

Transtracheal Stimulation of the Recurrent Laryngeal Nerve

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Phonation was induced in 10 mongrel dogs under general anesthesia by way of transtracheal stimulation of the recurrent laryngeal nerves under conditions of constant air flow. Although stimulation voltages were approximately 10 times the voltage required for direct stimulation, no cardiac or respiratory abnormalities were observed. Photoglottographic and electroglottographic signals were the same for both direct and transtracheally induced phonation. This phonation induction method can be used in chronic animal preparations to study vocal fold vibration sequentially and may be clinically applied to the treatment of patients with laryngeal problems that have failed to respond, or are not amenable, to standard forms of vocal rehabilitation.

Techniques for vocal rehabilitation have improved significantly within the last 10 years.¹ During this period, advances have been made in the use of injectable alloplastic materials for cord augmentation, laser surgery, and endoscopic cordal surgery. However, most applications of phonosurgical techniques currently do not permit assessment of vocal quality until after the patient is awake and the surgery completed.

As an alternative to general anesthesia, a number of authors have advocated performing phonosurgery on patients under local anesthesia.^{2,3} This has the advantage of permitting the surgeon to assess the success of the procedure and modify it during the surgery. Also, using local anesthesia removes the encumbrances of the endotracheal tube. At times, however, the technique is severely limited by the inability of a patient to undergo invasive procedures while awake.

Because a preponderance of patients prefer general anesthesia when undergoing phonosurgery, methods that can produce vocal fold vibration may answer a clinical need. Fukuda has de-

veloped an endoscopic technique employing an external vibrator to induce cord oscillations in patients under general anesthesia.⁴ A stroboscope is then used during surgery to examine the induced oscillations of the cords to determine when the cords are vibrating symmetrically. However, the relationship of externally induced to natural vocal fold vibration is unclear. Laboratory techniques for directly stimulating the recurrent laryngeal nerve have been developed in animal models, and when combined with constant air flow through the glottis can be used to produce phonation during general anesthesia.⁵ However, these techniques require a surgical neck exploration and dissection of the recurrent laryngeal nerves.

The idea of manipulating laryngeal phonatory control mechanisms during general anesthesia as a means to improve surgical outcome and decrease morbidity is not new. Direct electrical stimulation has been used by a number of surgeons to identify the recurrent laryngeal nerves during thyroid procedures.^{6,7} The recurrent laryngeal nerve is positively identified when electrical stimulation produces a palpable laryngeal adduction beneath the area of the cricothyroid membrane. A recently described technique transcutaneously or transtracheally stimulates the recurrent laryngeal nerves to produce vocal cord adduction or abduction;^{8,9} however, this technique has been used solely to control vocal fold static position only.

Our long range desire to develop a vocal rehabilitation technique permitting the examination

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of vocal fold vibration in patients under general anesthesia prompted the present study. Because the recurrent laryngeal nerves run in juxtaposition to the tracheoesophageal groove, stimulating them transtracheally while controlling subglottic air flow through a small tracheotomy would potentially allow examination of vocal fold vibration during general anesthesia.

METHODS

Ten animals underwent transtracheal and/or direct electrical stimulation of the recurrent laryngeal nerves under conditions of constant air flow.

Subjects

Ten adult male mongrel dogs, each weighing 25 to 30 kg, were used in the study. Each dog was screened to assess its suitability as a subject for the experiment. Only dogs with normal sounding, crisp barks were selected. Dogs with abnormal or unwitnessed barks were excluded from further consideration. Dogs with long necks were preferred for ease of preparation.

Experimental Preparation

The experimental setup was the same as described previously by the authors, and was similar to prior *in vivo* canine studies, except that the animals were also stimulated to phonate transtracheally.^{10,11} Five dogs were anesthetized with 2 ml of Innovar^R followed by intravenous pentobarbital until loss of the corneal reflex was achieved. The animals were then placed supine on an operating table and direct laryngoscopy was performed to confirm normal canine laryngeal anatomy. A 7 mm oral endotracheal tube was inserted, through which the animal breathed spontaneously. A vertical midline incision was made from the mandible to the sternum. The strap muscles and sternocleidomastoid muscles were retracted laterally to expose the larynx and trachea. The external branches of the superior laryngeal nerves were isolated at their entrance into the cricothyroid muscle. A gauze/silver electrode was applied to the nerves and insulated from the surrounding tissue. The recurrent laryngeal nerves were isolated 5 cm inferior to the larynx. Electrodes were applied as described above. Ground electrodes were sutured to the trachea. Electrolaryngographic (ELG) electrodes (Synchrovoice) were placed in

direct contact with the thyroid cartilage while the ground electrode was sutured to the skin.¹²

A 1.0 cm button was used to suspend the epiglottis anteriorly, through the thyrohyoid membrane, to improve visualization of the vocal folds. A distal tracheotomy was performed and an endotracheal tube passed to permit the animal to breathe spontaneously. A more proximal tracheotomy was performed, through which a cuffed tracheotomy tube was placed with its tip resting 10 cm below the glottis. The cuff on the superiorly directed tube was inflated to just seal the trachea. Air flow of 840 ml/sec was passed through the cephalad tracheotomy tube. The air was obtained from the UCLA physical plant. The air was bubbled through 5 cm of H₂O for warming and humidification. The temperature in the animals trachea was measured at 15 minute intervals to ensure a constant air flow temp of 37° C. A photoglottographic (PGG) light sensor (Centronics OSD 50-2) was placed on the animals trachea approximately 3 cm below the larynx.¹² A xenon light source and fiberoptic cable provided supraglottic illumination for the PGG. These same five animals also underwent transtracheal stimulation of the recurrent laryngeal nerves. The rostrally placed endotracheal tube was replaced with a tube modified so that electrodes were placed on the cuff of the tube (Fig. 1.). The cuff of the tube was rotated within the trachea so that the electrodes were oriented in juxtaposition to the tracheal-esophageal grooves. The ground electrode was sutured to the anterior tracheal wall.

A second group of five dogs underwent transtracheal stimulation only, without dissection of the recurrent laryngeal nerves. This was accomplished by performing first a low tracheotomy through which a small 6 mm tube was inserted so that the animals could breathe spontaneously, then a superior tracheotomy through which the modified endotracheal tube with the attached electrodes was inserted in a rostral direction. The cuff of the superiorly positioned tube was inflated to just seal the trachea. Through this tube, warm humidified air was passed into the subglottic space as already described. The superior laryngeal nerves were not stimulated in these five animals. The electrolaryngographic (ELG) electrodes were placed on the animals neck skin at the level of the thyroid cartilage, and the photoglottographic (PGG) sensor was placed on the neck skin just below the cricoid cartilage. These five animals also underwent electrocardiographic (EKG) monitoring during transtracheal electrical stimulation.

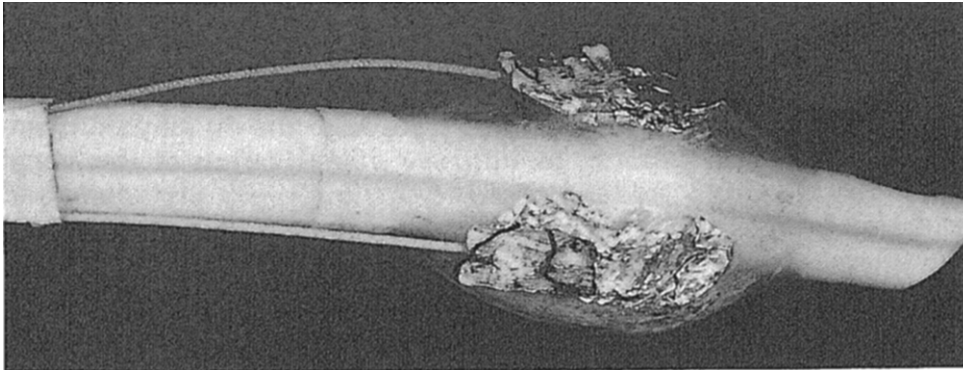


Figure 1. Modified endotracheal tube used for transtracheal stimulation of the recurrent laryngeal nerves.

Stimulus Parameters

Two WPI (301-T) nerve stimulators were used, one for superior laryngeal nerve stimulation and the other for direct or transtracheal recurrent laryngeal nerve stimulation. Voltages ranged from 0.5 to 0.9 volts for direct stimulation and 5 to 9 volts for transtracheal stimulation. Currents ranged from 0.1 to 0.15 mA for direct stimulation and 3 to 5 mA for transtracheal stimulation. The stimulus frequency was 80 Hz, with a pulse duration of 1.5 ms for both direct and transtracheal stimulation.

Data Acquisition

PGG, EGG, and EKG signals were visualized on two oscilloscopes (Tectronix digital storage 5116, Hitachi V1050-F) to assess the adequacy of the glottographic signals. Photoglottographic, electroglottographic, stimulus, and EKG signals were recorded by an XY plotter directly from the storage oscilloscope.

Experimental Design

The superior laryngeal nerves of five dogs underwent a constant low level of electrical stimulation. Phonation in these animals was produced first by direct electrical stimulation of the recurrent laryngeal nerves and subsequently by stimulation of the nerves transtracheally. In the second group of five animals, phonation was induced only by transtracheal recurrent laryngeal nerve stimulation. Two of the five animals in this second group were studied again at one week after the initial testing. During phonation, PGG, EGG, EKG, and electrical stimulus signals were recorded.

RESULTS

Figure 2 is an EKG of lead II recorded during and after electrical stimulation transtracheally. No cardiac arrhythmias were noted in any animal, either during or directly after electrical stimulation. Although the effect of the nerve stimulator

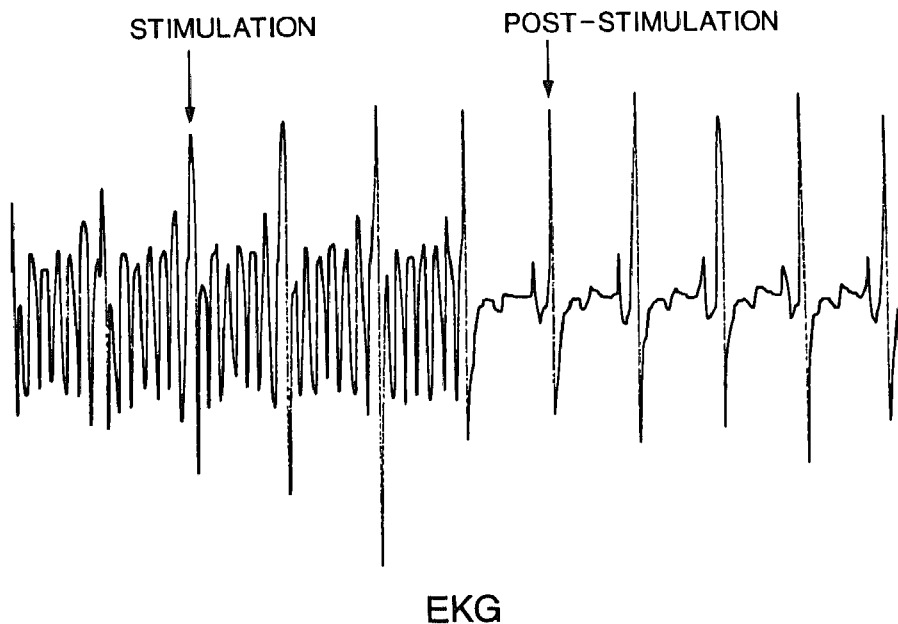


Figure 2. EKG of Lead II recorded during and after transtracheal electrical stimulation.

is superimposed over the EKG in Figure 2, regular QRS complexes are observed during transtracheal stimulation. A comparison of electrical stimulation values indicated that approximately 10 times the voltage was required to produce phonation transtracheally (5 volts) than through direct stimulation (0.5 volts). No changes in rate or pattern of respiration were observed during transtracheal stimulation.

Figures 3 and 4 show EGG and PGG waveforms obtained from the storage oscilloscope during direct and transtracheal electrical stimulation. In these figures, the overall shape of EGG and PGG signals is the same in direct and transtracheally induced phonation, and demonstrates a two margin (upper and lower) system of vibration.¹³ Comparisons of EGG and PGG signals for direct and transtracheally induced phonation

were the same for all animals tested, indicating the same vibratory mode for direct and transtracheal stimulation. Moreover, transtracheal stimulation was not observed to adversely effect normal physiologic control of vocal fold motion. After electrical stimulation, and full recovery from anesthesia, all animals were found to have intact vocal cord abduction during inspiration and adduction when subjected to tactile stimulation of the supraglottic area.

Figure 5 depicts representative EGG and PGG signals, recorded transcutaneously from one of the five animals that underwent transtracheal stimulation through a small tracheotomy. No superior laryngeal nerve stimulation was used and the EGG signal demonstrates a small plateau in the rising limb not seen in figures 3 and 4. This plateau represents the exaggerated elevation of

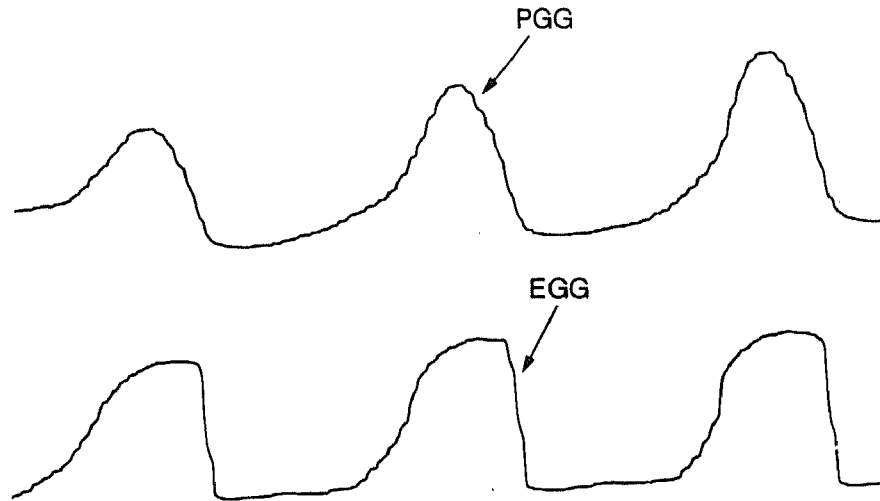


Figure 3. (top). PGG and EGG signals recorded from storage oscilloscope of phonation produced by direct electrical stimulation (fundamental frequency = 120 Hz).

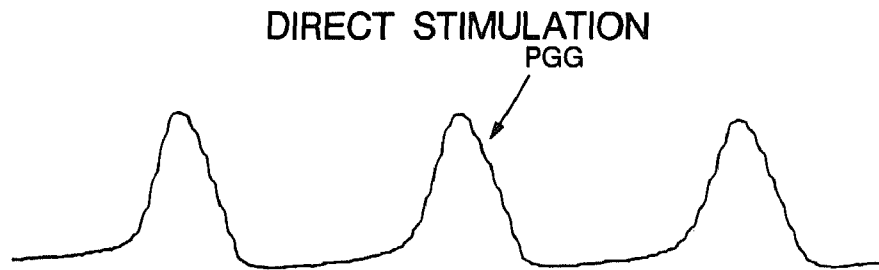
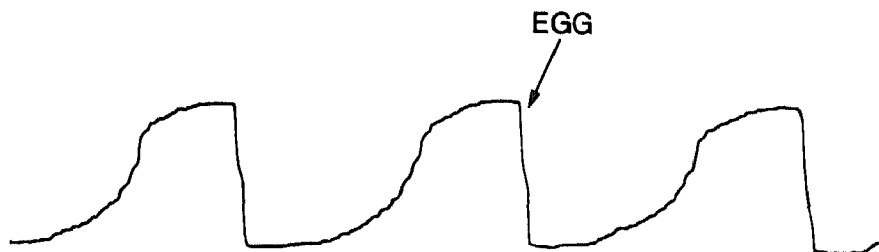


Figure 4. (bottom). PGG and EGG signals recorded from storage oscilloscope of phonation produced by transtracheal electrical stimulation (fundamental frequency = 120 Hz).



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the upper margin of the fold prior to opening due to the lack of contraction in the cricothyroid and its resulting tensing and thinning effect on the vocal fold. The plateau in the rising limb of the EGG was reduced simply by manually decreasing the distance between the cricoid and thyroid cartilages. It should be noted that the fundamental frequency of vibration is higher in Figure 5 than in Figures 3 and 4 (150 versus 120). Although no superior laryngeal stimulation was used in Figure 5, the higher fundamental frequency obtained was related to the ability of recurrent laryngeal nerve stimulation alone to modulate fundamental frequency. In this case, the higher fundamental frequency in Figure 5, when compared to Figures 3 and 4, represents an increased level of recurrent laryngeal nerve stimulation despite the lack of cricothyroid contraction. Two of the five animals in this group were studied again at one week without change in their PGG or EGG signals.

DISCUSSION

Our results indicate that the recurrent laryngeal nerves can be stimulated transtracheally and that this form of electrical stimulation can be used to elicit phonation during general anesthesia. This technique was not observed to cause abnormalities in cardiac or respiratory rates in the present study. Although Randall et al.¹⁴ observed a decreased atrial rate with stimulation of the left recurrent nerve at 5 volts in canines, that level of voltage was delivered directly not trans-

tracheally. Because 5 volts is approximately ten times the amount of direct electrical stimulation required to induce fold adduction, it is conceivable that Randall's results regarding atrial rate were produced by supramaximal nonphysiologic retrograde stimulation of fibers in the vagus nerve or recruitment of arterial baroreceptor fibers in the recurrent laryngeal nerve.¹⁵

The ability to induce phonation by transtracheal stimulation of the recurrent laryngeal nerve during anesthesia has two implications. First, with regard to animal studies, it may allow chronic preparations with permanent tracheostomies to be followed for the effects of laryngeal lesions over time. For example, the effects of radiographic therapy or vocal fold stripping may be followed sequentially in order to observe changes in vibration that occur with time. Second, with regard to vocal rehabilitation, it may be possible, in selected cases that have previously failed surgery and may require temporary tracheostomies, to transtracheally elicit phonation and directly examine and modify the nature of the vocal fold oscillations during surgical treatment. This technique also shows promise for patients with severe laryngeal injuries when the ability of the larynx to respond to electrical stimulation is in doubt, and may be useful diagnostically when vocal fold immobility results from either scarring or neuromuscular paralysis.

Further progress in this area will include a clinical investigational protocol and the development of a tracheostomy tube fitted with elec-

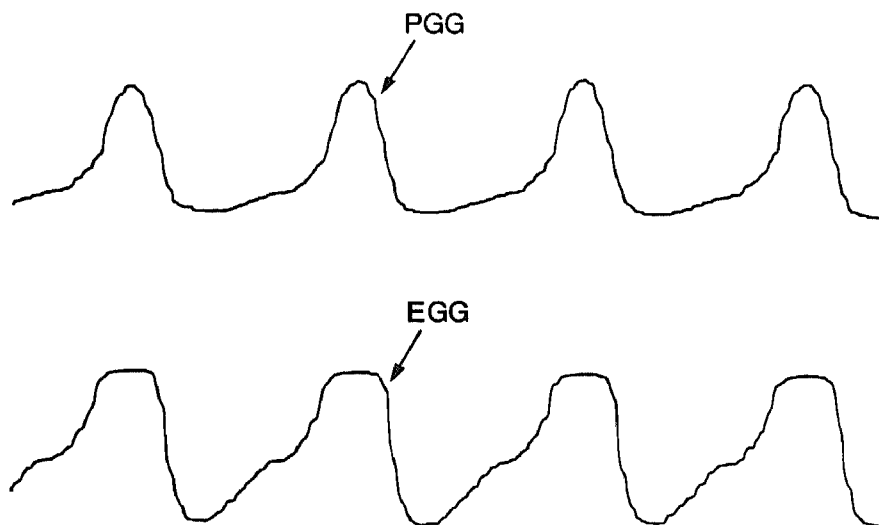


Figure 5. PGG and EGG signal recorded transcutaneously during transtracheally induced phonation. Note plateau in rising limb of EGG secondary to lack of superior laryngeal nerve stimulation (fundamental frequency = 150 Hz).

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trodes that can be inserted through a single tracheotomy with ports for controlling ventilation during anesthesia and rostral air flow to induce phonation. Presently, Implant Technologies Inc. makes a tracheostomy tube (Communitrache I) for ventilator dependent individuals through which air can be directed superiorly through a separate port to permit positive pressure ventilation and phonation.

SUMMARY

Phonation was induced in ten mongrel dogs under general anesthesia by way of transtracheal electrical stimulation of the recurrent laryngeal nerves under conditions of constant air flow. Although voltages for transtracheal stimulation were approximately ten times that required for direct stimulation of the recurrent laryngeal nerves, no cardiac or respiratory abnormalities were observed. Direct and transtracheally induced phonation resulted in similar PGG and EGG signals. Transtracheal stimulation of phonation can be used to sequentially study animal laryngeal vibration over time and may be clinically applicable to the treatment of patients with laryngeal problems that have failed to respond, or are not amenable, to standard forms of vocal rehabilitation.

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