that muscle and movement activity during baseline control conditions demonstrated no ictal or interictal like ECoG artifacts; and 4) that during interictal phases of seizures the ECoG wave form demonstrated typical ECoG suppression, followed by occasional interictal spikes. Interictal phases were defined as a sudden reduction in ECoG spike frequency and amplitude, associated with a reduction in extremity motor tone.

Experimental procedures. Through the inspiratory side of the respiratory circuit, humidified oxygen was supplied at 6–8 L/min to prevent activation of peripheral chemoreceptors. After an initial baseline period and blood gas were obtained, the piglets breathed room air for about 10 min. At the end of this period, expired airflow was collected into a 3.5-L bag for rebreathing, in five piglets. Rebreathing was initiated by connecting one end of the bag to the inspiratory side of the respiratory circuit. Rebreathing conditions were continued for about 5 min, or until the end-tidal carbon dioxide concentration was approximately 70 mm Hg. The rebreathing bag was removed, and the animal was then placed on supplemental oxygen as during the initial baseline period. After approximately 10 min or when stable respiratory patterns were evident, a new baseline was considered to have been achieved. Seizure activity was then induced with either PTZ or BIC, and 8–10 ictal-interictal cycles were observed, before administering an anticonvulsant. Three commonly recommended anticonvulsants were chosen from those used clinically for generalized seizure termination. Single doses of diazepam (0.5 mg/kg), lorazepam (0.2 mg/kg), or phenobarbital (20 mg/kg) were

administered as i.v. injections. No dose response or interanticonvulsant comparative analysis of effects were performed. These medicines were given to simulate an anticonvulsant effect for comparison to the other experimental conditions.

Continuous recordings of subglottic pressure, inspiratory airflow, integrated airflow, and ECoG were obtained, whereas representative epochs were digitized for off-line analysis. From these recordings, the presence of apnea during seizures was estimated as 20 s or longer periods of mean inspiratory integrated airflow of less than 10 mL. These episodes of apnea were judged to be obstructive when the associated average peak subglottic pressures were less than -10 cm H₂O, otherwise they were judged to be central hypoventilation. Arterial blood gases were sampled and analyzed (ABLII; Radiometer, Westlake, OH) at baseline, at the end of the rebreathing period, after stabilization during the new baseline period, during representative ictal and interictal responses, and 10 min after the anticonvulsant. Calculations of minute ventilation were performed from 60-s digitized computer records of typical responses during these same experimental conditions from each piglet.

The video output from the subglottic endoscope and the simultaneous airflow and pressure records were displayed on a split screen monitor (Toshiba) and recorded at 30 frames/s on standard VHS format tape. Conditions of the experiment were recorded using the audio channel. The VHS tapes were played back to select representative glottal views at the following phases of the respiratory cycle: 1) the onset of inspiration, I_o (i.e. the onset of negative subglottic airway pressure to less than -2 cm H₂O), 2) peak inspiratory pressure, I_p (i.e. the maximum inspiratory subglottic pressure between end-expiration and end-inspiration), and 3) the onset of expiration, E_o (i.e. when the subglottic airway pressure exceeds zero as pressure increases during expiration). GAP was determined from digitized frames by constructing a line around the limits of the vocal fold opening with a cursor to determine the area (expressed in cm²). To control for magnification variability, the area was divided by the anteroposterior glottal distance for each breath (expressed in cm). GAP data were analyzed using computer shareware (Image, version 1.47, National Institutes of Health).

Four or five consecutive breaths were analyzed for each condition where the glottis could be seen clearly. Three frames per analyzed breath, I_o , I_p , and E_o , were thus digitized. For each piglet, the number of breaths analyzed was baseline control, 5; rebreathing, 3; ictal, 5; interictal, 5; and postanticonvulsant, 3. The average values for each phase of the respiratory cycle was used for each experimental animal under each experimental condition.

Statistical analysis. Mean $\dot{V}_E$, pH, P_{aCO_2} , and P_{aO_2} were compared between conditions using a one-factor repeat measures ANOVA with isolation of significant differences based upon Scheffe's F test. Mean glottal area patency divided by length was compared with baseline and rebreathing conditions and respiratory phase using a one-factor repeat measures ANOVA. Some comparisons of blood gas and respiratory variables between upper airway intact and two piglets not breathing through the upper airway were performed using an

unpaired t test. Comparison of blood gas values for initial baseline and new baseline data were performed using a paired t test. Significance was assumed for $p < 0.05$.

RESULTS

Experiments were completed in six piglets, weight 9.0 ± 0.2 kg (mean $\pm$ SEM), range 8.2–9.5 kg, approximately 3.5–4 wk of age. Baseline blood gases demonstrated physiologic pH and normocarbica, and these values were not significantly different after rebreathing experiments were performed; mean changes in pH 0.015 and P_{aCO_2} 0.2 kPa ($p = \text{NS}$) before and after rebreathing were minor. Increases in arterial pressure and heart rate observed during rebreathing rapidly returned to baseline values during the new baseline period. During seizures, piglets demonstrated vigorous tonic-clonic activity in all extremities accompanied by an initial phase of opisthotonic, extensor posturing. Although there was no mortality during the experimental periods, severe hypercarbia (P_{aCO_2} greater than 15.7 kPa), and acidemia (pH less than 7.05) was evident in the four piglets breathing through an intact upper airway during the ictal phases of the experiments.

Mean respiratory variables were within physiologic ranges with the exception of hyperoxia under baseline conditions before seizures. During hypoxic-hypercarbic rebreathing, all piglets demonstrated hypoxia and hypercarbia accompanied by increases in airflow, subglottic pressure, and $\dot{V}_E$. In comparison, significant acidemia and hypercarbia occurred in piglets during ictal discharges, with some resolution of these effects during the interictal phases of seizures. The contribution of metabolic acidemia in these piglets is indicated by significant reductions in base excess after seizure induction (Table 1). Mean peak subglottic airway pressures were most negative during ictal conditions, with little evidence of airflow. Because the airway intact group responded vastly differently from piglets breathing through the tracheostomy (see below), blood gas and ventilatory data for the various experimental conditions are presented separately for these four piglets (Table 1).

Digitized tracings from a representative airway intact piglet (Fig. 1) demonstrate typical responses during baseline control, rebreathing, ictal, and interictal conditions. During rebreathing conditions, increased airflow and subglottic pressures were accompanied by increased mean glottal patency. During a typical ictal breath, GAP and airflow was nearly zero throughout the respiratory cycle, despite vigorous respiratory efforts indicated by the negative subglottic pressure fluctuations (Fig. 2). During ictal discharges, obstructive apneas were frequently associated with vocal fold closure. Rarely, obstruction was present when the glottis was patent (not shown). The transition to interictal phases of seizure discharges were nearly always accompanied by a sudden increase in tidal volume and slowing of respiratory frequency.

Piglets breathing through the tracheostomy had similar GAP compared with piglets breathing through an intact upper airway. Under all conditions except for anticonvulsive, mean GAP was greatest at peak inspiratory pressure (Fig. 3). During rebreathing, interictal, and anticonvulsant conditions, increases in GAP at the peak of inspiration were evident, when compared

Table 1. Comparison of arterial blood gas values and ventilation responses of four airway intact piglets under various experimental conditions

Parameter*	Experimental condition				
	Baseline	Rebreathing	Ictal	Interictal	Anticonvulsant
pH	7.41 $\pm$ 0.02†	7.19 $\pm$ 0.07	7.00 $\pm$ 0.03‡	7.20 $\pm$ 0.04	7.10 $\pm$ 0.08‡
Paco ₂	6.0 $\pm$ 0.2†	9.2 $\pm$ 0.6	14.1 $\pm$ 1.1‡	7.5 $\pm$ 0.8†	9.0 $\pm$ 1.2†
Pao ₂	70.4 $\pm$ 2.4†	6.0 $\pm$ 1.0‡	31.2 $\pm$ 8.8‡	59.3 $\pm$ 3.5†	47.3 $\pm$ 11.1†
Base excess	1.8 $\pm$ 0.4†	2.1 $\pm$ 0.5†	-14 $\pm$ 2.7‡	-7.8 $\pm$ 1.6‡	-8.2 $\pm$ 2.1‡
Ve	2.05 $\pm$ 0.21†	4.4 $\pm$ 0.30†‡	0 $\pm$ 0‡	4.73 $\pm$ 0.27†‡	3.60 $\pm$ .46†
P, airway	-10 $\pm$ 2.6	-13 $\pm$ 1.3	-18 $\pm$ 2.5	-16 $\pm$ 3.0	-14 $\pm$ 3.1
Resistance	67 $\pm$ 20	60 $\pm$ 5	Obstructed	70 $\pm$ 17	61 $\pm$ 5

* Mean $\pm$ SEM; Paco₂ and Pao₂, kPa; Ve, minute ventilation, L/min; P, peak inspiratory pressure, cm H₂O; resistance, peak inspiratory, cm H₂O/L/s.

† Significantly different compared to ictal, $p < 0.05$.

‡ Significantly different compared to baseline, $p < 0.05$.

with baseline conditions. GAP was nearly zero in all piglets during ictal discharges, regardless of the condition of the upper airway. Under interictal conditions, GAP was reduced at the onset of expiration, but widely patent during the remainder of the respiratory cycle. GAP at expiratory onset was less during interictal than other experimental conditions, although this was not statistically significant.

In comparing the responses of piglets breathing through an intact upper airway, to those with the upper airway bypassed, there was a significant increase in the mean duration of apnea in the intact group (5.6 $\pm$ 0.99 min) versus the bypassed group

(0.54 $\pm$ 0.12; $p < 0.05$, one-factor ANOVA). In the intact upper airway group, these apneas were predominately (88%) obstructive, whereas there were no obstructive apneas in the group breathing through a tracheostomy ($p < 0.05$, one-factor ANOVA). Both groups demonstrated a few seconds of central apnea at the onset of an ictal discharge during what was typically opisthotonic posturing. Blood gas values were significantly worsened in the intact upper airway group during ictal conditions for pH 7.00 $\pm$ 0.03 versus 7.19 $\pm$ 0.01 and Paco₂ 106 $\pm$ 7.9 versus 60 $\pm$ 0.1 ($p < 0.05$, t test). During rebreathing and 10 min after receiving anticonvulsants, blood gas values were not qualitatively different between these airway groups.

Piglets received an anticonvulsant after adequate ictal-interictal cycling had occurred. Three piglets received diazepam (0.5 mg/kg), whereas two received lorazepam (0.2 mg/kg) and one phenobarbital (20 mg/kg), all by rapid i.v. injection. No qualitative difference in respiratory responses were observed in GAP or blood gases between the different agents. Typical glottal responses after anticonvulsant administration were wide initial inspiratory patency and comparatively greater patency throughout the respiratory cycle (Fig. 3).

DISCUSSION

This study demonstrates the importance of the glottis in contributing to upper airway obstruction during experimental seizures in piglets induced with either i.v. PTZ or BIC. Both functional and direct visualization of glottal activity indicate that the vocal folds are tonically adducted during ictal conditions induced by these two different chemoconvulsants. These piglets developed severe hypercarbia and acidemia over a short time span, sometimes after 5–7 min of intermittent ictal discharges. During seizures piglets breathing through an intact upper airway developed significant hypoventilation, hypercarbia, and acidemia, whereas piglets breathing through a tracheostomy did not. During brief hypoxic-hypercapnic rebreathing in these same piglets, wide glottal dilatation was evident throughout the respiratory cycle. A beneficial effect of interictal cycles and three commonly used anticonvulsants appears to be glottal relaxation, reducing the glottal effects of ictal discharges.

The larynx participates in numerous physiologic behaviors including swallowing, coughing, vomiting, hiccuping, and

Figure 1. Representative tracings of inspiratory airflow (V, top), integrated airflow (fV, second from top), subglottic pressure (P, next to bottom), and ECoG under baseline control (left panel), rebreathing (second from left), ictal (second from right), and interictal (right) conditions in an airway intact, hyperoxic piglet with seizures induced with i.v. PTZ. Note the lack of airflow during the ictal discharge, despite negative pressure fluctuations in subglottic pressure.

Figure 2. Representative digitized images of subglottal area and an inset demonstrating inspiratory airflow (top trace on inset, inspiration down) and subglottic pressure (lower trace on inset, negative pressure down) under baseline control (left panels), ictal (left middle panels), interictal (right middle panels), and anticonvulsant (right panels) in a hyperoxic piglet with seizures induced with i.v. PTZ. Individual panels are from representative, single frames at the onset of inspiration (top row), peak inspiratory pressure (middle row), and the onset of expiration (bottom row). Simultaneous airflow and pressure on right hand side of the inset tracing correspond to the glottal area pictured. Note the glottal obstruction throughout the respiratory cycle during ictal conditions.

Figure 3. Glottal area patency during experimental conditions at three phases of respiration. Mean $\pm$ SEM, laryngeal area divided by vocal fold length, cm, in six piglets. *Significantly less glottal patency than under rebreathing conditions, $p < 0.05$. †Significantly greater patency than any other respiratory phase under the same conditions, $p < 0.05$. Comparisons for rebreathing data are for five piglets.

clearing the airway, and it is vital to airway protection, vocalization, and breathing (11). The role of the larynx during respiration is principally in the regulation of resistance to airflow. Most of the variations in laryngeal resistance take place at the vocal folds. The larynx accounts for approximately

25% of the total resistance of the respiratory system under normal, resting conditions (12). A linear relationship between air conductance and glottic area has been shown at normal flow rates in cats. Inspiratory abduction and expiratory adduction of the vocal folds has been seen by direct and indirect laryngoscopy in anesthetized animals and humans. Under conditions of hypercapnia and during hyperpneic states, the vocal folds are more widely abducted during inspiration, compared with the resting state (11, 12). This increase in abduction is carried into expiration and results in a decreased laryngeal resistance. In these piglets, during ictal states, tonic adduction of the vocal folds accounts for nearly all of the breaths associated with infinite resistance and periods of obstructive apnea.

A previous study in similarly prepared piglets demonstrated significant increases in subglottic resistances during seizures (9). The present study provides new data to assist in understanding the mechanisms of upper airway obstruction during experimental seizures. The current study provides direct evidence of glottal obstruction under similar experimental conditions. Central "feed forward" stimulation of respiratory drive has been postulated as the mechanism underlying increased phrenic nerve activity, more negative airway occlusion pressure, and increased minute ventilation in cats or piglets (5, 6, 13). This central excitation was not accompanied by changes in peripheral or central chemostimulation, and was reversed by an acute intercollicular decerebration, in seizures induced with subcortical penicillin in cats (5). The results of this study are consistent with the findings of these studies and expand upon

them by providing a mechanism preventing increased central respiratory drive from becoming manifest, namely through glottal obstruction.

Preliminary studies in paralyzed, ventilated cats with seizures induced with subcortical penicillin demonstrate a lack of phasic activation of laryngeal motor nerve activities (10). In particular, activation of the thyroarytenoid branch of the recurrent laryngeal nerve frequently occurred during neural inspiration, *i.e.* during phrenic activation, during ictal discharges in these cats. Further, excessive excitation of the thyroarytenoid branch was observed in several of these cats during prolonged ictal discharges. Because the thyroarytenoid branch muscle is the principal adductor of the larynx, these activations during seizures suggest a potential explanation for the observed adduction of the glottis during seizures in these piglets.

We cannot account for the excessive laryngeal adductor activity because of the anesthetic used. Some anesthetic agents preferentially reduce laryngeal adductor activity (14). Whether the glottis becomes obstructed during clinical seizures is unknown, but may help to explain the subset of patients who cannot be ventilated with positive pressure ventilation despite attempting to position the airway optimally. Endotracheal intubation would be difficult in these patients with glottal closure, but might be facilitated by rapidly terminating the seizure discharge. Supralaryngeal obstruction during ictal discharges occurred occasionally in these piglets, but was not prolonged. We attempted to record supraglottic views of the upper airway, but were unable to obtain technically adequate views because of vigorous movements during seizures.

CONCLUSION

Anesthetized, hyperoxic, spontaneously breathing piglets breathing through intact upper airways develop glottal obstruction

during severe experimental seizures induced with either *i.v.* PTZ or BIC. This glottal obstruction is accompanied by hypercarbia and acidemia, and occurs despite increased central respiratory drive. Compared with hypoxic-hypercarbic re-breathing conditions, glottal behavior during seizures is maladaptive. These data may help to explain respiratory obstruction complications during severe clinical convulsions.

Acknowledgments. The authors give sincerest thanks to Matthew Gregory and Donna Goyette for technical assistance.

REFERENCES

1. Working Group on Status Epilepticus 1993 Treatment of convulsive status epilepticus: recommendations of the Epilepsy Foundation of America's working group on status epilepticus. *JAMA* 270:854-859
2. Stambouly JJ, Pollack MM 1990 Iatrogenic illness in pediatric critical care. *Crit Care Med* 18:1248-1251
3. Chiulli DA, Terndrup TE, Kanter RK 1991 The influence of diazepam or lorazepam on the frequency of endotracheal intubation in childhood status epilepticus. *J Emerg Med* 9:13-17
4. Paydarfar D, Eldridge FL, Scott SC, Dowell RT, Wagner PG 1991 Respiratory responses to focal and generalized seizures in cats. *Am J Physiol* 260:R934-R940
5. Paydarfar D, Eldridge FL, Wagner PG, Dowell RT 1992 Neural respiratory responses to cortically induced seizures in cats. *Respir Physiol* 89:225-237
6. Terndrup TE, Starr F, Fordyce WE 1994 A piglet model of status epilepticus: comparison of cardiorespiratory and metabolic changes with two methods of pentyl-enetetrazol administration. *Ann Emerg Med* 23:470-479
7. Aminoff MJ, Simon RP 1980 Status epilepticus: causes, clinical features, and consequences in 98 patients. *Am J Med* 69:657-666
8. Navelet Y, Wood C, Robieux I, Tardieu M 1989 Seizures presenting as apnea. *Arch Dis Child* 19:199-207
9. Terndrup TE, Fordyce WE 1995 Role of the upper airway in respiratory responses during seizures. *Pediatr Res* 38:61-66
10. Terndrup TE, Knuth SL, Gdovin MJ, Bartlett D 1994 Respiratory motor nerve activities during fictive seizures. *FASEB J* 8:A910
11. Bartlett D Jr 1989 Respiratory function of the larynx. *Physiol Rev* 69:33-57
12. Bartlett D Jr 1986 Upper airway motor systems. In: Cherniack NS, Widdicombe JG (eds) *Handbook of Physiology, Sect. 3: The Respiratory System, Vol. II: Control of Breathing*. American Physiological Society, Bethesda, MD, pp 223-245
13. Terndrup TE, Fordyce WE 1994 Respiratory drive during status epilepticus and its treatment: comparison of diazepam or lorazepam. *Epilepsy Res* 20:21-30
14. Sherry JH, Megirian D 1974 Spontaneous and reflexly evoked laryngeal abductor and adductor muscle activity of cat. *Exp Neurol* 43:456-465