Functional differences between the two bellies of the cricothyroid muscle

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The contraction of the cricothyroid (CT) muscle, which results in a decrease in the distance between the thyroid and cricoid cartilages, is considered to be the main factor in lengthening the vocal folds. This is achieved by rotation of the CT joint. The CT muscle is composed of two distinct bellies, the pars recta and the pars obliqua. The function of each subunit is not clearly understood, although it is believed that they act differently because their fibers run in different directions. To clarify the function of the two bellies in phonation, the fundamental frequency (F0), vocal intensity, subglottic pressure, vocal fold length, and CT distance were measured using an in vivo canine laryngeal model. On the basis of these measurements, we demonstrated that the two bellies are varied in their effect on raising the pitch, rotation, and forward translation of the CT joint. The stimulation of the pars recta nerve resulted in a greater increase in the F0 value compared with that of pars obliqua. The combined activity of the pars recta and pars obliqua is important in adjustment of the vocal fold length. The CT approximations directed parallel to the pars recta and pars obliqua simultaneously were more effective in elevation of the pitch than the approximation placed parallel to the pars recta only. This finding may be clinically significant with regard to CT approximation thyroplasty in human trails. (Otolaryngol Head Neck Surg 1998;118:714-22.)

The frequency of vocal fold vibration is determined mainly by the tension of the vocal folds as stated in the body-cover theory.[1,2] The main tensors of the vocal folds are the cricothyroid (CT) and thyroarytenoid (TA) muscles. These muscles are innervated by the external branch of the superior laryngeal nerve (SLN) and the recurrent laryngeal nerve (RLN), respectively. The CT muscle spans the inferior angle between the cricoid and thyroid cartilages. The TA muscle runs parallel to the vocal ligament and may act as an antagonist to the CT muscle at high contraction levels. The TA muscle stabilizes the position of the two cartilages and the tension and therefore the length of the vocal folds imposed by the CT muscle.[3-6]

It has been well demonstrated that the CT muscle is of functional importance in the control of the fundamental frequency (F0) during phonation[7-13] and during respiration.[14-16] This muscle is composed of two distinct groups of fibers, termed pars recta and paras obliqua because of their orientations to the airway axis. The pars recta is situated to produce rotation of the CT joint. Hence the logical action of this muscle is to narrow the CT gap. This is accomplished by rotating the thyroid cartilage down toward the cricoid in the vertical axis, resulting in increases in the vocal fold length and tension. The pars obliqua, on the other hand, has an additional function of moving the CT joint forward. The main function of pars obliqua is to move the cricoid cartilage backward and to cause narrowing the CT gap. This results in an increase in vocal fold length and tension.[3,6,7,10,17,18]

Recently, Zaretsky and Sanders[19] reported that three distinct bellies of the CT muscle (rectus, oblique, and horizontal) each play a distinct role in the complex function of this muscle. According to their study, the three bellies differed in fiber orientation and were separated by distinct fascial planes. In addition, the researchers recorded differences in the electromyographic patterns of these bellies. Other authors have suggested functional differences between two bellies of the CT muscle (rectus and oblique). Using excised human larynges, Fink and Demarest,[5] Vilkman et al,[17,18] Sonesson,[20] and Mayet and Mundnich[21] found distinct effects of the pars recta and pars obliqua in the CT joint. These investigators suggested that the pars recta causes rotation in the CT joint. This in turn would be a more important determinant of the length adjust-

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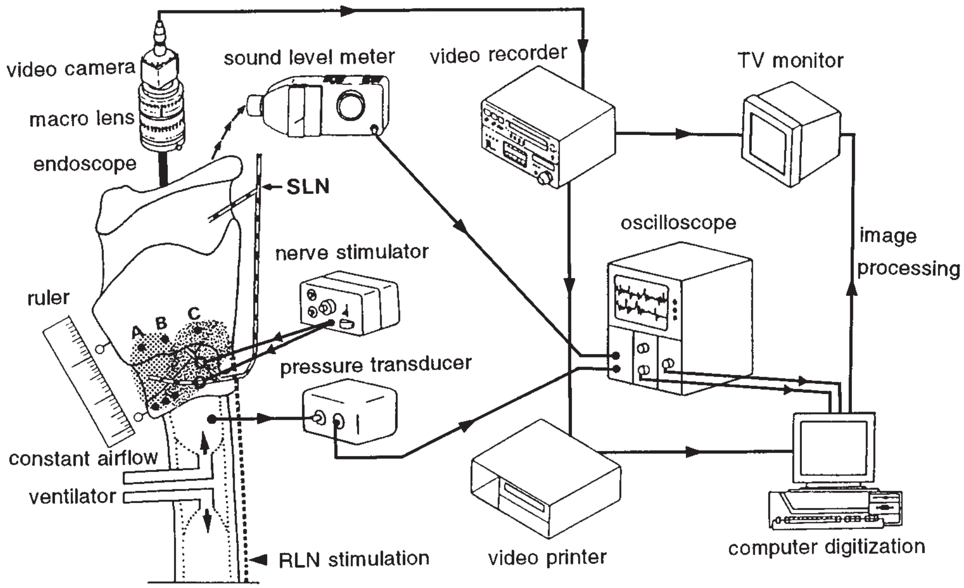

Fig. 1. Schematic presentation of in vivo laryngeal model. *SLN,* Superior laryngeal nerve; *A, B* and *C* are the suture sites.

ments of the vocal folds. The pars obliqua, on the other hand, results in forward translation of the thyroid cartilage. This also would be important in adjustment of the vocal fold length.

Fink and Demarest[5] measured the forward movement of the thyroid cartilage using lateral neck radiographs. They demonstrated that the forward translation was greatest in trained singers, less in untrained singers, and absent in nonsingers. Recently Fujisaki[22] and Vilkman et al.[23] associated the thyroid rotation with the accent component and the thyroid translation with the phrase component of speech. Fujisaki[22] proposed that the two bellies of the CT muscle work independently of each other and differ in the temporal pattern of their activities. No electromyographic evidence in humans, however, has distinguished the distinct role of these two bellies during phonation.[19]

A surgical technique has been proposed by Isshiki et al.[24-27] to elevate the vocal pitch in patients with androphonia caused by an androgenital syndrome or by reduced activity of the CT muscle or, less significantly, the strap muscle. This is accomplished by shortening the CT distance. They reported that the pitch-raising effect is greatest if the suture is placed somewhat anteriorly and it is better to avoid the anterior quarter of the thyroid ala as the site for suturing. They made the sutures almost parallel to the pars recta. Tanabe et al.[28] reported that this technique had the advantage of not impairing vocal fold vibration. The increase in pitch, however, was rather limited.

The current study used an in vivo canine laryngeal model to evaluate the tensor mechanisms of the CT muscle after stimulation of the main trunk of the external division of the SLN and the nerve branches to the pars recta and pars obliqua. The F0, subglottic pressure, vocal intensity, vocal fold length, and CT distance were measured. In addition, the most effective suture points in raising the pitch were determined. Finally, the F0 values were compared according to the suture sites of the CT approximations.

METHODS AND MATERIAL

In Vivo Canine Model

This study was performed in accordance with the Public Health Service Policy on Human Care and Use of Laboratory Animals, the National Institutes of Health Guide for the Care and Use of Laboratory Animals, and the Animal Welfare Act (7 U.S.C. et seq.). The animal use protocol was approved by the Institutional Animal Care and Use Committee of the University of California, Los Angeles.

This animal model is summarized in Fig. 1. Six healthy mongrel dogs (weighing approximately 25 kg to 30 kg) were premedicated with acepromazine maleate, and intravenous pentobarbital sodium (Nembutal) was given to a level of corneal anesthesia. Additional Nembutal was used to maintain this level of anesthesia during the procedure. The dog was placed supine on the operating table. Orotracheal intubation was performed and ventilation assisted with 95% oxygen was given.

Fig. 2. Photograph of vocal folds measuring the distance between two markers on vocal fold using calibration method.

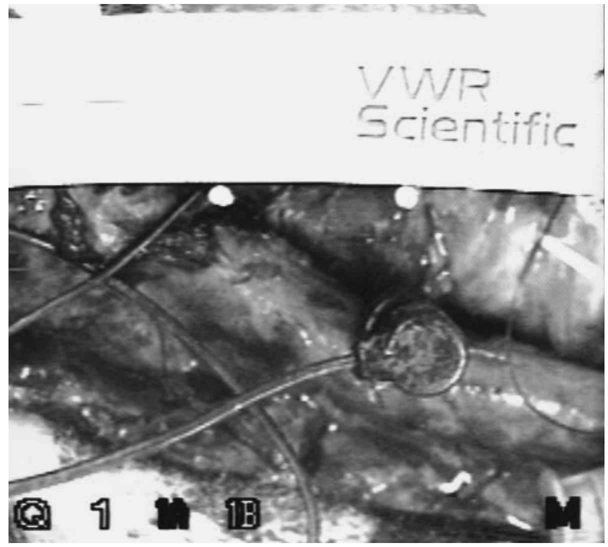

Fig. 3. Photograph of exposed larynx measuring the distance between two markers on midline thyroid and cricoid cartilages using centimeter ruler.

After a midline neck incision, the hyoid bone, larynx, and the trachea were exposed from the mandible to the sternal notch. A low tracheotomy was performed at the level of the suprasternal notch and cannulated with an endotracheal tube for ventilation. A second tracheotomy was performed about 2 cm superior to the first one and a cuffed endotracheal tube was passed in a rostal direction with the tip positioned 10 cm below the glottis. The epiglottis was suspended using a button from a fixed point for direct visualization of the vocal folds through the oral cavity. The RLNs were dissected on both sides and Harvard bipolar electrodes were applied to these nerves. A constant current nerve stimulator (Harvard subminiature electrode, South Natick, Mass.) was used to stimulate the RLNs to produce phonation. The frequency of stimulation was 80 Hz with a pulse duration of 1.5 msec for both nerve stimulators.

The room air was warmed and humidified by bubbling through 5 cm of water at 37° C. The air flow was controlled by a needle value (Whitey, Highland Heights, Ohio) and measured with a flowmeter (model F1500; Gilmont instruments, Great Neck, NY). The rate of air flow was about 390 ml per second constantly. A catheter-tipped pressure transducer (model SPC-303; Millar Instruments, Houston, Texas) was inserted through the superior tracheotomy to rest 1 cm below the vocal fold. The transducer was calibrated at the temperature of the trachea of the animal by submerging it in a water bath at 37° C to a depth just covering the sensor (0.5 cm) and then calibrating it against a mercury manometer from 0 to 100 mm Hg.

Dissection and Stimulation of the External Superior Laryngeal Nerves

The pars recta and pars obliqua of the CT muscle could be easily identified. The external trunk of the SLN was dissected at the midlevel of the thyroid cartilage and isolated about 1 cm. These isolated branches of the external SLN to the pars recta and pars obliqua also were dissected. The tiny tributaries between the nerves to the pars recta and pars obliqua were sectioned to prevent the simultaneous contraction when isolated nerve branches were stimulated.

A Grass model 54H stimulator (Quincy, Mass.) and a voltage stimulator (WR Medical Electronics RLN Stimulator, Model S2LH, St. Paul, Minn.) were used to provide varying amounts of current to isolate the nerve branches. The voltage varied according to the extent of contraction of the CT muscle. The low level stimulation of the nerve was the point at which whole or each belly of the CT muscle contracted mildly but distinctly. The high level stimulation was attained when no more contraction of these muscles occurred during nerve stimulation. No neighboring muscle contraction could be elicited by maximal stimulation of the isolated nerves.

Measurements of Waveform Signal

The acoustic and subglottic pressure signals were verified on a Tektronix oscilloscope (model 5116; Beaverton, Ore.) before the recordings. These signals were low-pass filtered at 3000 Hz and digitized at a rate of 20 kHz and recorded to a personal computer with a Labmaster analog-to-digital microprocessor. A multi-

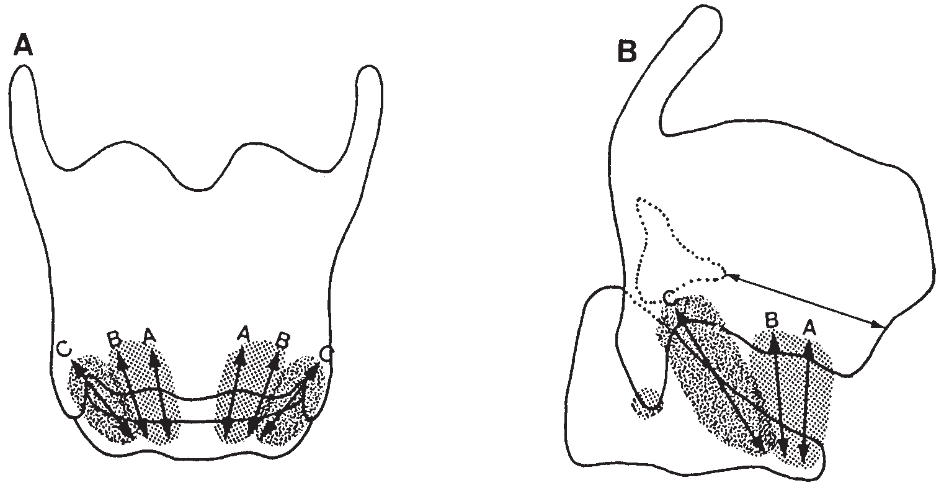

Fig. 4. The suture sites (*A, B, C*) for the CT approximation, anteroposterior view **(A)** and lateral view **(B)**.

purpose computer program (CSpeech 3.1; Paul Milenkovic, University of Wisconsin, Madison, Wis.) was used to analyze the F0, vocal intensity, and subglottic pressure measurements.

Measurements of Vocal Fold Length and Cricothyroid Distance

For measuring the change of vocal fold length before and after stimulation, two small markers were made on the upper surface of the vocal folds using gentian violet ink. The isolated branches of the SLN were stimulated, but the RLN was not stimulated. Videoendoscopy was performed using a Storz telescope (Storz Instrument Co., St. Louis, Mo.) connected with a fiberoptic cable. Images were viewed on a Sony video monitor (PVM 1341) and recorded using a charge-coupled device camera (Toshiba IKC30A, Buffalo Grove, Ill.) and ¾-inch videotape recorder (Sony VO-9850, Park Ridge, NJ). The camera was kept at a constant distance from the larynx throughout each experiment. The calibration method used for measuring the change of the vocal fold length before and after stimulation is shown in Fig. 2. The distances between two markers were measured with the software so that pixel units before and after stimulation could be converted to the percentage changed.

For measuring the change in the CT distance, two small needles with markers were located on the midline thyroid lamina at the vocal fold level and the midline of the anterior cricoid lamina. The fixed centimeter ruler was adjusted during measurements, as shown in Fig. 3. The video images were recorded using the above method. The changes in the CT distance were measured by calculating the distance between the two needles before and after stimulation.

Cricothyroid Approximations

The three suture sites on each side were marked on the thyroid and cricoid cartilages, as shown in Fig. 4: *A* represents the site parallel to the anterior portion of pars recta; *B* is the site parallel to the posterior portion of pars recta, and *C* is the site parallel to the pars obliqua. At all of the sites, nylon sutures were placed to draw the cricoid and thyroid cartilages closer together, as shown in Fig. 4. The CT approximations were classified into three types according to the suture sites mentioned above: the classic Isshiki type, in which the suture sites were parallel to the pars recta only on both sides (A+B); the modified type I, with four suture sites parallel to the pars recta and the pars obliqua simultaneously (A+C); and the modified type II (A+B+C), with all six suture sites approximated on both sides. The cricoid and thyroid cartilages were approximated as closely as possible. After stimulation of RLN on both sides to produce phonation, the F0s were measured separately according to the types of CT approximation.

Experimental Design

This in vivo canine laryngeal model was similar to other experimental preparations.[29,30] Six dogs were studied for the pitch control mechanism of the pars recta and pars obliqua of the CT muscle. The RLNs were stimulated to produce phonation with constant airflow. In three dogs, the stimulation level (both high and low) of isolated branches of the external SLN were varied. The acoustic and pressure signals were taken with

Table 1. Mean changes in F0, vocal intensity, and subglottic pressure

Variable	Site	Level	Dog 1	Dog 2	Dog 3
F0(Hz)	ESLN trunk				
		Low	31.7 (2.78)	23.6 (3.50)	80.2 (5.69)
		High	98.8 (5.88)	85.6 (10.12)	142.0 (6.56)
	Pars recta nerve				
		Low	15.9 (3.67)	14.7 (5.55)	54.2 (11.95)
		High	46.2 (7.38)	66.8 (11.42)	105.8 (5.18)
	Pars obliqua nerve				
		Low	9.5 (2.00)	7.6 (2.88)	59.6 (6.80)
		High	27.2 (10.97)	27.0 (8.89)	77.0 (12.22)
Intensity (V)	ESLN trunk				
		Low	0.7 (0.05)	0.3 (0.05)	0.1 (0.22)
		High	0.9 (0.47)	0.4 (0.24)	0.0 (0.15)
	Pars recta nerve				
		Low	1.3 (0.49)	0.2 (0.05)	–0.2 (0.07)
		High	1.6 (0.70)	0.4 (0.20)	–0.4 (0.14)
	Pars obliqua nerve				
		Low	0.9 (0.26)	0.2 (0.04)	0.0 (0.06)
		High	1.5 (0.22)	0.2 (0.10)	–0.1 (0.03)
Psub (mm Hg)	ESLN trunk				
		Low	–1.8 (4.30)	–2.9 (4.07)	–2.7 (1.72)
		High	–3.8 (1.88)	–3.2 (1.84)	–7.9 (1.62)
	Pars recta nerve				
		Low	–2.2 (2.00)	–1.1 (2.05)	–1.4 (1.42)
		High	–2.0 (2.78)	–3.6 (0.87)	–4.8 (3.65)
	Pars obliqua nerve				
		Low	–8.1 (1.62)	–0.3 (3.69)	–4.4 (0.69)
		High	–3.3 (6.58)	–2.6 (4.08)	–4.1 (1.95)

Standard deviations are given parenthetically.
ESLN, External superior laryngeal nerve; *Psub*, subglottic pressure; *F0*, fundamental frequency.

RLN stimulation and the changes in the CT distance and vocal fold length were taken without RLN stimulation. Various suture sites between the cricoid and thyroid cartilages were used in three other dogs. Three time trials were performed by the same procedure separated by at least 3 to 5 minutes to reduce fatigue effects. The data were evaluated at 300-millisecond intervals. The subglottic pressure, F0, and vocal intensity measurements were averaged from 10 consecutive cycles selected at random from a stable section of phonation. The changes in the vocal fold length and CT distance were measured using videoendoscopic images with markers. These changes were averaged three times before and after stimulation. The different sutures were made on the cricoid and thyroid cartilages before stimulation of the RLN. After stimulating the RLN for phonation, the suture sites were approximated separately according to the types of CT approximation. The F0 values were calculated using acoustic signals recorded in the computer and averaged three times.

RESULTS

Separate analysis of variance (ANOVAs) of repeated measures were undertaken for each dependent parameter (F0, vocal intensity, and subglottic pressure). The stimulation condition (with or without stimulation to the external SLN) was compared within the subjects, and the dogs, stimulation site, and stimulation level were compared between the subjects. Note that the vocal intensity and subglottic pressure were moderately but significantly correlated (Pearson's $r = 0.64$, $p < 0.01$, adjusted for multiple comparisons), and thus did not represent fully independent effects in this study.

The mean change in F0 values with stimulation to the external SLN is given in Table 1 for each dog and stimulation site. The F0 value increased significantly with stimulation of the external SLN ($F_{1,36} = 2744.82$, $p < 0.01$), with significant larger increases in F0 values at the higher stimulation level ($F_{1,36} = 417.07$, $p < 0.01$). The magnitude of the change in F0 values with stimulation varied significantly with the stimulation site ($F_{2,36} = 142.95$, $p < 0.01$).

Changes in vocal intensity with stimulation of the external SLN are shown in Table 1. The overall intensity increased slightly but significantly with stimulation ($F_{1,36} = 144.02$, $p < 0.01$). However, for dog 3, the changes occurred only when the pars recta was stimulated, and then the intensity decreased rather than increased, as occurred in dogs 1 and 2. This resulted in a significant correlation between the stimulation and the dog used ($F_{2,36} = 95.80$, $p < 0.01$) and a significant three-way correlation between the dogs, stimulation, and stimulation

Table 2. Mean changes in CT distance and vocal fold length

Variable	Site	Level	Dog 1	Dog 2	Dog 3
CTD(mm)	ESLN trunk				
		Low	1.2 (0.29)	1.3 (0.58)	2.2 (0.29)
		High	4.8 (0.29)	4.3 (0.58)	6.5 (0.50)
	Pars recta nerve				
		Low	1.0 (0.00)	1.2 (0.29)	2.0 (0.00)
		High	4.5 (0.50)	4.0 (0.50)	5.0 (0.00)
	Pars obliqua nerve				
		Low	0.7 (0.29)	0.7 (0.29)	1.0 (0.50)
		High	2.5 (0.50)	2.8 (0.29)	3.3 (0.29)
VFL(%)	ESLN trunk				
		Low	12.1 (0.96)	8.1 (0.66)	8.4 (0.79)
		High	27.7 (0.96)	24.6 (1.08)	33.9 (1.67)
	Pars recta nerve				
		Low	8.4 (0.78)	7.1 (0.59)	6.9 (1.21)
		High	21.9 (1.63)	20.6 (0.80)	25.7 (1.08)
	Pars obliqua nerve				
		Low	3.5 (0.65)	3.8 (0.29)	5.0 (0.35)
		High	11.3 (0.76)	9.9 (0.84)	14.0 (0.44)

Standard deviations are given parenthetically.
ESLN, External superior laryngeal nerve; *CTD,* cricothyroid distance; *VFL*, vocal fold length.

site ($F_{4,36} = 6.11$, $p < 0.01$). No significant differences among stimulation sites were observed, and no differences were noted between stimulation levels.

The effects of stimulation of the external SLN on subglottic pressure are given in Table 1. The subglottic pressure decreased significantly with this nerve stimulation ($F_{2,36} = 426.36$, $p < 0.01$), but no differences among levels or stimulation sites were observed, and no significant interactions were observed.

Table 2 shows the average changes in CT distances for each dog, stimulation site, and stimulation level. Separate three-way (dog by stimulation site by stimulation level) ANOVAs were undertaken for each dependent measure. The change in CT distance increased with increasing stimulation ($F_{1,36} = 825.81$, $p < 0.01$). Across stimulation levels, each stimulation site differed significantly from the other ($F_{2,36} = 80.52$, $p < 0.01$; Scheffé post-hoc comparisons $p < 0.01$). The change in CT distance was the greatest when the external trunk of the SLN was stimulated, and was the least when the pars obliqua nerve was stimulated. Differences between dogs were also significant ($F_{2,36} = 35.23$, $p < 0.01$), as was the interaction between stimulation sites and stimulation level (Table 2).

The results for the vocal fold length parallel those for the CT distance, with significant differences between stimulation levels ($F_{1,36} = 3028.81$, $p < 0.01$), stimulation sites ($F_{2,36} = 661.25$, $p < 0.01$), and dogs ($F_{2,36} = 56.23$, $p < 0.01$). Scheffé post-hoc comparisons showed significant differences between all stimulation sites, with the greatest change in vocal fold length when the external trunk of the SLN was stimulated, and the least when the pars obliqua nerve was stimulated ($p < 0.01$). All interaction effects were also significant (Table 2).

Finally, a two-way (dog by CT approximation type) ANOVA compared the effects of different approximation types on the F0 values. Significant differences among the types were observed ($F_{2,18} = 806.51$, $p < 0.01$). Scheffe post-hoc comparisons indicated that the modified types (A+C and A+B+C) each differed significantly from the classic Isshiki type ($p < 0.01$), A+B, but did not differ significantly from each other ($p > 0.01$) (Table 3).

DISCUSSION

In this study, we assumed that the fatigue effects built up gradually in the animal model, and thus the measures within a single stimulation off/stimulation on trial would reflect these effects approximately equally. Thus the effects of stimulation to a single belly of the CT muscle could be estimated with repeated measures ANOVA, even if the relative contributions of the pars recta and pars obliqua could not be accurately determined from the current design.

This study demonstrated the largest elevation in F0 values with stimulation of the external trunk of the SLN compared with stimulation of isolated branches to the pars recta and pars obliqua. Stimulation of the pars recta nerve branch resulted in greater increases in the F0 levels compared with that of the pars obliqua nerve branch. The rise in F0 values was directly proportional to the stimulation intensity. The changes in CT distance and vocal fold length showed the same tendency as that

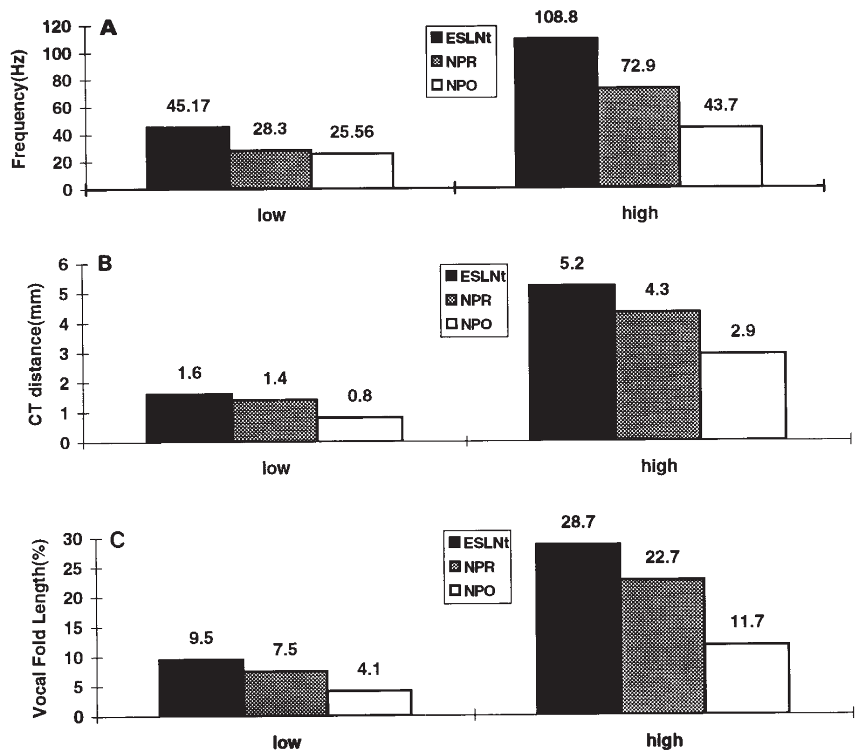

Fig. 5. Plots for the changes of F0 **(A)**, CT distance **(B)**, and vocal fold length **(C)** with levels of stimulation of external trunk of SLN (*ESLNt*), nerve to pars recta (*NPR*), and nerve to pars obliqua (*NPO*).

Table 3. F0 (Hz) Distributions with suture sites

	Baseline	A + B	A + C	A + B + C
Dog 4	102 (2.7)	207 (2.5)	235 (6.0)	230 (1.5)
Dog 5	125 (2.5)	186 (0.7)	267 (2.1)	276 (2.5)
Dog 6	107 (1.5)	121 (1.2)	144 (2.7)	139 (1.2)

Standard deviations are given parenthetically.
Baseline values are F0 during RLN stimulation without CT approximation.
F0, Fundamental frequency.

of the F0 (Fig. 5). The largest rise in F0 values during stimulation of the external trunk of SLN was the result of the greatest shortening in CT distance and greatest lengthening of the vocal folds in comparison with the other stimulation sites. Kitajima et al.[31] has reported that in excised human larynges, the relationship between CT distance and vocal pitch is generally linear. It appears that the CT distance is shortened most during stimulation of the external trunk of the SLN compared with stimulation of the pars recta and pars obliqua nerve branches alone. In addition, the pars recta nerve branch appears to be a more effective tensor than the pars obliqua nerve branch. This would explain the dominant effect of the pars recta compared with the pars obliqua in raising the pitch.

Previous studies have demonstrated an increase in subglottic pressure with increasing pitch. Yanagihara and von Leden[9] demonstrated that a decrease in subglottic pressure was correlated with a lowered pitch. In the current study, the subglottic pressure decreased significantly with CT stimulation, but no significant difference was found with relation to the stimulation sites and stimulation levels. This finding may be explained by some degree of abduction of the vocal folds seen with CT muscle stimulation. On the correlation between the vocal intensity and the CT muscle electrical activity, Yanagihara and von Leden[9] also reported a lack of correlation between the intensity and measured activity of the muscle. In this study, there was a rise in vocal intensity and site of stimulation intensity, but no correlation was found between the vocal intensity and site or level of stimulation.

We suggest that these different results of F0 values, CT distance, and vocal fold length among stimulation sites may represent the different articulatory movements in the CT joint (Fig. 6). Fink and Demarest[5] reported

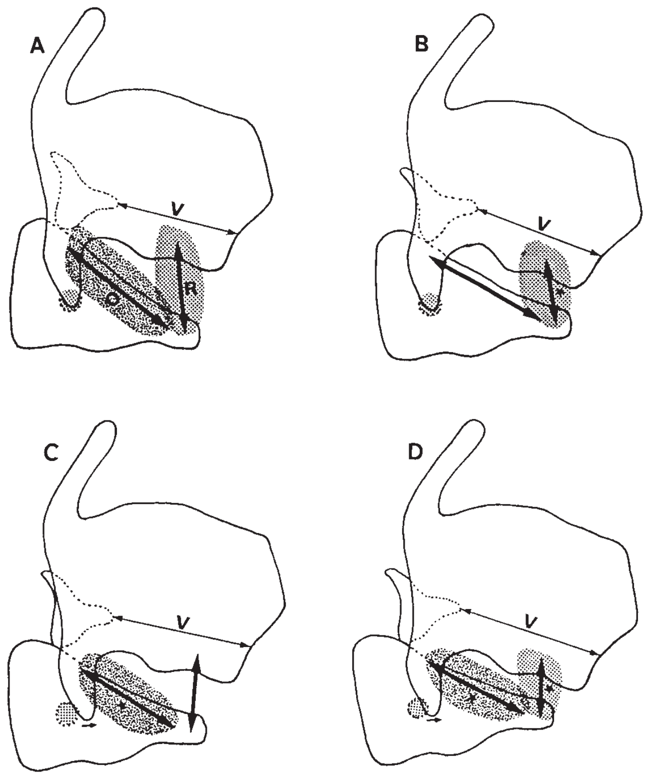

Fig. 6. The movements of the thyroid and cricoid cartilages. **A,** resting state; **B,** After stimulation of nerve to pars recta (*R*); **C,** Nerve to pars obliqua (*O*); and **D,** external trunk of SLN. *V,* Vocal folds. The *black star* marks mean contraction of corresponding muscle.

that the two bellies were functionally distinct. The pars recta elongates and therefore tenses the vocal ligament. The fibers of this muscle run nearly perpendicular to the axis of rotation of the CT articulation. The pars obliqua is responsible for forward translation of the CT joint. This is the result of the oblique orientation of its muscle fibers. Vilkman et al.[17,18] also suggested that the forward translation might be important in adjustments of the vocal fold length. Mayet and Mundnich[21] demonstrated that the forward translation of the CT articulation in a sagittal plane is possible only in certain rotational positions of the joint. Sonesson[20] found varying configurations of the vocal folds when they were lengthened either by rotation or forward translation of the CT joint. He suggested that these findings may be significant in regulation of quality and timbre of voice. Both these types of joint movements, however, are important in frequency regulation by changing the CT distance and vocal fold length. The stimulation of the external trunk of the SLN resulted in both rotation and forward translation of the CT joint; in other words, this reflected the function of both the pars recta and pars obliqua.

The different articulatory movements of the two bellies of the CT muscle have been studied using radiographic images of the cricoid and thyroid cartilages. Sonesson[20] concluded that the anterior translation of the thyroid accounted for 75% of vocal fold elongation associated with raising the pitch. Fink and Demarest[5] demonstrated that professional singers exhibited a larger CT space on lateral radiographs than untrained singers when producing the same pitch. They also found a greater ventrodorsal gliding in trained than in untrained singers. There has been some criticism of these data, however. Stone and Nuttal[8] reported that the data of Sonesson may be based on the cricoid artifact. With sufficient upward rotation of the cricoid arch, the superior aspect of the cricoid signet may approximate the posterior pharyngeal wall. Continued elevation of the arch would cause forward displacement of the caudad portion of the cricoid signet and consequently the thyroid cartilage. This displacement could be misinterpreted as translation of the thyroid cartilage when attention is focused solely on this structure.

Isshiki et al.[24,26,27] were the first to describe the CT approximation for raising the pitch by simulating the contraction of the CT muscle with sutures. The sutures were placed at four sites, all almost parallel to the rectus portion of the CT muscle. They reported a substantial rise in vocal pitch with this procedure. Kitajima et al.[31] attempted to determine the best site for suture placement for pitch elevation. They placed the sutures at various locations, including parallel to the pars recta and pars obliqua. No significant differences were noted, however, among any of these suture locations. In our experiments with the in vivo canine study, we determined the suture location more effective for raising the pitch. We found that the sutures placed parallel to the pars recta and pars obliqua simultaneously were more effective in elevation of the pitch compared with one suture placed parallel to the pars recta only. This finding may be clinically significant with regard to the placement of the suture site in human trials.

In conclusion, it appears that two types of CT joint movement are caused by contraction of the CT muscle. The pars recta portion of this muscle results in a vertical axis of displacement, whereas the pars obliqua portion causes a displacement in the horizontal axis. The fundamental frequency is mostly affected by rotation of the CT joint resulting from the contraction of the pars recta. The pars obliqua, however, is also important in controlling the F0. The greatest increases in the F0 value were noted when both portions were stimulated simultaneously. The synergistic function of these two bellies may be an important physiologic factor in controlling the length of the vocal folds. The CT approximation with the sutures placed parallel to both the pars recta and pars obliqua may be more effective than previously described methods for elevation of the pitch.

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