Science for Singers

A SERIES OF VOICE RESEARCH COLUMNS BY INGO R. TITZE, PHD

Why Do We Have a Vocal Ligament?

Dogs don't have one. Pigs do. It seems that about half of the vocalizing vertebrates have vocal ligaments and the other half don't. Even in humans, there doesn't seem to be a compelling physiologic reason to have one - unless you are a singer, of course! For this select group of humans, the vocal ligament may make the difference between a wide pitch range and a mediocre one.

Let me explain. In general, ligaments are the "ropes" and "chains" that tie together various structures in the human body. They connect cartilages to other cartilages and to bones. They allow a certain amount of freedom of movement between hard structures, but ultimately limit such movement. Most of us have seen the large number of ligaments that are found in a turkey leg. On the dinner plate, these ligaments are annoying as we try to separate pieces of meat from them, yet this dinner plate dissection may convince us that a bird has a great need for many of these connecting strands. Within the leg muscle, the ligaments are the puppet strings that help move the claws. They are also the safety valves that prevents excessive extension of the muscles.

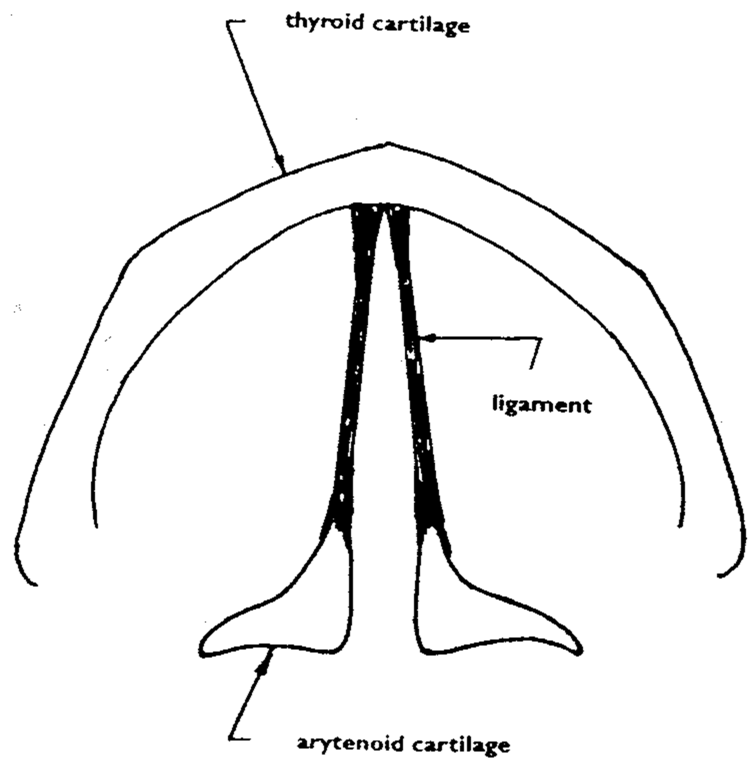

Figure 1. The vocal ligament.

In the vocal folds, the vocal ligament connects the tips of the vocal processes of the arytenoid cartilage to the thyroid cartilage (Figure 1). If all of the muscle and skin is removed from the vocal fold, as in the figure, a thin strand remains that has the semblance of a string. In fact, the term *vocal cord* originated from the concept that the vocal ligament is string-like. Acoustically, this ligament has the properties of a guitar or violin string. But it is not uniform in cross-section. At the endpoints, the ligament thickens, whereas in the middle it is relatively thin, approximately 1 mm x 1 mm in cross-section. It is believed that the thickening at the endpoints serves to strengthen the ligament and keep it from receiving excessive bending forces, whereas the thinner middle section makes it more flexible.

Ligaments have a very interesting mechanical property. Being composed mainly of collagen fibers, ligaments can usually be extended about 20 to 30 percent of their rest length with relative ease. The collagen fibers, which are loosely woven together, first align themselves in a single direction in this initial elongation, like in the stretching of a cheese cloth. At some point, however, the fibers prevent any

further elongation and become very indistensible, like cotton threads. At that point, the fibers can support large tensions without being further extended (Figure 2).

In analogy with stringed instruments, the fundamental frequency of vibration of the ligament can be calculated rather easily with the formula

$$F_0 = \frac{1}{2L}\sqrt{\frac{\sigma}{\rho}}$$

where s is the stress in the ligament, σ is the density, and ρ is the length. To achieve a fundamental frequency greater than 1,000 Hz (female singers can do this, as well as some males in falsetto register), the stress in the string must be on the order of a million Pascals. This represents a force of nearly a pound applied to a strand of collagen fibers about 1 mm^2 in cross-section. Such a stress (force per unit area) is much larger than any muscle can produce within itself by active contraction. Even the thyroarytenoid muscle, which is the bulk of the vocal fold, cannot produce this type of stress within itself. Hence, it cannot be used as a tensor for very high pitches.

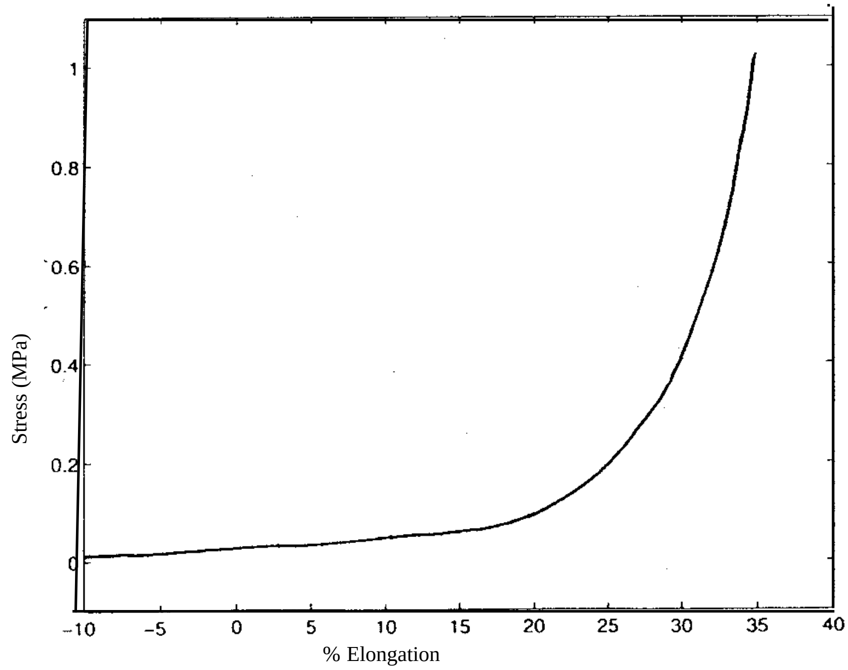

Figure 2. Stress in a human ligament as percent elongation increases from the rest length.

What supplies this large stress to the vocal ligament, then? It is the cricothyroid muscle. Not that this muscle is a whole lot stronger than the thyroarytenoid muscle, but it effectively applies its force to only a portion of the vocal fold, namely the stiffest portion. By pulling the arytenoid cartilage backward, the cricothyroid muscle magnifies the stress in the ligament because the ligament is considerably thinner than the muscle. In other words, a mechanical advantage is obtained with a thick muscle working to stretch a thin ligament. Specifically, the stress is amplified by the ratio of the area of the muscle to the area of the ligament, which can be as large as 20:1.

But the ligament must not be too thin, otherwise it can rupture. Thus, there is a delicate balance between having a thin enough ligament that can support high tensions and be flexible, but not so thin that it tears. The ligament must also be unencumbered by surrounding tissue. It must be able to maintain its string-like oscillation. Any obstruction in its vicinity, such as a cyst or a polyp, would definitely have a perturbing nature. Surgeons therefore take great care in maintaining the integrity of the ligament when removing growths on or near the ligament. Also, the singer can free the ligament by relaxing the thyroarytenoid muscle.

So, why do we have a ligament? To sing high. Why do pigs have a ligament? To squeal high. But I don't know why dogs can whine high, and wouldn't suggest that the Italian *squillo* has anything to do with squealing.

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