Active and Passive Properties of Canine Abduction/Adduction Laryngeal Muscles

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Summary: Active and passive characteristics of the canine adductor- abductor muscles were investigated through a series of experiments conducted in vitro. Samples of canine posterior cricoarytenoid muscle (PCA), lateral cricoarytenoid muscle (LCA), and interarytenoid muscle (IA) were dissected from dog larynges excised a few minutes before death and kept in Krebs-Ringer solution at a temperature of 37°C ± 1°C and a pH of 7.4 ± 0.05. Active twitch and tetanic force was obtained in an isometric condition by applying field stimulation to the muscle samples through a pair of parallel-plate platinum electrodes. Force and elongation of the samples were obtained electronically with a dual-servo system (ergometer). The results indicate that the twitch contraction times of the three muscles are very similar, with the average of 32 ± 1.9 ms for PCA, 29 ± 1.6 ms for LCA, and 32 ± 2.4 ms for IA across all elongations. Thus, PCA, LCA, and IA muscles are all faster than the cricothyroid (CT) muscles but slower than the thyroarytenoid (TA) muscles. The tetanic force response times of these muscles are also similar, with a maximum rate of force increase of 0.14 N/ms.

Key Words: Canine larynx—PCA—LCA—Posturing—Laryngeal muscles—Tetanic contraction—Twitch response—Contractile properties.

INTRODUCTION

Vocal fold posturing, an essential component of respiration and speech production, is a process that controls the vocal folds length, tension, glottal width, and glottal flow resistance before or during phonation. Contraction of one or more of the five intrinsic laryngeal muscles, the thyroarytenoid (TA), cricothyroid (CT), interarytenoid (IA), posterior cricoarytenoid (PCA), and lateral cricoarytenoid (LCA), is involved. The speed of contraction of these muscles, the level of their activation, and their time-dependent stress-strain relations has a major influence on all aspects of voice production. Of these muscles, CT and TA are primarily involved in length

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and tension control. TA, LCA, and IA are all adductors, whereas PCA is the sole abductor of the vocal folds.[1–4]

Models of vocal fold posturing require information on the geometry and structure of the laryngeal cartilages and joints, origin and insertion of laryngeal muscles, and response to neural excitation. In particular, a dynamic (time-dependent) model of posturing depends on the active and passive properties of the aforementioned muscles including contraction times, force-elongation relations, and force-velocity relations.[5–8] In addition to modeling, the dynamic and physiological properties of these muscles can lend themselves to clinical evaluation of laryngeal function and a better understanding of interactions among muscle groups.[3,9,10]

In recent years, new anatomical and geometrical data have emerged on the laryngeal cartilages and muscles, some with electronic caliper techniques,[11–13] and some with the most advanced MRI techniques that provide submillimeter accuracy.[14,15] These data sets give new hope to accurate biomechanical modeling of laryngeal function. The active and passive properties of two laryngeal muscles, the TA and CT, are well documented.[16–25] However, data on active and passive properties of other laryngeal muscles are still scarce. Only the twitch contraction of PCA muscle has been investigated due to its importance as the sole abductor in speech and respiration.[17,19,26,27] The muscle twitch is a fundamental unit of contraction from which any tetanic contraction can be derived through the summation of the twitch forces that are separated by a randomized activation delay. This delay is based on means and standard deviation of motor unit firing frequencies as described and modeled by Titze.[28] Although the twitch contraction time is accepted as an indicator of a muscle's speed of contraction, the biomechanical models that employ these muscles in vocal fold vibration[6] and vocal fold posturing[8] are in need of tetanic contraction characteristics. Specifically, the time course and active stress-strain behavior are needed for the constitutive equations. Also, passive properties such as Young's modulus and stress-strain relations are needed to complete the quantification of a muscle model.

The purpose of this study was to quantify the twitch and tetanic contraction times and the passive stress-strain relationship for the PCA, LCA, and IA muscles. A simplified model for the tetanic contraction will be presented. Given the current difficulty of obtaining viable tissue and maintaining this viability in vitro over an hour or so of measurement time, highly selective measurements had to be made on our canine tissue samples. At present, we opted for contraction time and stress-strain relationships, but we were not able to obtain force-velocity relations.

METHODOLOGY

Canine larynges were harvested from other research laboratories. (No animals were sacrificed solely for the purpose of our experiment.) The larynges were excised a few minutes before death and immediately submerged in Krebs solution. This solution was continuously aerated with a mixture of 95% oxygen and 5% carbon dioxide. The pH of the solution was 7.4 ± 0.05, and the temperature was maintained about 37°C with an immersion circulator (Fisher Circulation Model 73). The harvested larynges were brought to our laboratory in medium less than 10 minutes after excision.

Before dissection, the average length of the each sample was measured in situ with a caliper. The length of LCA and PCA muscle samples ranged between 12 to 18 mm, and the length of IA muscle samples ranged from 6 to 10 mm. Dissection of the muscle samples was then started immediately, with the larynx continually submerged in the aerated Krebs solution. Due to the large fanning out of the PCA muscle on the cricoid cartilage, samples from this muscle were then either from the vertical portion or the oblique portion. The LCA samples were taken from either left or right side, opposite the PCA sample side, to retain a piece of arytenoid cartilage on the end of both muscles. Most muscle samples were approximately 4 to 7 mm wide and 3 to 5 mm thick. A piece of cartilage was also retained on the cricoid end. LCA and IA samples were taken from the whole muscle and trimmed to about 4 to 5 mm widths. The cross-sectional area of each sample was calculated from the mass and length after removal from the Krebs chamber and removal of the excess liquid with tissue paper.

Experimental method

A (4-0) Tevdek polyester suture was inserted through each end piece of cartilage and tied. Using