Pediatric Voice: Delineating the Voice Science and Investigating Child Training Methods Toward Pedagogical Application

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PEDIATRIC VOICE: DELINEATING THE VOICE SCIENCE AND INVESTIGATING CHILD TRAINING METHODS TOWARD PEDAGOGICAL APPLICATION

By

Maria Fenty Denison

A DOCTORAL ESSAY

Submitted to the Faculty of the University of Miami in partial fulfillment of the requirements for the degree of Doctor of Musical Arts

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A doctoral essay submitted in partial fulfillment of the requirements for the degree of Doctor of Musical Arts

PEDIATRIC VOICE: DELINEATING THE VOICE SCIENCE AND INVESTIGATING CHILD TRAINING METHODS TOWARD PEDAGOGICAL APPLICATION

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This study investigates the synergistic relationship between voice science and voice pedagogy to inform the practices of voice teachers, music educators, and voice trainers. Furthermore, it is an effort to augment existing knowledge of the anatomy and physiology of the pediatric voice so voice professionals may design targeted curricula in pediatric pedagogy. The most current materials in voice science and voice pedagogy were reviewed and relevant findings connecting both fields of study delineated. In the field of voice science, research concerning the progression of the vocal mechanism from fetus through adolescence was evaluated to clarify physiological findings potentially relevant to voice teaching. Similarly, the practices of voice pedagogues were reviewed in order to ascertain whether those practices were research-based, observational, or suppositional. The results found in the amassed literature provided context for current thought in both fields.

New technological modalities provided the most current and authentic depiction of the pediatric laryngeal structure. These depictions applied pedagogically provide a point of justification for the anatomical scrutiny of the pediatric larynx. Research findings also contextualize the observational
assessments of voice pedagogues, which in turn substantiates the practical application voice science has in teaching. Additionally, studies have not only found that pediatric vocal mechanism is resilient, but also that it is suited to the vocal demands of childhood and adolescence. Finally, the physical *act of singing* is somatic in the normal pediatric vocal mechanism. However, tangential issues in the process of singing, physiological growth, and developmental factors impact *ability* and *capability* in the developing singer. The identification of synergistic connections provides both clarification of the anatomical development of the pediatric voice and contextualization of the resultant findings toward pedagogical application.
ACKNOWLEDGEMENTS

The completion of this document has been an endeavor accomplished with the support of family, faculty, and friends. This process combined both subject matter near and dear to my heart and years of teaching students of all ages, but most especially and affectionately the youngest developing singers — to use Welch’s term — from age one through adolescence. All of the children and young adults who it has been my privilege to teach have informed this research and are warmly thanked.

The University of Miami Frost School of Music is an amazing and eclectic place. There, all forms of music are studied and embraced offering each student the opportunity to expand and build upon knowledge in unexpected ways. I am extremely grateful to UM and its faculty, staff and administration, for the opportunity given me to pursue this degree.

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MFD 2012
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CHAPTER ONE

Introduction

Singing begins from the moment we are able to emit sound. Eminent otolaryngologist and voice researcher Robert T. Sataloff, has said that fetuses are able to initiate vocalizations in utero.\(^1\) Human beings first intone vocal melodies by echoing patterns of speech. Singing has the potential to be a lifetime capability; therefore, a life-long means of expression. Smith & Sataloff state that “lifelong singing begins with the development of good vocal habits at an early age.”\(^2\) The longevity inherent in the singing voice is reason to investigate the pursuit of vocal health.

Because of modern technological capabilities, children are exposed to many kinds of singing. Internet access provides children with opportunities to sing anything they like. DeVries noted in that “new media technology…and[s] a significant role in their engagement with music…they are aware of the way music is present in the world, both in and out of school.”\(^3\) When children sing, they naturally tend to imitate what they hear. Teaching children techniques designed for maintain vocal health will likely create a habit of healthy vocal behaviors.

Choral practitioners often possess pedagogical knowledge, and so strive to incorporate techniques designed to assess voices and keep voices healthy.

The pediatric voice and its machinations offer challenges to voice professionals

---

unlike those encountered when teaching the adult voice. Because most higher education programs tend not to offer classes in the anatomy and physiology of the pediatric voice, teachers and conductors feel uncertain when faced with training children.\textsuperscript{4} Some teachers will not working with children and adolescents, preferring to wait until after puberty to address the singing voice.\textsuperscript{5} However, recent scientific research in the developing pediatric larynx provides a framework pedagogues can access to design salient curricula for pediatric singers.

**Background of the Study**

Human beings communicate with their voices. Vocal communication is a facet of our innate *interactive-expressive* ability. Through this ability human beings process and integrate potential capability.\textsuperscript{6} Opportunities for singing seem ever-present in society. Children are exposed to innumerable examples of vocal production models prior to high school and college. As children become more socially active, social demands on the voice that are exceptional and can affect vocal health. Activities both in and out of school affect the voice. Loud music, long phone and skype conversations, crowds, traffic and the emotional outbursts of adolescence and teenage *angst* can cause abnormal phonation habits that may affect overall voice health.\textsuperscript{7}

\textsuperscript{7} Michael Fuchs, Sylvia Meurt, Susann Thiel, Roland, Täschner, Andreas Dietz, and Götz Gelbrich, "Influence of singing activity, age, and sex on voice performance parameters, on subjects' perception and use of their voice in childhood and adolescence," *Journal of Voice* 23, no. 2 (March 2009): 183.
As previously stated, singing is rooted in our innate human ability toward *interactive-expressivity*.\(^8\) Intoned melody, or speech, elicits the human association with bonding and “pleasant feeling-states,” which helps people recall responses to pleasure in order to survive and thrive.\(^9\) If singing evokes bonding and pleasure it will likely be an activity human beings will want to repeat. Therefore, it is likely that children who enjoy singing will want to continue singing throughout their lives. If they sing without the benefit of the guidance of a knowledgeable educator, they may develop poor vocal habits.

Considering the numbers of children that do sing, the need for educators to understanding of the idiosyncrasies inherent in the pediatric voice is clear. Pedagogues can create appropriate and informed guidance once the opportunity to examine current science is made easily accessible. According to Skelton, many training methods exist that are valuable, but the volume of research literature is difficult to assimilate.\(^{10}\) Delineating current research in pediatric voice science can acquaint voice pedagogues with evidentiary findings, thus informing their educational models.

Traditionally, voice teachers tend to refrain from offering private solo study to children prior to and during puberty. Additionally, there are teachers and practitioners who advocate the cessation of singing during adolescence.\(^{11}\) According to Skelton, insufficient consensus exists regarding how to approach the training of these singers because “most likely it is not the issue of teaching

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\(^8\) Thurman and Welch, vol. 3, 680.
\(^9\) Thurman and Welch, vol.3, 673.
\(^{10}\) Skelton, 537.
\(^{11}\) Skelton, 537.
children to sing itself that worries pedagogues, but rather how such instruction can proceed responsibly and effectively.” However, voice pedagogues can be successful in addressing the vocal health of young singers if they review current scientific findings that can aide in creating a viable pedagogical paradigm for children.

As stated previously, voice pedagogy students are typically trained using the adult laryngeal model and adult vocal expectations. This is likely because until recently, research in the field of pediatric voice science has been lacking. Recent findings in the pediatric laryngeal structure seem not to be incorporated into most voice pedagogy curricula. This is likely one reason why pedagogues tend not to teach students at this age. Also, the study of pediatric laryngeal morphology will extend an educator’s breadth of knowledge and form a foundational perspective from which to view the adult larynx.

Learning about the vocal stages of the larynx help pedagogues envision a continuum that reflects lifelong singing. Graham Welch, in discussing the developing child voice, proposes a sequential model for training young singers predicated on four developmental stages. He states, “singing skills are learned in a continuum of developmental behavior patterns…[these behavior patterns] suggest a developmental sequence in children’s singing...” for which a growing body of evidence exists. The idea that training singers is sequential and developmental can be extrapolated to encompass a paradigm for lifelong voice education.

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12 Skelton, 542.
health and form a comprehensive understanding of the vocal mechanism. This “lifelong vocal continuum” is a basis for the present study.

Need for the Study

This study delineated both historical aspects of voice science and voice pedagogy along with current literature to determine if tangential themes exit that may inform the training of the pediatric voice. Evidentiary research on the pediatric voice is in its nascency and is not likely to be readily available to pedagogues who train the child’s voice through adolescence.\(^\text{15}\) It is common to refer to the adult laryngeal structure and histology in order to address the child voice. However, technology is evolving that will likely “bridge the fields and to help answer some of the basic questions that are essential to both disciplines.”\(^\text{16}\)

By interpreting voice science research, an increasingly accurate assessment emerges regarding the pediatric larynx and its mutation during puberty. These assessments are used to identify emergent themes in the relationship of voice science and voice pedagogy. This is intended to provide insight into the development of the pediatric voice that could be useful to voice pedagogues. Professionals who train singers should strive to understand how the voice grows and develops. Whether training children or adults there are clear and evidentiary physiological differences.\(^\text{17}\) Knowledge of these differences will likely


\(^{16}\) Hartnick et al., 14.

\(^{17}\) Sataloff, 46.
result in “optimal training and minimal risk of vocal injury” to students of any age.\textsuperscript{18}

The study also provided data for comparison of the adult and pediatric larynges in order to illustrate differences in the morphology and histology of each. It also identified the characteristics of laryngeal mutation, as they are currently understood. This study discusses these findings to identify possible correlations between mutation events and observations of voice pedagogues.

\textit{Purpose of the Study}

The purpose of this study was to discover if synergy existed between the fields of voice science and voice pedagogy that could be extrapolated to inform the development of training approaches for the pediatric voice.

\textit{Research Questions}

Specific research questions addressed by this study included:

1. What are the developmental findings of the morphology of the pediatric larynx?

2. Are there findings to support differentiation in laryngeal structure by gender?

3. What are the physiological manifestations scientists and pedagogues observe in the pediatric voice?

In order to illustrate what studies have found regarding the pediatric larynx, an effort was made to delineate what is known about adult laryngeal structure through current voice science research and to differentiate the

\textsuperscript{18} Sataloff, 46.
characteristics of the adult larynx from the pediatric larynx. In regard to the pediatric voice, mutation and its influence on laryngeal development is seminal, as is gender differentiation. The physiological characteristics of the pediatric larynx may be observed not only on an anatomical level by voice scientists, but also by aural or technical representations observed by voice pedagogues. By defining commonalities between the works of voice scientists and the observations of voice teachers, an opportunity was provided to create synergy between the two fields.

**Delimitations**

For the purposes of this study, voice professionals who ascribe to specific nomenclature such as voice, vocal, or choral, were referred to collectively as pedagogues. Also, with the exception of research regarding history, voice science articles represented the most current findings. “Current findings” is defined as articles published from 1975 through March 2012. Lastly, though the research in this paper is extensive, it is not nor is it intended to be exhaustive.

**Method**

**Materials**

The materials in this study represented publications in two overarching fields of study: (1) voice science and (2) voice pedagogy. For the purposes of this study, *voice science* refers to the body of research findings regarding the anatomy and physiology of both the child and adult. Research in voice science included: historical perspectives regarding knowledge of the voice; the
development of voice science as a field of study; current research (1975-2012) in pediatric and adult laryngeal morphology and histology; differentiation by gender; and the beginnings and development of pediatric voice research. Several descriptive terms were employed to delineate pediatric voice science studies, including: embryonic, fetus, infant, prepubertal, pubertal, postpubertal, circumpubertal, pre-menarcheal, menarcheal, post-menarcheal, child, adolescent, and young adult. The hypothesis, procedures, data, and conclusions were identified for later application.

The second field examined was voice pedagogy. For the purposes of this study, voice pedagogy refers to an amalgamation of studies, strategies, methods, and techniques for the training of singers. The pedagogical approaches of voice teachers and choral professionals were surveyed. Pedagogues who were included in this study met the following criteria: they possessed a perceived knowledge and dedication to the training of either children or adults; they had experience with training the male voice, female voice, or both; and they possessed data based on scientific research or observational evidence.

Results

The results of findings contained within the amassed literature provided both context and perspective for identifying synergy in the fields of voice science and voice pedagogy. More specifically, the findings led to clarity in understanding the nascency of pediatric laryngology and its potential relationship to the field of voice pedagogy. From this perspective, conclusions regarding an informed and healthy approach to training the pediatric voice could be created. Delineating the
findings reported in the sciences and collating emergent themes with those considered analogous in voice training could inspire propagation of pedagogical strategies.
CHAPTER TWO

Review of Voice Science Literature

Pediatric laryngology is in its nascency and looks to its adult counterpart for much of its clinical underpinnings; however ... the tools exist potentially to bridge the fields and to help answer some of the basic questions that are essential to both disciplines.\(^{19}\) Hartnick, 2005

Introductory Remarks

This chapter will explore the scientific and analytical findings of researchers in the field of voice, specifically that of the pediatric voice. In this study, topics for consideration include but are not limited to: the anthropological background on the evolution of the vocal mechanism and development of the laryngeal structure; a historical overview of the origins of voice science; technological discoveries and advances in voice research; the nascency and emergence of research in the pediatric voice; and evidentiary studies in gender differentiation.

The purpose of this chapter is to provide historical perspective of voice research and delineate current scientific findings on laryngeal anatomy and physiology. Research in pediatric laryngology changes rapidly as new and less invasive methods of examining the structure of the childhood larynx is developed.\(^{20}\) Understanding the pediatric vocal mechanism will likely inform the pedagogical foundations of voice teachers, thereby strengthening their ability to

\(^{19}\) Hartnick et al., 14.
provide healthy instruction to young singers and information to avoid illness and injury.\textsuperscript{21}

For the purposes of this study, the following research questions were explored in order to assess and delineate research in voice science:

1. What are the developmental findings of the morphology of the pediatric larynx?
2. Are there findings to support differentiation in laryngeal structure by gender?
3. What are the physiological manifestations scientists and pedagogues observe in the pediatric voice?

Analyzing the preceding questions will guide the explorations of topical studies in representing the research findings and discerning their relevance toward pedagogical application.

\textit{Voice Science Literature}

\textit{Evolution of the Vocal Mechanism}

In order to accurately conceptualize the potential vocalizations that can be emitted from the human larynx, the development of speech must be considered. Speech can be studied independently of language. Two prerequisites are necessary for modern human speech abilities: (1) modification of vocal tract morphology, and (2) development of vocal imitative ability.\textsuperscript{22}

Since the human ability to phonate, resonate, and articulate sound applies both to singing and speech, there is an intrinsic relationship between the two actions. Miller described the relationship between singing and speech as a "major tenet" of the Italian national school of singing. Proponents of this school advocate the dictums, si canta come si parla (one sings as one speaks) and chi pronuncia bene canta bene (he who enunciates well sings well). Rinta & Welch found that, in prepubertal children, how the voice is used for speaking and singing is a continuum rather than two distinct behaviors.

The ability to speak is a function that separates human beings from other creatures on the planet. The primary function of the larynx is as a sphincter that serves to protect the respiratory system from foreign objects entering the lungs. V. E. Negus, a pioneer in laryngeal evolution who published his findings in 1949, stated that while there is no biological need for song or speech, the larynx is uniquely conducive to phonation. This is likely why D. Ralph Appleman refers to the larynx as a "biological-biosocial organ." Social and cultural factors exist among human beings that necessitate communication.

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24 Miller, 5.
25 Rinta and Welch, 677.
27 Negus, 516.
29 Negus, 516.
Miller described primates and other mammals as having larynges that are situated high in the neck, accompanied by a shortened pharynx.\textsuperscript{30} This resulted in a short vocal tract. The short vocal tract in animals makes speech physiologically impossible. Reby & McComb in their studies on vocal communication in deer identified more specifically that the laryngeal structure in herbivores is restricted in movement by a “short and tough” membrane that connects the thyroid cartilage and the hyoid bone.\textsuperscript{31} The thyrohyoid membrane in humans is longer and more flexible. Since, this in not the case in animals, vocalization is limited by restricted laryngeal movement in combination with less vocal tract space.\textsuperscript{32} However, due to the hormonal influx during mating, the thyrohyoid muscle becomes more flexible allowing the sternohyoid muscles, those that pull the laryngeal structure toward the sternum to contract. The larynx then descends further down the neck, elongating the vocal tract. The descent of the larynx toward the sternum allows enough acoustically resonant space for the stag to emit long vocalizations or “roars” akin to human singing.\textsuperscript{33}

The acquisition of a low larynx is unique to humans among the primates. Its descent out of the range of the oropharynx further into the neck is necessary for sufficient vocalic space required for speech.\textsuperscript{34} J. Abitbol, P. Abitbol, and B.

\textsuperscript{30} Miller, 1.
\textsuperscript{32} Reby and McComb, 244.
\textsuperscript{33} Reby and McComb, 244.
\textsuperscript{34} Reby and McComb, 256.
Abitbol asserted that it was the development of upright stance and bipedal locomotion that allowed the larynx, as we know it today, to develop.\textsuperscript{35}

Figure 1 depicts a comparison of the vocal tract of a contemporary human male and his hominid ancestor. Differences in vocal tract length are evidenced in both the distance between the end of the soft palate in the pharynx and the level of the vocal folds within the laryngeal structure. Evolution has caused the oral cavity of humans to shorten compared with that of our hominid ancestors and modern relative primates. In addition, the human larynx has settled in a lower position that requires an elongation of the neck as well as the pharynx within the vocal tract. This evolutionary development allows for flexibility of the tongue and a resonating cavity suited for the vocalic intonations required for speech and song.\textsuperscript{36}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Vocal tract changes in hominid evolution.\textsuperscript{37}}
\end{figure}

\textsuperscript{36} Negus, 517.
Miller referred to the findings of Leiberman & Crelin, who in 1971 first postulated that Neanderthals did not have the possibility for speech due to shorten vocal tract length, in his description of the presupposed limitations of the pre-*Homo sapien* vocal tract. The shape of the Neanderthal vocal tract could only have allowed for limited vowel formation. The restricted pharyngeal space would have likely resulted in nasal vocalizations.

There is ongoing debate within the scientific community regarding precisely at what point in their evolutionary development hominids could produce “fully modern speech.” However, the distinction between humans and primates is clear: humans alone possess the structure for the phonatory requirements of speech. According to Miller, human beings are “ideally constructed for phonation...the human larynx performs linguistic feats not available to any other creature on the planet.”

**Basic Laryngeal Structure**

Succinctly defined, the ability to phonate is a combination of the physical actions of the adduction (closing) of the vocal folds and respiration (the incitation of airflow through the vocal folds). In order to compare and contrast the pediatric larynx with that of the adult larynx, knowledge of the basic adult laryngeal structure is required. Miller described the larynx as “tripartite” (consisting of three parts), forming one anatomical unit. The tripartite unit

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39 Miller, 3.
40 Miller, 4.
41 Miller, 1.
42 Miller, 2.
identified by Miller included: the tongue, the hyoid bone, and the laryngeal structure. Appleman, who predated Miller, described the structure of the larynx proper as framework of cartilages: the epiglottis, the thyroid cartilage, the cricoid cartilage and the paired arytenoid cartilages.

Laryngeal cartilages

The epiglottis (Fig. 2), a thin leaf-shaped cartilage, is attached to the thyroid cartilage. The thyroid (which means shield) cartilage (Fig.3) is the most prominent and identifiable element in the framework of the larynx. The thyroid cartilage rests on top of the cricoid cartilage (Fig. 4). The cricoid cartilage is shaped like a signet ring with the largest portion seated posteriorly in the structure and articulated atop the trachea. There are two paired cartilages, the arytenoid cartilages (See Fig. 5), which sit on the posterior prominence of the cricoid cartilage. They are two small pyramid-shaped cartilages with triangular bases.

The cartilages of the larynx form a framework for the muscles, nerves, blood vessels and tissues that surround it. The larynx itself has the flexibility to move up and down in the neck in order to perform both life-sustaining functions, such as swallowing, and phonation. Noted voice scientist, Ingo Titze, discussed the reason for the cartilaginous morphology of the larynx as a requirement for mobility. The facility required in the laryngeal structure would preclude any rigid body attachments to the skeleton. Mobility necessitated that the majority of the

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43 Miller, 3.
44 Appleman, 44-45.
Figure 2. Sagittal view of laryngeal cartilages with featuring the epiglottis.  

Figure 3. Sagittal view of the thyroid cartilage.

47 “Anatomy of the Larynx,” Thyroid Cartilage.
Figure 4. Cricoid cartilage (A) anterior view (B) posterior face.\textsuperscript{48}

Figure 5. Arytenoid cartilages alone and situated on the posterior process of the cricoid cartilage.\textsuperscript{49}

\textsuperscript{48} “Anatomy of the Larynx," Cricoid Cartilage.

\textsuperscript{49} “Anatomy of the Larynx," Arytenoid Cartilages.
framework of the larynx be cartilage. Only one bone, the hyoid bone, is in the vicinity of the larynx, but even this bone is not articulated to the skeleton. It is important to note the thyroid cartilage. In addition to being the largest single structure in the laryngeal framework, it is the cartilage that offers a visible, evidentiary glimpse of vocal mutation in the pediatric voice. In the adult male, the thyroid cartilage is visible in the neck at the laryngeal prominence or Adam’s apple. This prominence is formed at the midline of the thyroid cartilage creating a protrusion in the neck depending upon its angular acuity. In adults, this angle can range from 90° to 120° on average. The variance in the angle plays a critical role in differentiating not only age, but also gender.

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51 Titze, 4.
52 Titze, 6.
In discussing the basic anatomy and physiology of the larynx, Sataloff described four anatomical units: skeleton, mucosa, intrinsic muscles, and extrinsic muscles.\textsuperscript{53} In his statements regarding the critical elements of the laryngeal skeleton, he identified the thyroid, cricoid and arytenoid cartilages, and omitted the epiglottis as a prominent part of the structure.

The intrinsic musculature of the larynx includes those muscles responsible for the movement of the larynx itself. The muscles do not move the larynx up and down in the neck, but rather they allow the cartilages to pivot and react to each other. The muscles are named so as to illustrate their interdependent relationships. The paired thyroarytenoid muscles extend from the vocal process of the arytenoid cartilages to the lamina of the interior face of the thyroid cartilage, just below the laryngeal prominence (see Fig. 7). The thyroarytenoid muscles are also known as the vocalis.\textsuperscript{54}

The laryngeal mucosa (membrane layer) is the layer or layers that cover the muscles. In the larynx, they are stratified (multi-layered) and squamous (scaly) sometimes containing collagen and elastic fibers. The complex anatomical structure allows the movement within and around the larynx to be facile and reflexive. Intricacy in structure in combination with finessed response enables singers to exhort the vocal folds into expressivity and phonatory beauty.\textsuperscript{55}

\textsuperscript{54} Sataloff, 5.
\textsuperscript{55} Sataloff, 5.
Historical Overview of Medical Voice Literature

In 1989, David S. Cooper, published a four-part series that illustrated a historical perspective of voice science. It is an overview that traced the origins of voice science back to the Age of Enlightenment. For example, the notebooks of Leonardo da Vinci contained his observations on the larynx. Da Vinci was interested in the fluidity of its machinations and the vibratory aspects of voice production.57

It is justified that interest exists in determining the relationship between vocal fold modulation and principles of velocity exists. Daniel Bernoulli (1700-1782) was interested in the subject of hydrodynamics. He was originally trained as a doctor; eventually he became a noted mathematician turned physicist whose work led to the publication of a treatise on hydraulics in 1738. The genesis of this treatise can be traced back to his interest in respiration, which was the

56 “Thyroarytenoid Muscle:
subject of his medical dissertation. Bernoulli’s premise lay in the physical
c principle that static pressure and dynamic pressure impact the fluidity of flow
through a tube. ⁵⁸ In other words, when the velocity of a fluid increases, the
pressure exerted by the fluid decreases.

In the following diagram (see Fig. 8), this principle or effect is illustrated. As
air is blown across the sheet of paper, the air friction causes the pressure
exerted by that paper’s own weight to decrease, allowing the paper rise. This
aerodynamic principle also applies to flight.

![Figure 8. The Bernoulli Effect. Faster moving air creates lower pressure.⁵⁹](image)

Bernoulli’s principle was thought to apply directly to vocal fold vibration.
William Vennard was ostensibly one of the first voice pedagogues to become
interested in understanding the science of the voice. He declared this principle to
be complicit in phonation. ⁶⁰ Since the subglottal region of the larynx is conical, he
surmised that a decrease in pressure occurred when air flowed through, drawing
the vocal folds together. He stated, “…there is a narrowing of the air passage

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⁵⁸ Cooper, 2.
sufficient for the Bernoulli Effect to draw the, [the vocal folds] together…the Bernoulli Effect sucks them into vibration."\(^{61}\)

The Bernoulli Effect was the initial paradigm for understanding how the vocal folds vibrate. However, as studies in aerodynamics and phonatory physiology progressed, restrictions in Bernoulli’s concept became evident. According to Titze, these restrictions made the Bernoulli Effect “overstated.”\(^{62}\)

Regarding recent research in the vibratory function of the vocal folds, Titze explained that it is the “interactions of fluid flow and tissue movement” that cause the repetitive action that open and close the vocal folds.\(^{63}\)

Though supposition existed in the 19\(^{th}\) century, regarding the phonatory oscillation of the vocal folds, significant work by physicists and voice scientists in this area was not published until the 20\(^{th}\) century. Among those studying phonation and acoustics were Tonndorf, Van den Berg, Fant, Flanagan & Langraf, Hollien & Mitchell, Hirano, Ishizaka & Matsudaira, Sunberg, Goldstein, Fletcher, Elliott & Bowsher. These scientists and many others formed the field of contemporary voice science.\(^{64, 65}\)

In the 1990s, the field of voice erupted with scientists throughout the world specializing in newly explored fields of study including; vowel spectrum analysis, spectography of vocal harmonics and frequencies, and vocal tract wave interactions. As technological advances continue, the field of voice science

\(^{61}\) Vennard, 41.  
\(^{62}\) Titze, 72.  
\(^{63}\) Titze, 70-74.  
\(^{64}\) Copper, 1-2.  
broadens and evolves into an increasingly active and multi-faceted area of study.\textsuperscript{66}

\textit{Initial Studies in Pediatric Laryngology}

Studies on the childhood larynx have advanced at a significantly slower rate than the research on the adult larynx. According to Thibeault,

…there is a paucity of literature specific to pediatric vocal fold science. Research specific to the pediatric vocal fold and its development has lagged behind that regarding the adult vocal fold.\textsuperscript{67}

This is likely due to the invasive nature of procedures used to observe laryngeal function.

Kahane was an early proponent of obtaining authoritative data on pediatric laryngeal morphology; his work is repeatedly cited in the research of current voice scientists. According to Kahane, “few quantitative studies have been reported on the morphology of the circumpubertal larynx.”\textsuperscript{68} In order to obtain the desired objective measurements of the circumpubertal laryngeal structure, Kahane measured the cadaveric larynges of ten female and ten male Caucasian subjects aged 9 to 18 years. The data collection illustrated morphological differences in development as the subjects progressed in age. He discovered that while the prepubertal and postpubertal female larynges were similar in size and weight, this was not the case with males. He also observed that the male

\textsuperscript{66} Wolfe at al.
thyroid cartilage both grew significantly and shifted angle during puberty causing noticeable observance of dimorphism between the sexes. The significant growth in the thyroid cartilage in males tended to result in an increase in vocal fold length that was more than twice that in females.  

Areas of discrimination in the Kahane study included size of the individual cartilages, mass of the laryngeal structure, and total vocal fold length, all of which held variations that suggested results dependent upon the circumpubertal state of the specimen. For example, a notable discrepancy was found in the weights of the prepubertal and pubescent larynges. This finding indicated that onset of cartilage ossification in the older pediatric larynx impacted the weight of the structure though significant size differences had not occurred (see Fig. 10).

Although his study examined a small sample of people, Kahane’s study was the largest of its kind at that time. Kahane’s initial studies predated Ingo Titze’s work on the angle of the thyroid lamina discussed previously in this chapter; Kahane’s findings are similar. Notably, no remarkable difference in vocal fold length was evident in prepubescent children. Additionally, Kahane found that in the prepubescent larynx of both sexes, both cartilage and muscle was relative in size to that of the adult female larynx. This observation could be informative for voice pedagogues.

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69 Kahane, 11.
70 Kahane, 17.
71 Kahane, 18.
Figure 9. Kahane’s diagrams of the adolescent larynx. Differentiation in laryngeal sizes between prepubertal and pubertal male and female larynges.

Key: prepubertal male - - -; prepubertal female - · ·; pubertal male — -; pubertal female –x–.  

Development of the Laryngoscopy

The ability to study the larynx and specifics of its morphology is relatively new technology. Tracheal intubation has been used in surgery for over 100

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72 Kahane,13.
years. Though this advance in creating airway access was helpful in saving lives, the procedure was originally “performed blind using the fingers to palpate [examine by touch] the laryngeal inlet and guide the tube into the trachea.” This life-saving procedure led to the development of a serviceable method for viewing vocal folds. The laryngoscope offered doctors and scientists options for viewing the larynx for diagnostic purposes. This method was invasive and likely too cumbersome to be used on children in order to view the pediatric larynx in vivo. Until developments in laryngoscopic technology advanced, evidentiary findings in the morphology and histology of the pediatric larynx were gained through cadaveric studies.

The Advent of the Contemporary Laryngoscope

In 1941, Robert Miller invented the rigid laryngoscope, or Miller blade, which offered better access to the site of surgical intubation. Sir Robert Macintosh developed the curved version two years later. These two laryngoscope models were considered “state-of-the-art” in viewing the airway for nearly 50 years.

The first laryngoscopes were “essentially metal spatulas with a light bulb on the tip. The blade lifted the tongue out of the way, and the light bulb illuminated the glottic [the vocal folds and the opening between] structures.” The figures below (see Figs. 10-12), illustrate current versions of both the Miller and Macintosh blades and the method for their use in viewing the vocal folds for intubation.

74 Sakles and Rodgers, 1.
75 Sakles and Rodgers, 1.
Figure 10. Contemporary Miller laryngoscope blade.\textsuperscript{76}

Figure 11. Contemporary Macintosh laryngoscope blade.\textsuperscript{77}

Figure 12. Proper use of Miller blade laryngoscope.\textsuperscript{78}


\textsuperscript{77} Laryngoscope Blade Sales, Macintosh Laryngoscope Flexitip Blade.
The first means by which the vocal folds were viewed for evaluative purposes was by the mirror, which was much like that found in a contemporary dental office (see Figs. 13 and 14).\textsuperscript{79} This step is often the first measure in assessing pathology. The use of the dental mirror to view the larynx is often attributed to the Spanish voice teacher Manuel Garcia (1805-1906). Garcia gave an extensive presentation on the subject in 1854, claiming to have used the mirror to view his own larynx.\textsuperscript{80}

However, there were other physicians on the European continent whose concept predated Garcia’s by nearly 50 years. In 1805, German physician, Bozzini invented a speculum called “the light conductor, or a simple apparatus for

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\textsuperscript{78} Laryngoscope Blade Sales, Trueview Optical View Laryngoscope.
\textsuperscript{79} John C. Sakles and Ross B. Rodgers, "Advances in airway imaging."
the illumination of the internal cavities and spaces in the living animal body. He also published an account of its use and his method of reflecting light down the speculum with candlelight.

Other scientists and laryngologists who experimented with devices for viewing the larynx included: Babington, Leveret, Türck, Czermack. Whether Türck or Czermack was they first to view the living larynx is contested.

Czermack used a mirror that reflected light into the oral cavity in order to glimpse a view of the live larynx with a mirror for diagnostic purposes (see Fig. 15).

Figure 15. Czermack examining a subject using the light-concentrating mirror.

Babington developed an instrument in 1829 that he called a “glottiscope.” The glottiscope would have been used in a similar manner to that of Czermack (see Fig. 16). In order to view the glottis (the space between the vocal folds)

83 Jahn and Blitzer, 181.
84 Jahn and Blitzer, 182.
85 Jahn and Blitzer, 182.
Babington retracted the tongue with a spatula. This technique and those similar tended not to be adopted as general practice due to patient intolerance.\textsuperscript{86}

Numerous speculative apparatuses followed until the time of Miller and Macintosh. An apparatus designed by Avery in 1844, was predicated on the design of the miner’s hat and Bozzini and Czermack’s speculums (see Fig. 16).

One of the more unusual constructions was that of the suspension laryngoscope invented by Gustav Killian in 1919 (see Fig. 17). Killian’s apparatus, particularly when compared with Czermack’s (Fig. 15) and

\begin{figure}[h]
\centering
\includegraphics[scale=0.5]{AveryLaryngoscope.png}
\caption{Avery’s candlelight-reflecting headgear and laryngoscope pairing.\textsuperscript{87}}
\end{figure}

\textsuperscript{86} James B. Snow, Phillip A. Wackym, and John Jacob Ballenger, \textit{Ballenger’s Otorhinolaryngology: Head and Neck Surgery}. (Shelton, CT: People’s Medical Pub. House/B C Decker, 2009), 83.
\textsuperscript{87} Jahn and Blitzer, 182.
Avery’s (Fig. 16), was likely one of the more invasive introduced to the scientific community. Although it may have offered the best opportunity for a physician to view the larynx, the awkward posture endured by the patient made Killian’s apparatus impractical.

Ultimately, a combined instrument that provided both illumination and magnification was required. The invention of the fiberoptic laryngoscope, involved the attachment of a tiny light bulb to the laryngoscope of the Miller or Macintosh speculum in the 1940s. This was preferred and advocated by voice scientists such as Negus.\textsuperscript{89} Observing the type of instrumentation available to view the living larynx \textit{(in vivo) }; Killian’s suspension laryngoscopy and gallows, Babbington’s lighted speculum with metal tongue retractor, and the rigid Miller

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{figure17.png}
\caption{Killian performing a suspension laryngoscopy. The patient’s head is suspended by attaching the laryngoscope to the gallows.\textsuperscript{88}}
\end{figure}

\textsuperscript{88} Jahn and Blitzer, 183.
\textsuperscript{89} Jahn and Blitzer, 183.
and Macintosh speculum’s designed for the adult transoral (through the mouth) cavity, avoiding studies in pediatric laryngeal structure seems warranted.

Developments in Technology for Vocal Fold Research

Fiberoptic Laryngoscopy

In the 1980s, fiberoptic intubation was popularized. Fiberoptic techniques transfer images and light along flexible glass fibers. Advances in technology allowed a tiny camera to be incorporated into the end of the flexible scope, allowing the larynx to be indirectly viewed. There are two types of fiberoptic laryngoscopies. The type of speculum used to perform the procedure delineates them: rigid or flexible. The rigid speculum or “rod-lens telescope” is also called the "rigid transoral endoscope." The flexible speculum is known as the flexible fiberoptic laryngoscope. By the 1990s, the latter was also equipped with a videoendoscopes or a lighted instrument with videographic capability by the 1990s. This allowed for the patient not only to see his or her own larynx, but for the ability to record and preserve visual documentation of a healthy or a pathological larynx (see Figs. 18 and 19).

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91 Snow et al., 957.
92 Snow et al., 959.
94 Doyle, S167.
Figure 18. Transoral placement of the rod-lens telescopic laryngoscope.\textsuperscript{95}

Figure 19. Flexible fiberscope passed through the nasopharynx, oropharynx, and hypopharynx. Also an endoscope, it is passed along the posterior wall of the pharynx to view laryngeal function during phonation.\textsuperscript{96}

Both the rigid and flexible laryngoscopies require topical anesthetization, which is helpful with patient tolerance. Both are used in the offices of

\textsuperscript{95} Snow et al., 960.

\textsuperscript{96} Snow et al., 960.
contemporary otolaryngologists; however, while the flexible scope may be more tolerable, the rigid scope has better resolution (see Figs. 20 and 21).\textsuperscript{97}

Figure 20. \textit{Left.} A flexible fiberoptiscope view of the vocal folds. \textit{Right.} The same vocal folds seen through a rigid transoral endoscope.\textsuperscript{98}

Figure 21. Normal cycle of the vocal folds from abduction to adduction through videolaryngoscopy.\textsuperscript{99}

Saiïto introduced fiberoptic technology in Japan in 1973. He used a fiberoptic bronchoscope to look at the vocal folds by passing it through the nose."\textsuperscript{100} The

\textsuperscript{97} Lucian, Flexible Fiberoptic Laryngoscopy.
\textsuperscript{98} Lucian, Flexible Fiberoptic Laryngoscopy.
\textsuperscript{99} Abitbol et al., 428.
advent of this less invasive procedure emboldened scientists to begin to observe the living pediatric larynx, since the scope can be manufactured as small as 4mm in width.\textsuperscript{101} Abitbol et al. advance this modality by developing an evaluative process they called “dynamic vocal exploration.”\textsuperscript{102} This process allowed for the observation of the vocal folds while the subject was singing or speaking, by means of utilizing emerging videographic technologies.

In 1982, Tetsuzo Inouye presented a paper at the \textit{Third International Conference in Paediatric Otolaryngology} that detailed the use of the flexible fiberoptic laryngoscope on the child larynx in the treatment of laryngeal dysfunction.\textsuperscript{103} In his paper, Inouye referenced three types of fiberoptic laryngoscopes and the possibility of their use with children from infancy through adolescence. At the conference, he introduced the international community to the technique he employed for scoping children. Inouye stated that flexible fiberoptiscopes has been used in children “for the past few years,” making him one of earliest scientists to use it and report findings on that usage.\textsuperscript{104} Additionally, the summation of his research regarding this technology as an appropriate modality for children is illustrated in Table 1. Inouye’s concluding statements on the efficacy of these instruments for use on children yielded

\textsuperscript{100} Abitbol et al., 427.
\textsuperscript{101} Lucian, Flexible Fiberoptic Laryngoscopy.
\textsuperscript{102} Abitbol et al, 427.
\textsuperscript{104} Inouye, 322.
positive results. He felt that the flexible scope, in particular, was easily handled and well-tolerated with cooperation from the children having been excellent.\textsuperscript{105}

\textit{Video Imagining and Sonography}

"Research and science in the field of laryngology is at an exciting point in its evolution."\textsuperscript{106} Developments in video imaging and sonographic examination have made it possible to examine and assess prenatal patterns of growth in the fetus. Results of continuing research of the structure of the pediatric larynx have focused on the histology (microscopic structure of the tissue) of the vocal fold.

\textbf{Table 1. Inouye’s findings regarding rigid and flexible laryngoscope}\textsuperscript{107}

\begin{center}
\begin{tabular}{|l|l|l|}
\hline
\textbf{ADVANTAGES AND DISADVANTAGES OF RIGID LARYNGOSCOPE AND FIBEROPTIC LARYNGOSCOPE} & \textbf{Rigid laryngoscope} & \textbf{Fiberoptic laryngoscope} \\
\hline
Handling & difficult & easy \\
Complications & often & rare \\
Resolving power & clear & more to be investigated \\
Photography & excellent & good \\
Removal of foreign body & possible in every case & limited to certain cases \\
Biopsy & possible in every case & possible to a certain extent \\
Discomfort & much & little \\
Observations & clear & clear \\
Ventilation & good & good \\
Intervention possibility & possible in almost every case & limited mainly to Type C \\
\hline
\end{tabular}
\end{center}

itself. A consensus of opinion indicated that vocal folds of a newborn infant are encompassed single-layered structure. As the child ages, there is evidence of a

\textsuperscript{105} Inouye, 323.
\textsuperscript{107} Inouye, 323.
second cellular layer developing by as early as five months. The vocal ligament is the short band of tough connective tissue found in the intermediate and deep tissue of the lamina propria. Throughout childhood the vocal ligament is a monolayer membrane. Around pubertal onset, it begins transforms to its bi-layered adult form.\textsuperscript{108}

The ultrasound is an accepted diagnostic and evaluative modality for assessing the laryngeal structure of children.\textsuperscript{109} In 1991, Garel, Contencin, Polonovski, Hassan, and Nary considered it “new technology.”\textsuperscript{110} Their conclusions stated that it was a non-invasive modality that did not require sedation and produced easily replicable results. They concluded that this method of imaging the larynx was practical regardless of patient age.\textsuperscript{111}

While the ultrasound is a means of assessing growth in embryonic development and morphometric characteristics, the majority of available research lies in studies using cadavers. To research the vocal fold length in human fetuses, Cicecibasi, Keles, and Uyar, studied 40 spontaneously aborted fetuses. These fetuses were from both the second and third trimesters and had no apparent malformations.\textsuperscript{112} There were 25 male and 15 female fetuses assessed for the mean average of both the vocal folds and the cartilaginous structures of

\textsuperscript{111} Garel et al., 110.
the larynx (see Table 2). The findings were differentiated by gender. Notably, both the left and right vocal folds were consistently the same length: male fetus = 2.22mm ± 0.47; female fetus = 2.14 ± 0.38. Though vocal length was slightly greater in males, Cicekcibasi et al. commented that this result was not significant statistically.\textsuperscript{113}

Table 2. Data illustrating comparison in mean vocal fold length in fetuses\textsuperscript{114}

<table>
<thead>
<tr>
<th>Vocal Fold = VC</th>
<th>Second Trimester (Length in Millimeters)</th>
<th>Third Trimester (Length in Millimeters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male Mean ± Standard Deviation</td>
<td>Female Mean ± Standard Deviation</td>
</tr>
<tr>
<td>VC- right</td>
<td>1.87 ± 0.24</td>
<td>2.00 ± 0.44</td>
</tr>
<tr>
<td>VC- left</td>
<td>1.87 ± 0.24</td>
<td>2.00 ± 0.44</td>
</tr>
</tbody>
</table>

Source: Data adapted from Cicekcibasi et al, 2008.

While evidentiary insights can be gained by observing the living pediatric laryngeal structure, dissection analysis provides conclusions that may be more exhaustive. Hans Edmund Eckel, Juergen Koebke, and Claus Pototschnig developed a technique for dissection that they believe elucidates findings.\textsuperscript{115}

In Eckel et al.’s study, 43 excised cadaverous, pediatric larynges from babies aged 1 to 60 months old were sliced vertically with a diamond band saw and subjected to investigation through computer-assisted technology. This technique is called \textit{plasitination}. “Plastinated whole organ serial sections”

\textsuperscript{113} Cicekcibasi et al., 687.
\textsuperscript{114} Cicekcibasi et al., 687.
produced the most accurate histological description yet observed.\textsuperscript{116} Plastination of the cadaveric tissue provided a valuable method of tissue preservation for the researchers. The larynges were dehydrated, deep-frozen, sliced into 4mm sections, and painted with an epoxy resin; a sheet of a whole organ section was produced. The researchers were then able to investigate whole-organ sections histologically with definitive results.\textsuperscript{117}

Eckel et al. found that the subglottal airway grew rapidly between 0-24 months and then stabilized. Additionally, they found that there was no sexual dimorphism between the larynges of these children. The idea that the pre-pubescent children show no difference in morphology is important. Through morphometric analysis, Eckel et al. determined that the infant larynx is not simply a miniature of the adult larynx. In fact, “it [the infant larynx] shows differences in its position relative to the vertebral column, in the composition of cartilages and soft tissues, and in environmental adaptation.”\textsuperscript{118}

\textit{Innovation in “in vivo” and Noninvasive Histological Evaluation}

Technology has illuminated what scientists know about the human vocal fold. Evolving technology will soon likely allow scientists and otolaryngologists to view the live larynx in terms of the superficial layers of the \textit{lamina propria} in cogent ways. A recent technological advance, optical coherence tomography (OCT), introduced by Huang, Swanson, Lin, Schuman, Stinson, and Chang to

\begin{footnotesize}
\textsuperscript{116} Eckel et al., 232.
\textsuperscript{118} Eckel et al., 235.
\end{footnotesize}
the scientific community as a “noninvasive cross-sectional imaging in biological systems.” Though OCT was introduced in 1991, most of its application has been undertaken in the field of ophthalmology. According to Susan L. Thibeault, OCT is an imaging modality using infrared light through tissue and reflects a vertical cross-section of histological results. OCT is relatively new as an evaluative tool in otolaryngology and it provides a deep tissue analysis at high resolution.

An early article on the efficacy of the use of OCT for histological surveys of the larynx appeared in 1999. Rubinstein, Schalch, DiSilvio, Betancourt, and Wong found that although OCT is able to achieve high resolution, the level of visual penetration in most tissues is 2mm. Currently, OCT is most useful in identifying anomalous pathologies in the laryngeal membranes (see Fig. 22). OCT provides real-time imaging in which "single layers of the vocal folds could be distinguished from each other." This modality provides a non-invasive option for viewing internal layers of the live vocal fold. As the technology progresses, a multitude of applications could evolve.

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120 Susan L. Thibeault, "Emerging Science Regarding the Human Vocal Fold," in Pediatric Voice Disorders: Diagnosis and Treatment, by Christopher J. Hartnick and Mark Boseley (San Diego, CA: Plural Pub., 2008), 16.
121 Thibeault, 16.
124 Thibeault, 18.
Figures 23 and 24 illustrate a cavernous cross-section of the lamina propria and its layers, while Figure 25 offers a similar view, \textit{in vivo}, via OCT imaging.\textsuperscript{125}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure22.png}
\caption{A. Optical coherence tomography (OCT) of normal vocal fold histology. BM indicates basal membrane [superficial layer of lamina propria or Reineke's space]\textsuperscript{126}; LP, lamina propria; SSE, stratified squamous epithelium. B. OCT of the vocal cords showing normal anatomy.\textsuperscript{127}}
\end{figure}

\textsuperscript{125} Luersen et al., 186.
\textsuperscript{126} K. Luersen et al., 185.
\textsuperscript{127} Rubenstein et al, 359.
Figure 23. Histological section of the human vocal fold. The thickness of the lamina propria mucosae is approximately 1mm.  

Figure 24. Histological cross-section of Lamina propria. (1 = epithelium, 2 = lamina propria mucosa).

Figure 25. OCT image of lamina propria.

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\(^{128}\) Luersen et al., 186.
According to Leuin, Suter, Desjardins, Vakoc, Bouma, and Tearney, a team of American and Canadian researchers lead by eminent pediatric voice scientists Hartnick and Boudoux, “most of our current understanding of pediatric vocal fold structure is extrapolated from studies of adult vocal folds.” The team presented findings on visualization of the pediatric vocal folds in vivo. OTC enabled them to achieve a large field of view and tissue depth. Evaluation of lamina propria revealed a three-dimensional, multi-layered structure that was comprehensive.

Boudoux et al. stated that this technology was useful when compared with previous cadaveric histological studies. However, the equipment requires a small probe that was difficult for children to tolerate while awake. Children needed general anesthesia and an operating room in order to be assessed, rendering the procedure impractical. The authors concluded that, while the ability to view the vocal folds in vivo via microscopic imaging is possible, its practical use in children is limited due to its current level of development, lack of resolution clarity, and difficulty of administration.

131 Boudoux et al., 269.
132 Boudoux et al., 275.
133 Boudoux et al., 275.
Histology of the Adult Vocal Fold

In 1975, Hirano introduced the most recent and currently accepted microanatomy of the human vocal folds.\textsuperscript{134} Having identified three discernable layers in the lamina propria, he labeled them; superficial, intermediate, and deep thus defining the structure of the human vocal fold as \textit{trilaminar} (see Fig. 25).\textsuperscript{135}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure25}
\caption{Hirano's 1984 depiction of the layered structure of the human vocal fold, including identification of the "transition zone."\textsuperscript{136, 137}}
\end{figure}

The characterization of the layers initially defined by Hirano has been a subject of “controversy” in the voice science community.\textsuperscript{138} This is because

\textsuperscript{135} Hartnick and Boseley, 7.
\textsuperscript{137} Hartnick et al., 6.
subsequent research on vocal fold histology has led to differing opinions on the distinction of each layer and the descriptive nomenclature. Figure 26 illustrates an accepted and alternate method of labeling the vocal fold layers that is congruent with that of Titze.\(^\text{139}\)

![Figure 26. Vocal fold section from the British Voice Association.\(^{140}\)](image)

To clarify the differentiation, Titze created a table (see Fig. 27) that offers a recommended schema for vocal fold histology. The intermediate and deep layers of the *lamina propria*, those comprised predominantly of elastin fibers, protein and collagen, form the vocal ligament. The vocal ligament and the thyroarytenoid muscle (vocalis) together form the body of the vocal folds. The superficial layer of *lamina propria* and the epithelium form the mucosa.\(^\text{141}\)

According to Titze, the purpose of the tri-layer *lamina propria* is for resilience. It

\(^{139}\) Titze, 17.
\(^{141}\) Titze, 18.
responds to impact like a “balloon filled with water.”\textsuperscript{142} The mucosal layers encapsulate the internal ligament and muscle providing the necessary pliancy for the vocal folds to function.

Figure 27. Titze’s schema for the layered vocal folds structure.\textsuperscript{143}

**Table 3. Recreation of Hartnick et al.’s comparison of schema for the lamina propria**\textsuperscript{144}

<table>
<thead>
<tr>
<th>Different Systems of Defining the Cover/Body of the Lamina Propria of the Vocal Fold</th>
<th>COVER</th>
<th>BODY</th>
<th>TRANSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hirano</strong></td>
<td>Epithelium, SLP</td>
<td>Vocalis Muscle</td>
<td>MLP, DLP*</td>
</tr>
<tr>
<td><strong>Titze</strong></td>
<td>Epithelium, SLP, MLP</td>
<td>DLP, Vocalis muscle</td>
<td></td>
</tr>
<tr>
<td><strong>Hammond</strong></td>
<td>Epithelium, SLP, MLP</td>
<td>MLP, DLP Vocalis Muscle</td>
<td></td>
</tr>
<tr>
<td><strong>Dikkers</strong></td>
<td>Epithelium, SLP</td>
<td>Conus elasticus, Vocalis muscle</td>
<td></td>
</tr>
</tbody>
</table>

Varying descriptions and definitions of the layers structure of the human vocal fold as seen in published English literature.

SLP = superficial layer of the lamina propria; MLP = middle layer of the lamina propria; DLP = deep layer of the lamina propria

**Source:** Data adapted from Hartnick et al, 2005.

*Hirano’s “transition zone”\textsuperscript{145} as illustrated in his depiction of the lamina propria. (Fig. 26)

\textsuperscript{142} Titze, 37.

\textsuperscript{143} Titze, 18.

\textsuperscript{144} Hartnick et al., 7.

\textsuperscript{145} Hartnick et al., 17.
Table 3 (previous page) illustrates Hartnick, Rehbar, and Prasad’s comparison of the differing schema documented by scientists regarding the delineation of the layers and structure of the lamina propria.

*Research Findings in Pediatric Vocal Fold Histology*

Hartnick has completed concentrated research on the pediatric *lamina propria* at the cellular level. These cells are considered consequential in the identifying differentiation in the three layers of the vocal folds. Hartnick is a pioneer in distinguishing cellular differences in vocal fold development from infancy though adolescence. Congruent with findings described by Sato and Hirano, he delineated a monolayer of cells within the newborn vocal fold. By 5 months old, there were two identifiable cellular layers and by 7 years old, there were three. The emergence of the three-layered vocal fold by age 7 was earlier than was previously thought. The third layer, which is essentially the adult structure, was previously not thought not to develop until sometime during adolescent mutation. The growth of the third layer of the lamina propria introduces both and lengthen and a thickening of the vocal folds during puberty. This permutation develops in a manner that is both sporadic and inconsistent affecting the vibratory capability of the vocal folds. This is likely due to unpredictability of vocal fold shape and length, compromising pitch clarity and register facility.

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145 Hartnick et al., 6.
146 Hartnick and Boseley, 7.
147 Hartnick and Boseley, 8.
148 Titze, 182.
Hartnick & Boseley not only found that the infant lamina propria was bilayered by 5 months, but also that the superficial layer was thicker from ages 0-5 than it will be in adulthood. Between 5 and 7 years old, the superficial layer begins to thin to a fifth of its size and continues to decrease until about age 10. At age 10, it begins to resemble the thickness of the superficial layer of adult vocal folds. This assessment of vocal fold mutation led them to conclude that the developmental characteristics of the emerging adult fold were present by age 10. Small sample size precluded pronouncement of definitive results.

Hartnick’s research in the pediatric lamina propria is not limited to prepubertal children. In 2005, Hartnick et al. presented supplemental findings on subjects 0-18 years of age. When examining the discernable layers of the prepubertal lamina propria, they identified “distinct regions of cell density.” Subsequently, Hartnick et al. surmised that the cellular regions were distinct in their population density and that these cellular density populations were the key to pinpointing mutation onset in prepubescent children. They believe that the cellular regions, which are comprised primarily of elastin and collagen, are the pre-evolutionary stage that will develop into the fibrous bands present in the adult lamina propria. The developmental suppositions deduced by Hartnick et al. could likely lead to the ability to pinpoint when and how mutational onset is triggered. A scientifically quantifiable study of the cell distribution pattern at the molecular level would be needed to produce more authoritative data.

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149 Hartnick and Boseley, 8.
150 Hartnick and Boseley, 10.
151 Hartnick et al., 4.
152 Hartnick et al., 4.
While the characteristics of the emerging adult vocal fold may be recognized by age ten, elastin and collagen fibers are not discernable until 13 years of age. The emergence of fibrous bands of elastin and collagen will form the layering in the vocal fold structure that creates the lamina propria of the adult fold. Therefore, mutation at the cellular level, in combination with the onset of growth in vocal fold length, likely describes the essence of the mutating histology of the vocal fold during adolescence.

Until recently, pediatric voice scientist and laryngologists have referred to research in adult laryngeal physiology in order to establish their clinical constructs. However, conclusive findings regarding the nature of the prepubescent differentiated cell regions could likely inform aspects of currently understood regarding the adult vocal structure.

Growth in Vocal Fold Length

The vocal folds of newborns average 6 to 8 millimeters in length in both male and female infants. In adulthood, gender differences become apparent. By age 20, females average 8 to 11.5 millimeters in vocal fold length, while males average 11 to 16 millimeters of complete growth. These are the lengths found by Titze in 1994. However, achieving consensus on vocal fold length can also be affected by technological developments. For example, a 2010 study by Hu, Zhu, Luo, Gao, and Yang reported any even greater variance in adult vocal fold

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153 Hartnick et al., 4.
154 Hartnick et al., 14.
length. In subjects from 18 to 60 years of age the female range was 10.68mm to 15.28mm and the male range was 11.85mm to 20.04mm (see Table 4).  

**Table 4. Normal sonographic measurements of adult true vocal folds**

<table>
<thead>
<tr>
<th>Group</th>
<th>Participants, n</th>
<th>Length, mm</th>
<th>Width, mm</th>
<th>Thickness, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;18 y</td>
<td>Male 34</td>
<td>11.85 ± 3.40</td>
<td>4.04 ± 0.81</td>
<td>4.25 ± 1.00</td>
</tr>
<tr>
<td></td>
<td>Female 31</td>
<td>10.68 ± 2.56</td>
<td>3.88 ± 0.68</td>
<td>3.83 ± 0.73</td>
</tr>
<tr>
<td>18-39 y</td>
<td>Male 30</td>
<td>19.93 ± 1.33</td>
<td>6.21 ± 0.38</td>
<td>6.22 ± 0.41</td>
</tr>
<tr>
<td></td>
<td>Female 30</td>
<td>15.28 ± 0.56</td>
<td>4.98 ± 0.26</td>
<td>5.07 ± 0.25</td>
</tr>
<tr>
<td>40-59 y</td>
<td>Male 18</td>
<td>20.04 ± 1.78</td>
<td>6.23 ± 0.53</td>
<td>6.05 ± 0.42</td>
</tr>
<tr>
<td></td>
<td>Female 27</td>
<td>14.89 ± 0.66</td>
<td>4.90 ± 0.35</td>
<td>4.94 ± 0.27</td>
</tr>
<tr>
<td>≥60 y</td>
<td>Male 8</td>
<td>19.70 ± 2.07</td>
<td>6.15 ± 0.49</td>
<td>5.88 ± 0.42</td>
</tr>
<tr>
<td></td>
<td>Female 21</td>
<td>14.64 ± 1.03</td>
<td>4.88 ± 0.33</td>
<td>4.84 ± 0.39</td>
</tr>
</tbody>
</table>

Data are mean ± SD. The measurements of 5 participants in the 18- to 39-year male group, 12 participants in the 40- to 59-year male group, and 13 participants in the 60-year and older male group were missing because of ossification of the thyroid cartilage.

Because of the influx of the hormone testosterone, a disproportionally greater amount of growth occurs in the vocal fold length of the male larynx. In males, the elongation of the vocal folds causes the larynx, which had generally maintained a prepubertal tilt of 110° to 120°, to adjust to an angle of approximately 90° (see Fig. 29). This causes thyroid cartilage to protrude in the neck, producing the laryngeal prominence or Adam’s Apple. The laryngeal prominence is a physical and visual manifestation of male maturation.

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157 Hu et al., 1027.


Figure 28. Comparison of the 120° prepubertal tilt at the laryngeal prominence (A) to the postpubertal tilt of 90° (B).

**Pediatric Laryngeal Cartilages**

Sataloff has assessed laryngeal development in children from the time they are *in utero* through young adulthood. He identifies initial anatomical characteristics of the embryonic, infant, and preschool larynges. The hyoid bone is not yet a “bone” at birth, but is a cartilaginous structure attached to the thyroid cartilage. By age 2, the hyoid and thyroid separate and the ossification of the hyoid bone begins. The epiglottis is “bulky and omega-shaped” structure (see Fig. 29) that through puberty unfolds and flattens into inverted teardrop shaped epiglottis found in an adult larynx.  

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160 Sataloff, "Vocal Aging and its Medical Implications," 45.
161 “Omega Laryngoscopic View of the Epiglottis in a Child with Laryngomalacia, Demonstrating the Omega Shaped Epiglottis, released to public domain.
The laryngeal position of the child larynx is higher than that of an adult, resting at about the third cervical vertebrae (C3). It will eventually descend to the level of C6-C7 by 20 years of age.\textsuperscript{162} The higher laryngeal position directly affects vocal tract space and therefore, resonance capability.\textsuperscript{163}

The growth of secondary sex characteristics coincides with other major alterations of laryngeal anatomy during puberty. Sataloff’s stated age range for the onset of puberty in the American male is 9.5 years to 14 years of age with completion at 18 years; and the American female’s transition begins at 8 years to 15 years with completion at 16.5 years. During mutation Sataloff asserts that vocal fold length increases by as much as 60 percent in males and as much as 34 percent in females.\textsuperscript{164}

Pediatric laryngeal cartilages have characteristics that differ from those of adults. Differences in laryngeal gross anatomy will likely impact voice production. Hartnick & Boseley found that the cartilaginous structure of the child larynx was “less rigid” and that of an adult.\textsuperscript{165} The superior cornu of the thyroid cartilage is longer in children than adults; also, the height of the thyroid lamina is taller compared to the entire height of the laryngeal structure.\textsuperscript{166} Due to the elongation of the thyroid cartilage, “children have more slender thyroid cartilages with a larger predominance of the superior cornu…than is found in adults.”\textsuperscript{167}

\textsuperscript{162} Sataloff, "Vocal Aging and its Medical Implications," 45.
\textsuperscript{163} Esther Jane Hardenbergh, "Laryngeal Anatomy" (lecture, Advanced Vocal Pedagogy, University of Miami, Coral Gables, FL, February 9, 2010).
\textsuperscript{164} Sataloff, "Vocal Aging and its Medical Implications," 47.
\textsuperscript{165} Hartnick and Boseley, 26.
\textsuperscript{167} Wysocki et al., 197.
Wysocki et al. studied measurements of the prepubertal and postpubertal cadaveric larynx (see Figs. 30 and 31). The difference in relative length of the muscular process of the arytenoid cartilage was notable (see Figs. 32 and 33). Cartilage length in adults was “significantly larger” than in children. The impact of this assessment is important to the field of vocal study. The longer length in the adult muscle process creates a greater levering action for the articulated musculature, which allows the adduction (closing) and abduction (opening) of the vocal folds to be more “active” than in children.

Figure 30. Anterior and lateral view of thyroid cartilage. Superior cornu is the region 1b.

Figure 31. Larynx. Anterior view.

168 Wysocki et al., 193.
169 Wysocki et al., 198.
170 Wysocki et al., 193.
171 Wysocki et al., 193.
Ultimately, the evidentiary findings of Wysocki et al. provide a baseline for creating comparative ratios of the cartilaginous structure of children, particularly adolescents, and adults. The researchers’ final conclusions suggested the existence of three life-stage approximate cartilage ratios: infant (0-2 years), child (3-7 years), and adolescent (8-12 years). The dimension variation of the cartilages of the child larynx was about two times smaller than that of the pubertal larynx. The most compelling results were that the most considerable growth occurred between ages 8-12 and that age was the primary contributing factor for assessing human laryngeal proportions, not sex. These findings create an authentic timeline assessing excitations in development with the growth outcome of the adult larynx to be 4 times that of its size in infancy.

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172 Wysocki et al., 193.
173 Wysocki et al., 193.
174 Wysocki et al., 198.
Gender Differentiation and the Voice

*Puberty, the passage from childhood to adulthood, represents a hormonal earthquake for the individual. At this time, the secondary sexual characteristics appear, as well as the physical and physiological changes that are particular to each sex.*

**Universal Findings**

The larynx is a hormone-dependent organ. Human beings are subject to developmental mutations that occur due to a changing hormonal climate. The hormonal climate of the circumpubertal singer directly impacts vocal development and determines the sex characteristics of the voice. The individuality of a voice is recognized through acoustic resonance. Acoustic resonance refers to the harmonics and frequency intensity of vocal sounds. Each person’s series of harmonic frequencies is individual and unique. Abitbol et al. suggest the notion of a “vocal print” as being similar to a fingerprint that identifies one voice from another. Each singer’s *vocal print* is individual and reveals characteristics that impact our personhood in terms of communication, personality, and expression.

Harmonics are “hormonally dependent.” Adolescents, therefore, receive a new and unfamiliar *vocal print* at puberty, since the larynx is affected by a new hormonal climate. Abitbol et al. state that hormones like estrogen, progesterone, and androgens determine the sex characteristics of the voice by introducing as

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175 Abitbol et al., 434.
176 Abitbol et al., 424.
177 Abitbol et al., 424.
179 Raj et al, 363.
shift in “hormonal climate.” If androgens, which are essential for male sexuality, are not present during puberty, the character of the voice will be female. The influx of hormones throughout the body spurs the onset of growth in the laryngeal cartilages. This growth impacts the surrounding intrinsic and extrinsic musculature. In 2005, Barlow & Howard assessed laryngeal growth from childhood to adolescence. They found that the dimensional change of male and female larynges was rapid and aperiodic (see Fig. 34). Spurts in pubertal growth necessitate constant adaptation to the emerging laryngeal structure, thus affecting the muscle control skills requisite for singing and speech. Barlow & Howard’s findings are congruent with Kahane’s (1978) findings regarding mutational rapidity and the amount morphometric growth.

Figure 34 (Left). Laryngeal growth during puberty derived from Kahane.

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180 Abithol et al., 425.
182 Barlow and Howard, 67.
**Fundamental Frequency and Gender Differentiation**

Mutation is a time of vocal instability, which Fuchs et al. characterize as "decreased vocal efficiency caused by rapid growth of the larynx and the vocal folds due to endocrine control of testosterone and growth hormones." Since the vocal print is identified through harmonics and frequency intensity, research regarding the measurement of the fundamental frequency ($F_o$) is often studied for possible pattern differentiation by gender.

Fundamental frequencies measure how high or low the voice sounds in Hz or cycles of sound. The vocal fold response to changes in subglottal air pressure correlates to the frequency of vocal fold vibration resulting in "spectral peaks in the sound spectrum" or formants. It is the frequencies and formants in a voice that generate the harmonics responsible for its unique character.

In a longitudinal study of the speaking voice of prepubertal and pubertal children, Whiteside, Hodgson, and Tapster found that measured differences in frequencies offered insight into varying mutational patterns of girls and boys. Trends in developmental mutation could be identified by their study and sex differences were documented in speaking fundamentals. However, participants only numbered 15-20 and were from the same geographic region; additionally,

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the participants were within a range of differentiation that other researchers like Sergeant & Welch would call inconsequential.188

Sergeant & Welch undertook a longitudinal study of 320 children aged 4-11 regarding the average frequency spectra found in singing. Initially, they cite numerous studies on speech differentiation intended to support the idea of identifying gender differences in speech. They concluded that fundamental frequency (Fₒ) in speech was a “poor predictor of male/female voice identity,” because they discovered that collective evidence supported the opposite hypothesis, that fundamental frequency did not predict gendered voice identity.189 They also stated that findings were often conflicting and of inadequate sample size.

Voice scientists continue to search for phoniatric predictors that may be evidenced in the speaking voice of children at the onset of mutation. While fundamental frequency may not useful for scientifically differentiating gender, it may be relevant in determining the “initiation and completion of adolescence.” Sergeant & Welch suggest that, rather than Fₒ, a prominent factor in gender differentiation in speech is prosody. The intonation of melodic patterns in speech make will likely suggest gender to the listener. Because a song has a predetermined melodic line, it is not subject to the personal habits and behaviors of an individual’s

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188 Sergeant and Welch, 320.
intonation. Thus, song is a better modality for frequency comparison by gender.

Finally, “energy” can be a significant factor in gender distinction. Spectral energy can be measured to determine the dimensions of power, or energy, per Hz. In delineating the spectral qualities of vocal tone of singers and displaying the developmental characteristics of pubertal onset, Puts, Gaulin, and Verdolini attributed descriptors to tone qualities. Descriptors of female tone quality included light, clear, focused, and expressive. Male descriptors included strong, positive, matter-of-fact, and confident.

**Male Differentiation**

Pubertal onset refers to the influx of hormones throughout the body that are necessary for mutation from childhood to adulthood. Approximately 6 months after onset, laryngeal development begins. The first step in the development of the larynx is cartilage growth, which then triggers the events of voice change both in males and females. The specific age of mutational onset is a matter of ongoing debate, and one, according to Hartnick’s research, that we are not yet technologically able to determine. However, determining a reliable mean age is relevant, particularly as it informs training methods (ie. Cooksey’s

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190 Sergeant and Welch, 320.
192 Barlow and Howard, 69.
193 Hollien, 2.
194 Barlow and Howard, 69.
195 Arnold E. Aronson and Diane M. Bless, *Clinical Voice Disorders* (New York: Thieme, 2009), 16.
196 Hartnick et al., 4.
voice mutation stages). Table 5 demonstrates the mean age of male pubertal onset as determined by eminent voice scientists throughout the last century.

**Table 5. Mean age of male mutational onset per specific researcher**

<table>
<thead>
<tr>
<th>RESEARCH SOURCE</th>
<th>YEAR PUBLISHED</th>
<th>MEAN AGE in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sturdy</td>
<td>1939</td>
<td>14.25</td>
</tr>
<tr>
<td>Friesen</td>
<td>1972</td>
<td>13.8</td>
</tr>
<tr>
<td>Cooksey</td>
<td>1984</td>
<td>13.5</td>
</tr>
<tr>
<td>Hollien Green, and Massey</td>
<td>1994</td>
<td>13.4</td>
</tr>
</tbody>
</table>

Source: Data adapted from Fisher, "Effect of Ethnicity on the Age of Onset of the Male Voice Change," p. 117.

The male voice change is more obvious than that of the female. The growth of the male thyroid cartilage creates a visual representation of mutation with the appearance of the laryngeal prominence, or Adam’s apple. According to Abitbol et al., voice change in males may take up to 5 years from onset to completion. If this is the case, and onset begins at 13.4 years of age (Hollien, Green and Massey, 1994), the male voice change may actually extend beyond the normally accepted pediatric range, which concludes at 18, and into young adulthood.

**Female Differentiation**

As the body enters the pubescent stage, an influx of hormones is introduced in order to facilitate the onset of mutation. In females, this hormone is estrogen. Estrogen is responsible for the development of secondary sex characteristics.

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199 Albitbol et al., 434.
characteristics in females. Abitbol et al. found that this influx of hormones had an effect on the laryngeal mucosa of females. For the female, the hormonal influx is not only a temporary mutational effect, but also recurs monthly. Estrogen actually modifies the laryngeal mucosa, altering its structure just before ovulation. This recurrence of a monthly hormonal influx is called *premenstrual vocal syndrome* (PVS). It is evidenced by increased dryness in the vocal folds because of mucosal changes that occur due to the increase in hormone levels. The dryness in the vocal folds results in edema (swelling). While dryness and swelling seem contraindicated, edema is the body’s protective response to a lack of appropriate fluid levels. Abitbol et al. assert, “this increase in production of mucous, although quite substantial, does not usually affect the speaking or singing voice.” This statement seems antithetical to the resultant findings extrapolated in Table 6.

**Table 6. Comparison of clinical complaints and evidentiary findings in the vocal folds during Premenstrual Vocal Syndrome (PVS)**

<table>
<thead>
<tr>
<th>Clinical Signs of PVS in the Voice</th>
<th>Evidentiary Results of PVS via Videolaryngoscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vocal fatigue</td>
<td>1. Congested vocal folds, edema</td>
</tr>
<tr>
<td>2. Decreased range, especially high</td>
<td>2. Mini varicose veins in the superior surface of the vocal fold mucosa</td>
</tr>
<tr>
<td>3. Loss in volume extremes (p/ff)</td>
<td>3. Less supple epithelium, decreased amplitude, asymmetry in folds</td>
</tr>
<tr>
<td>4. Loss of high harmonics resulting in huskier voice</td>
<td>4. Edema of the posterior third of folds</td>
</tr>
<tr>
<td>5. Posterior chink.</td>
<td></td>
</tr>
</tbody>
</table>

Source: Data adapted from Abitbol et al., "Sex Hormones and the Female Voice," p. 435.
Posterior Glottal Chink

"The posterior glottal chink (PGC) is defined as a posterior triangular gap extending from the wall of the glottis to the tip of the vocal process present on maximal closure of the glottis (see Fig. 35)." It was thought to have been an abnormality in the closure of the glottis. The posterior glottal chink (PGC) is found to be more prevalent in females than males. Research regarding why PGC is more prevalent in females than males seems to not be readily available. However, observations in occurrence and gender exist. Chandran, Hanna, Lurie, and Sataloff discovered incidental evidence in their evaluation of endoscopic assessment modalities the observed the prevalence in PGC in female patients. Specifically, of the 28 females examined, 22 had PGCs detected by both the flexible and rigid endoscopy. Of the 24 males examined, four had PGCs detected by both diagnostic modalities. Though the study was intended to compare diagnostic methods in the context of a pilot study, the incidental outcome is notable.

Studies regarding the posterior chink are ongoing and its developmental function has yet to be conclusively determined. In addition to knowledge of the existence of PGC, Hartnick & Boseley have found evidence that prepubertal children have a decreased ability to maintain medial glottal compression during

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206 Swapna Chandran et al., 591.
207 Swapna Chandran et al., 591.
adduction or closure of the vocal folds for phonation.\textsuperscript{209} This could affect the degree to which a posterior glottal chink exists. While the posterior chink will likely “have gradual resolution over time…clear developmental milestones or characteristics related to these features have yet to be thoroughly defined.”\textsuperscript{210}

![Figure 35. Posterior glottal chink. Normal glottal opening during abduction (A), glottis during adduction with PGC in evidence\textsuperscript{211}]

While much remains unknown about the posterior glottal chink, it is important to note that Hartnick & Boseley state that there is an expectation of resolution of the PGC by adulthood, though resolution is not universal.\textsuperscript{212} Prevalent opinion exists in the voice science community that regards PGC as a normal event among prepubescent females and males. In their studies on speech and laryngeal vibratory function, Biever & Bless found that “[i]t is unlikely that the appearance of this phenomenon can be attributed to a vocal

\textsuperscript{209} Hartnick and Boseley, p.26.
\textsuperscript{210} Hartnick and Boseley, p.26.
\textsuperscript{212} Schneider and Bigenzahn, 591.
pathology. This was also found to be true in the research of Schneider & Bigenzahn in their research on the speaking voice and the influence of incomplete glottal adduction in young, healthy women. These findings suggest the presence of a posterior glottal gap in females. The presence of a PGC likely translates to incomplete closure of the vocal folds during phonation. Aspiration or air escaping during vocal sound is not aesthetically preferential in speech or singing. Air heard during phonation is likely to be interpreted as dysfunction in the physiological production of sound. Titze speaks of vocal efficiency regarding optimal phonatory output. Vocal efficiency is “integrally connect with energy” or subglottal pressure and aerodynamics. Voice trainers will likely interpret a breathy sound as insufficient coordination of the musculature for full glottal closure (adduction) and/or inefficient power or airstream to the vocal folds for energy efficient phonation. Should a singer have a PGC, is it possible that air will be present in phonation due to the triangular gap in the glottis. However, this is not necessarily due to insufficient energy efficiency, rather it may be due to presence of an undiagosed posterior glottal chink. Thus, ignorance of the possibility of PGC in adolescence could likely cause voice trainers to misinterpret the reason for compromised vocal energy efficiency in puberty.

214 Schneider and Bigenzahn, 591.  
215 Titze, 241.  
216 Swapna Chandran et al., 591.
Summary

The historical evolution the human voice provides context into human development. The development of human beings speech capability is not merely function of advancement in the *Homo sapien* species, but also of the transformation evolution causing the need to communicate.

The phonatory capability of human beings has developmentally integrated into a processing network that enables communication in an intimate way; linked to both necessity and emotion. Due to the necessity to communicate, understanding the machinations of the voice and maintaining its function has been a topic of scientific speculation and research throughout the centuries. As technological advancements were made, particularly in the 19th-century, scientists were compelled to explore the vocal mechanism in more substantial ways. This research continues to the present day.

Current advances in technology have presented scientists with the opportunity to investigate laryngeal function through live assessment using various ultrasonic, fiberoptic, and imaging modalities. Additionally, development computer assisted technology has accessed the ability to assess histological gradations on a microscopic level beyond any previous ability. New modalities in laryngeal evaluation enable scientists to explore the pediatric larynx in dynamic ways not previously available. The resultant findings likely offer an authoritative understanding the pediatric physiology that will provide saliency for voice teachers and educators in developing training practices for children.
The diagnostic capabilities available to laryngologists through new modalities and advancements in technological imaging and microscopic, histological evaluation of the vocal mechanism on a cellular level led to new conclusions regarding vocal fold morphology of the pediatric voice. Evaluation of the pediatric lamina propria offered salient and distinctive evidence not previously delineated. Hartnick et al.\textsuperscript{217} and Nita et al.\textsuperscript{218} found distinction in the development of the lamina propria that provided new insight into vocal development in utero through adolescence. These finding provide information that allows for the creation of a developmental progression or timeline by which conclusions regarding pediatric vocal capability can be drawn.

For voice teachers, the findings of Hartnick et al. and Nita et al. both refute and confirm currents practices. In reality, the pediatric vocal mechanism appears to be an efficient and practical instrument for the phonatory expectations of infants, children, and adolescents. Therefore, practitioners who espouse the notation that the child voice is delicate, implying that it is neither up to nor build for the task of singing as noted by Skelton\textsuperscript{219} are misinformed. The science seems to support the opposite conclusions; that is that the pediatric vocal structure is pliant and resilient, ostensibly built to the vocal demands of childhood of which singing is one.

\begin{footnotesize}
\begin{itemize}
\item[218] Luciana M. Nita et al., "The presence of a vocal ligament in fetuses: a histochemical and ultrastructural study," Journal of Anatomy 215, no. 6 (August 2009).
\end{itemize}
\end{footnotesize}
CHAPTER THREE

Review of Pediatric Vocal Pedagogy Literature

It is important for all professionals who train and care for singers to understand as much as possible about the growth and development of the voice and to understand clearly anatomic and physiologic differences among children, adolescents, adults and the elderly. Such knowledge should lead to optimal training and minimal risk of vocal injury.220 Sataloff, 1999

Introductory Remarks

Voice training and techniques have existed throughout recorded history.221 Though the specifics of anatomy were unknown, speculation on laryngeal function can be traced back to the Greek philosopher, Aristotle (384-322 B.C) and the Roman doctor, Galen (130-200 A.D.).222 Most forms of notated vocal music have concurrent treatises on the preferred production of sound for the time. Methods of singing have changed as often in relation to contemporary aesthetic perceptions of vocal sound. The preferred sound of each respective period led the voice teachers of each age to develop paradigms intended to instruct singers on how replicate the current vocal predilections.223

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220 Sataloff, 46.
221 Miller, 47.
Developmental Considerations toward Pedagogic Strategies

*Interactive Communication and Human Development*

The fetus *in utero* develops the auditory processing ability at about 20 weeks, as evidenced by Thiery, et al. and Ryder.\(^{224}\) The need for human interaction from infancy has been documented through the multiple studies of Field et al., who reported the ability to learn would be significantly compromised without the input of expressive interaction between an infant and caregiver.\(^{225}\) This interactive communication initially manifests itself in vocalizations preparing the ability “for optimum survival and thriving when they [infants] are consistently in the presence of a caring, interactive adult.”\(^ {226}\) Psychologists have assigned the term *motherese* to the communicative action between caregiver and infant.\(^ {227}\) The primary modes of communication with infants are: song, speech, and touch.

Babies learn to respond to caregivers consciously, creating non-verbal vocalizations. In response patterns modeled by the caregiver, babies’ non-verbal vocalizations are “manipulation[s] of pitch, timbre, rhythm, and dynamics that [form] the basis of their communications system.”\(^ {228}\) The most frequent sound pre-natal infants experience, next the mother’s heart beat, is the mother’s voice. The inflection of utterances between child and parent not only elicits bonding, but also affects the developmental disposition of the child for emotional expressivity.

\(^{225}\) Thurman and Grambsch, 661.
\(^{226}\) Thurman and Grambsch, 671.
\(^{228}\) Hodges and Sebald, 41.
and cognitive learning.\textsuperscript{229} Thurman and Grambsch consider the human voice the primary means through which needs, thoughts, emotions and wants are communicated. The voice then, wields a connection to the essence of humanity and possesses the ability to reveal, “who we are.”\textsuperscript{230} Since human beings are predisposed to interpret vocalizations as interactive communication, the pursuit of \textit{sound-making} is essential.\textsuperscript{231}

\textit{Vocal Inflection in Child Development}

In relation to the study of child developmental stages, Howard Gardner asserts the concept of “multiple intelligences.” \textit{Musical intelligence} is one of the “intelligences” he identifies. Gardner found musical intelligence to run in “structural parallel” to linguistic intelligence.\textsuperscript{232} In singing, music and language abilities intersect. The intersection of language and music allows for our ability to understand the patterns of speech and interpret meaning through the melodic intonation patterns, or prosody. In studying prosodic speech, music education theorists Gordon, Papousek, Thurman, and Gopnik found speech prosody to be connected to the “processing of melodic-harmonic contours.”\textsuperscript{233} Papousek identified \textit{preverbal vocal development} in six stages with “melodic modulation and primitive articulation” present in cooing by 2 to 3 months of age.\textsuperscript{234}

\begin{itemize}
\item \textsuperscript{229} Thurman and Grambsch, 673.
\item \textsuperscript{230} Thurman and Grambsch, 673.
\item \textsuperscript{231} Hodges and Sebold, 41.
\item \textsuperscript{232} Howard Gardner, \textit{Intelligence Reframed: Multiple Intelligences for the 21st Century} (New York, NY: Basic Books, 1999), 41-43.
\item \textsuperscript{233} Thurman and Grambsch, 680.
\item \textsuperscript{234} Thurman and Grambsch, 681.
\end{itemize}
Innate Expression and Song

Human beings possess a “primary repertoire of innate abilities” and a “secondary repertoire of learned abilities.”235 Like Maslow did when he compiled his Maslow’s Hierarchy of Needs (see Fig. 35), Thurman and Welch codified the requirements of human survival into clusters of capability-ability. Throughout life, these capabilities or “adaptive potentials” increase in order for the person to thrive and survive.236 As the primary abilities of human beings develop, their secondary abilities, capabilities, or adaptive potentials expand the dimensions of personality traits beyond interaction and into perception.237

Figure 36. Maslow’s Hierarchy of Needs.238

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235 Thurman and Grambsch, 662.
236 Thurman and Grambsch, 662.
237 Thurman and Grambsch, 662.
According to Thurman & Welch’s *human capability-ability clusters*, feelings are perceptions within the value-emotive realm (see Table 7, p. 72). Maslow, Edelman, Hodges & Sebold, and other researchers have found that music affects human emotions by altering mood and resulting in “feeling-moments.” Singing and musical sounds are perceived from birth. Researchers have observed pitch-matching ability in 3 to 6 month olds and short, repetitive songs in babble that are accurate in pitch. Thurman & Grambsch state “singing brings a feeling-expressive dimension to human communication that language alone cannot provide.” It is a “symbolic behavior” that identifies us uniquely as human beings. Song, then, possesses an additional element innate to human expression not perceived in speech alone.

Pedagogical Perspectives on the Pediatric Voice

*Childhood Singing*

Singers who are children are “developing singers.” In addition to the physiological changes that occur as they get older (as discussed in the previous chapter) children who are involved in singing activities are developing stronger neural processing for auditory acumen. As the brain learns, competency in coordinating pitch matching, rhythm, and text can be achieved. Success in attaining these competencies lies in the sequencing of developmentally

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240 Thurman and Grambsch, 682.
241 Thurman and Grambsch, 682.
242 Hodges and Sebold, 15.
Table 7. Human capability-ability clusters.\textsuperscript{244}

<table>
<thead>
<tr>
<th>Perceptual capability-ability clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Categorizations within senses</td>
</tr>
<tr>
<td>auditory</td>
</tr>
<tr>
<td>visual</td>
</tr>
<tr>
<td>vestibular</td>
</tr>
<tr>
<td>olfactory</td>
</tr>
<tr>
<td>gustatory</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value-emotive capability-ability clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Categorizations within homeostatic neuroendocrine states (feelings and emotions)</td>
</tr>
<tr>
<td>+ their self-regulation (threat-benefit categorizing, pleasure-displeasure categorizing)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conceptual capability-ability clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructing adaptive</td>
</tr>
<tr>
<td>Verbal explanatory</td>
</tr>
<tr>
<td>Literal observation</td>
</tr>
<tr>
<td>patterned relationships between perceptual and value emotive</td>
</tr>
<tr>
<td>analytic, sequential, interpretive, detail-oriented</td>
</tr>
<tr>
<td>integrative, whole pattern, cluster-based, non-verbal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensorimotor capability-ability clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protective reflexive movements (including vocal sound-making)</td>
</tr>
<tr>
<td>coordinated, adaptive, purposeful</td>
</tr>
<tr>
<td>that are expressions of</td>
</tr>
<tr>
<td>perceptual, value-emotive-conceptual capability-ability clusters</td>
</tr>
</tbody>
</table>

Source: Data adapted from Thurman and Grambsch, \textit{Bodymind and voice: foundations in music education}, p. 662.

According to Welch, a form of sequencing lies in song deconstruction. Deconstructing songs by essential elements will “facilitate

\textsuperscript{244} Thurman and Grambsch, 662.
\textsuperscript{245} “GIML Web Site.” Gordon Institute for Music Learning, 2008.
exploration, play, and mastery through subsequent recombination,” enabling children to gain the tools of music making.\footnote{Welch, 709.}

Welch’s studies with children serve to support Edwin Gordon’s *Music Learning Theory*. Gordon also delineated and defined *audiation*; calling it “the foundation of musicianship.”\footnote{“GIML Web Site.” Audiation.} According to Gordon, “audiation is to music what thought is to speech (see Table 7).”\footnote{Edwin Gordon, *Learning Sequences in Music* (Chicago, IL: GIA Publications, 1997), 10.} Bluestine says that audition involves “inner [hearing] music with comprehension.”\footnote{Eric Bluestine, *The Ways Children Learn Music: An Introduction and Practical Guide to Music Learning Theory* (Chicago, IL: GIA Publications, 2000), 12.} When comprehension of melodic patterns is achieved, the “developing singer” will be capable of independent singing.\footnote{Welch, 712.} Welch identifies healthy modeling and sound environments that are actively stimulating as significant elements of proficient singing.\footnote{Welch, 713.}

**Table 8. Gordon’s stages of audiation**

<table>
<thead>
<tr>
<th>Stage of Audition</th>
<th>Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>Momentary retention</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Initiating and audiating tonal and rhythmic patterns; recognizing and identifying tonal center and macrobeats</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Establishing objective or subjective tonality and meter</td>
</tr>
<tr>
<td>Stage 4</td>
<td>Consciously retaining in audiation tonal patterns and rhythm patterns that we have organized</td>
</tr>
<tr>
<td>Stage 5</td>
<td>Consciously recalling patterns organized and audiated in other pieces of music</td>
</tr>
<tr>
<td>Stage 6</td>
<td>Conscious prediction of patterns</td>
</tr>
</tbody>
</table>

Source: Data adapted from Gordon, *GIML Web Site*, Audiation.
**Ensemble Singing and Children**

In addition to any possible musical exposure at home, many children will likely experience singing in school or community group settings. Many voice trainers discuss the formation of good habits for young singers. Though teachers and pedagogues like Kemp, Smith & Sataloff, Miller, Leck, and Gackle may have differing ideas for precisely what constitutes “good habits” and methods for student achievement, they often refer to these habits of singing as *lifetime* or *lifelong.*\(^{252}\)\(^{253}\)

**Engaging Prepubertal Children**

Success with young singers is inexorably joined with their enjoyment of the process. According to Doreen Rao, an outcome of singing should include “enjoyment of music for its own sake.”\(^{254}\) With guidance, children can learn to use their voices well and gain satisfaction and joy in the process.\(^{255}\) Leck advocates the four *sensory learning anchors* and incorporates them into his teaching to train singers in proper voice use: (1) aural, (2) visual, (3) kinesthetic sensation, and (4) movement.\(^{256}\) Within these modalities, Leck guides his singers to healthy vocal production through concepts such as vowel modification, vocal modeling, articulation, agility and relaxation, resonance, and range.\(^{257}\)

Doreen Rao also remarks on advantages in the development of vocal skill

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\(^{253}\) Smith and Sataloff, 20.
\(^{255}\) Leck, 13.
\(^{256}\) Leck, 13.
\(^{257}\) Leck, 13-52.
derived through ensemble singing. She advocates performance-based education through which singers experience high quality repertoire and develop their musicianship skills through a variety of musical genres.\textsuperscript{258}

\textit{Singing and Adolescence}

The adolescent voice change should be celebrated.\textsuperscript{259} Discussing their voice change with adolescents will give them an understanding of and appreciation for the transition they are experiencing. Communication enables transitional singers to feel successful and encourages self-actuating participation.\textsuperscript{260} This participation will likely aide in the development of a healthy vocal identity for adolescent singers.

If the human voice reveals the inner self, as asserted earlier in this chapter, it is likely that voice perception and voice change will affect adolescent identity. Monks found evidentiary studies from multiple sources indicating that vocal sound and self-identity were linked.\textsuperscript{261} North and Hargreaves demonstrated a positive link between musical ability, adolescent identity, and self-concept.\textsuperscript{262} In her longitudinal study designed to assess adolescent vocal identity, Monks concluded that adolescent singers were actively aware of their vocal changes as they evolved during puberty. The students also perceived that these changes affected their performance. They found their vocal transitions unpredictable and

\textsuperscript{258} Rao, 5.
\textsuperscript{259} Patrick K. Freer, \textit{Getting Started with Middle School Chorus} (Lanham: Rowman \& Littlefield Education, 2009), 69.
\textsuperscript{260} Freer, 72.
\textsuperscript{262} Monks, 246.
often did not possess knowledge regarding vocal mutation. It was further noted that self-criticism of performance was typically inaccurate compared with performance reality. Utilizing confidence-building techniques in choral classrooms could develop both vocal and self-esteem.263

Fuchs et al. completed a study on higher esteem for students undergoing the vocal transition that compared the singing abilities of children who were regularly involved in singing activities with the singing abilities of non-singing children. Regular involvement included those children who sang at least twice a week. They discovered that the usable singing range of students, who had received regular voice training, either individually or in a group, was wider than that of the non-singers. Each student’s knowledge of extended range tended to positively affect that singer’s self-perception of vocal production. Consequently, Fuchs et al. concluded that the results of singing during childhood and adolescence could be beneficial.264 Child-training practices that create opportunities for adolescents to develop realistic tools for self-assessment could likely be included among those considered “beneficial” by Fuchs et al.

Researchers have discovered what some pedagogues have suspected: male and female prepubescent voices are physiologically similar (see Table 2, p.

263 Monks, 254.
Friddle surveyed literature and teaching methods concerning the male changing voice and asserted that voice professionals will agree that both male and female prepubescent children possess similar ranges, endurance, and lung capacity; thus, repertoire for these children can be identical. While this may be true, an unexpected result of the study by Fuchs et al. found that boys showed better values for control, intensity, and duration at about age 10 and that the male subjects’ vocal control was conscious. This could be due the varying rates of change in the male voice at pubertal onset. If the respiratory capacity of males strengthens in advance of evidentiary laryngeal growth, this could explain higher values for intensity and duration while the subject is still considered prepubescent.

**Male Vocal Transition**

Terminology for referring to the male voice change varies widely. Adjectives for mutation are likely to reflect the training methods of the pedagogue. Some descriptors include: changing, breaking, mutating, transitioning, cambiata, morphing, pubescent, and adolescent. Henry Leck introduces the term *expanding*. Cooksey identifies the male voice change as

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268 Fuchs et al, 188.


undergoing growth *stages*. Cooksey urges the need for voice trainers to understand the “maturation process,” or growth stages, of singers. Specifically, he stresses the need for boys to sing through their voice change because he believes that professional guidance through the transition will keep male singers involved in music throughout their lives. Although it could change the achievement potential of a choir, the idea of singing through transition seems to be the current opinion among choral pedagogues.

*The “Broken” Voice*

Historically, particularly in the English boychoir model, boys were *exited* from the choir once the voice “broke.” The breaking of the voice is interpreted by Cooksey as a “rendering asunder” and a “forceful shattering” of the prepubescent voice, implying that it is no longer whole. Once the voice broke; the prescribed strategy was to stop singing. It was thought that to “exercise” the voice at this time would prove harmful. This is still the in the boychoir schools of England today, because the sound that is esteemed within the British aesthetic requires that boys must leave the choir once the voice breaks. Additionally, boys may not continue as a member in a section that accesses a lower range because it is believed that the voice has not matured enough nor is it settled. Thus,

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273 Friddle, 35.
275 Leck, 178.
boys who are experiencing the voice change have no formal opportunity for singing in the British model.

_Principles of Training the Adolescent Male Singer_

The male adolescent voice change can be disconcerting for the trainer, especially because every voice change is individual.\(^{277}\) Aperiodic and rapid growth spurts can be perplexing and frustrating to both pedagogues and students alike.\(^{278}\) Trainers may not understand of the physiological capabilities of the emerging voice; thus, may not be able to adequately address the needs of the adolescent singer.

_Choral Training Paradigms (Male Transition)_

_Duncan McKenzie._ Before scientists were able to assess the pediatric voice through non-invasive, technological means, voice trainers established schema to guide those who teach the child singer. Designated “one of the most distinguished music educators in American History” in the November 1956 edition of _Music Journal_, Duncan McKenzie established a protocol for the training of boys’ voices. Contrary to the strict British policy of removing boys from choral participation during mutation, McKenzie espoused a paradigm of inclusion reflective of the prevalent ethos in the United States.\(^{279}\)

The preservation of the boy’s ability to sing was foundational to program

\(^{277}\) Leck, 183.
success. The “comfortable range policy” and the “alto-tenor” plan were “voice transfer” systems. This meant that a chorister’s voice was regularly assessed and shifted through voice parts as range capability necessitated. McKenzie insisted that knowledgeable professionals were required to guide adolescent males through transition. Abilities for assessment included: onset, range, vocal gaps, and the strongest register of the voice. McKenzie seemed reticent to specifically provide pitch ranges for classification purposes. Chiefly, he retained adolescent males in his choirs by making the experience both vocally satisfying and suitably engaging.

Frederick Swanson. Frederick Swanson began teaching in public school in 1932. There, he found male junior high choral participation decidedly lacking when compared with that of female participation. Swanson’s impression was that music educators were ill-equipped to assist boys with the “unexpected quirks” of voice change. In order to have boys feel success and ownership in their own voice change, Swanson asserted that adolescent boys undergo a voice check every six weeks, keep an audio record of the evaluation, and graph any change. In this way, the assessment would be visual and auditory, allowing both the teacher and the singer to track vocal evolution. Because adolescence “is not orderly, logical, or predictable,” Swanson encouraged teachers to be innovative by adapting vocal lines and transposing repertoire according to the

280 McKenzie, 29.
283 Swanson, 47.
voice graph results.\textsuperscript{285} He was also a proponent of separating the choir by gender whenever possible.

The \textit{Cambiata} Concept

\textit{Irvin Cooper.} Originally born in England, Irvin Cooper was a professor of music education at Florida State University. His tenure as a teacher led him to seek practices that would maintain boys' participation in choir through middle school. Further investigation directed him to study the early adolescent voice. He devised a system that centered on the notion of the \textit{cambiata} or \textit{phase of change} of the adolescent male singer.\textsuperscript{286} There are 4 phases in the \textit{cambiata} concept: soprano (unchanged male voice), \textit{cambiata} (first phase of male voice change), baritone (second phase male voice change), bass (changed male voice). Cooper held that the \textit{cambiata} voice had a distinct timbre unto itself than he perceived as rich and referred to as “woolly.”\textsuperscript{287} According to Collins, Cooper was “belligerent” about the distinctiveness in vocal color of the early adolescent male voice.\textsuperscript{288} His conviction concerning the \textit{cambiata} sound is conspicuous in the naming of the paradigm.

\textit{Don L. Collins.} Founder of \textit{Cambiata Vocal Institute for Early Adolescent Vocal Music} currently located at the University of North Texas, Don Collins watched as the British practice of “quieting” the adolescent voice during mutation disenfranchised boys from choirs, who then never to returned to singing. The American choral culture evolved to include transitional singers. Collins, like many

\textsuperscript{285} Swanson, 48, 50.
\textsuperscript{287} Collins, Don L. "The Cambiata Concept."
\textsuperscript{288} Collins, Don L. "The Cambiata Concept."
others, worked to edit music in order to make it appropriate for the changing voice. The desire to keep adolescents actively involved in choral programs led him to espouse the *cambiata concept* of Irvin Collins and continue to support a proven strategy for voice classification.\(^{289}\) His intention was to interact with both the music education and choral communities to provide education for children’s choir teachers and to promote understanding of the early adolescent or *cambiata* voice.\(^{290}\) Collins ostensibly embraced Cooper’s movement and transformed it into an international institution.

*John Cooksey.* The rate at which growth stages (spurts) occur varies for every boy. Cooksey describes the male voice change within two axioms of growth: macroanatomy and microanatomy. The complementary physiological phrases for these axioms from the previous chapter would likely be: pediatric laryngeal morphology (macroanatomy) and pediatric laryngeal histology (microanatomy). Cooksey based his assertions on the research of Kahane (laryngeal morphology) and Hirano (laryngeal histology).\(^{291}\)

The growth stages schematized by Cooksey reflected the cyclical phases identified in the human body’s growth processes. Intermittent among growth episodes are stabilization periods during which the body acclimates to the changes experienced. As discussed previously, adolescent mutational onset is initiated hormonally.\(^{292}\) Cooksey proposes “five landmark stages” that serve to interpret the aperiodic episodes of growth during male adolescence. These

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\(^{290}\) Collins, Don L. "The Cambiata Concept."

\(^{291}\) Cooksey, 822.

\(^{292}\) Abitbol et al., 424.
stages are termed: early mutation, high mutation, mutation climax, stabilizing post-mutation, and developing post-mutation. The stages were distinguished based on the research of numerous voice scientists, including Naidr, Zboril & Sevcik, Frank & Sparber, Tanner, Lee, Cooksey, Beckett & Wiseman, Barresi & Bless, and Cooksey.²⁹³ Cooksey regards these stages as implicit, noting the age-range for pubertal onset as between 10 and 14.

*Kenneth Phillips.* Specializing in developing the voices of young children and early adolescents, Kenneth Phillips describes singing as a “deeply personal act” for which teachers are charged to provide a safe environment.²⁹⁴ Deeply concerned with the vulnerability and potentiality for embarrassment in adolescence, Phillips advocates music educators be proactive in directly addressing vocal mutation with choristers. The psychological and physiological issues students experience during adolescence can prove daunting; therefore, it is imperative that negativity, intimidation, and ridicule have no place in the middle school music classroom. Additionally, Phillips suggests music teacher regard themselves as voice teachers creating self-awareness in the transitional singer to establish healthy speaking and singing behaviors.²⁹⁵

*Henry Leck.* Henry Leck describes the relationship of conductor and children’s choir as one of developmental artistry. He believes that in striving for the machinations of sound, conductors often overlook the art. He believes that choristers are integral to the artistry of the choir; they are not “artists in

²⁹³ Cooksey, 823.
²⁹⁵ Phillips, "Creating a safe environment for singing."
Specifically addressing male transitional singers, Leck views the mutating voice as a whole and continual instrument. In other words, there is not an “old” voice and a “new” voice, but an expanding voice.\textsuperscript{297} He further asserts that while research may be informative, voice classification is limited, “hypothetical and rarely applies to the whole voice.”\textsuperscript{298} Leck recommends joining the treble voice to the chest and merging low voice with the high voice through exercises that travel from the top of the range to the bottom. He explains that the voice will then develop enough facility through practice to minimize any “breaks” or passaggio.\textsuperscript{299} Leck like his predecessors advocates singing through vocal mutation in order to maintain the ability to sing once transition has concluded.

\textit{Choral Summary - Male Transition}

The choral pedagogues practicing in America in the 20\textsuperscript{th}- and early 21\textsuperscript{st}-century seem united in their convictions to rebuff the British boychoir model in favor of a model of inclusion for choristers in vocal transition. Reasons for adopting this new philosophy included the psychological health of adolescent male choir participants and the perceived physiological benefit of exercising the vocal musculature throughout mutation. Though the methods of choir directors varied, their intentions seem congruous (see Table 9, p.85).

\begin{flushleft}
\begin{footnotesize}
\textsuperscript{296} Leck, 1.
\textsuperscript{297} Leck, 178-179.
\textsuperscript{298} Leck, 182.
\textsuperscript{299} Leck, 182, 186.
\end{footnotesize}
\end{flushleft}
Table 9. Choral training methods for adolescent boys

<table>
<thead>
<tr>
<th>Pedagogue</th>
<th>Choral Schema</th>
<th>Idiomatic Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Royal School of Church Music</strong></td>
<td>Church School Model of Great Britain-</td>
<td>When the boys are no longer able to sing treble, the voice is quieted for a period of adjustment</td>
</tr>
<tr>
<td>(Est. 1927)</td>
<td>Trebles and altos only</td>
<td></td>
</tr>
<tr>
<td><strong>Duncan McKenzie</strong></td>
<td>Comfortable Range Policy,</td>
<td>Test boys for range comfort &amp; region of tonal power, Alto/tenor describes the sound of a boys voice after mutational onset, determining part transfer</td>
</tr>
<tr>
<td>(1956)</td>
<td>Alto/Tenor Timbre Recognition-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>As boys gain low notes, they lose high notes</td>
<td></td>
</tr>
<tr>
<td><strong>Frederick Swanson</strong></td>
<td>Voice Checks and Voice Graphs</td>
<td>Based on the belief on very rapid mutation. Repertoire should be chosen to fit changing voices. Tracking builds masculine pride</td>
</tr>
<tr>
<td>(1957)</td>
<td>Boys should be checked every 6 weeks and track it</td>
<td></td>
</tr>
<tr>
<td><strong>Cooper and Collins</strong></td>
<td>The Cambiata Approach <em>cambiata</em> refers to &quot;phase of change.&quot;*300  *Cambiata Vocal Institute for Early Adolescent Vocal Music</td>
<td>Four stages in male adolescence: treble, <em>cambiata</em>, baritone, bass Tenors do not exist during vocal transition</td>
</tr>
<tr>
<td>(1960s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>John Cooksey</strong></td>
<td>Contemporary, Eclectic Theory (1977); Microanatomy and</td>
<td>Five Growth Stages: early mutation; high mutation; mutation climax (transitional apex); stabilizing post-mutation; and developing post-mutation</td>
</tr>
<tr>
<td>(1994)</td>
<td>Macroanatomy (1994) - the morphological and the histological do not grow concurrently</td>
<td></td>
</tr>
<tr>
<td><strong>Ken Phillips</strong></td>
<td>Pre-Change Preparation Approach-</td>
<td>Advocates solid vocal technique thru K-12 in order to encourage muscle development and easy singing - Comfortable singers will risk singing in transition</td>
</tr>
<tr>
<td>(1992)</td>
<td>Importance of putting pedagogy first. Vocal technique first, repertoire second</td>
<td></td>
</tr>
<tr>
<td><strong>Henry Leck</strong></td>
<td>The Expanding Voice- The single, unified voice, three octave voice with no break</td>
<td>Bass voice is only a lower register. Men who keep high voice always sing high. Not a &quot;changing&quot; voice, but an unchanged treble with low register added</td>
</tr>
<tr>
<td>(2009)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


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300 Collins, Don L. "The Cambiata Concept."
Female Vocal Transition

Girls are aware of their voice changes. Bonnie Blu Williams in her study on menarcheal girls noted that girls observed the characteristics associated with voice change and were able to articulate their observations. Though the findings of voice researchers like Kahane concluded that the growth of prepubertal and postpubertal female larynges were similar in size and weight, girls were able to detect the symptoms of mutation early in their vocal evolution. Though physiological growth in female adolescents is less than that of males, Williams asserts that the early symptomatic response of girls likely supports the conjecture that the female voice change is observed at a younger age. Not only do girls notice the subtle differences that they experience with their voice, but also it is likely that they are aware of this transition for a longer length of time (up to two years), longer than boys.

Principles of Training the Adolescent Female Singer

Observational analysis, scientific research, and broad speculation on the male adolescent voice change have existed for over 100 years. Hollien in his work on observing adolescence through shifts in fundamental frequency noted

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302 Kahane, 11.
303 Williams, 38.
304 Williams, 38.
that little evidentiary data exists regarding vocal mutation in females.\textsuperscript{306} Though the female laryngeal structural differences from prepuberty to postpuberty tend to be observed as less invasive than that of male structural differences, girls are more perceptive of vocal changes.\textsuperscript{307} Therefore, as Monks suggested, if female students are actively aware of their voice change, teachers and trainers would likely achieve success in the training of adolescent female singers, by creating programs that build esteem.\textsuperscript{308} Also, if girls are aware of changes in their voice in advance of physically observable indications, teachers must be knowledgeable of the traits and signals their students are likely to display. Proaction, as Phillips recommends, will likely create an environment of trust conducive to building the confidence to sing through transition.\textsuperscript{309}

\textit{Choral Training Paradigms (Female Transition)}

\textit{Anthony Baressi.} In 1985, Anthony Baressi built upon Cooksey’s early voice classifications (1977) in order to further his research on adolescent voice change to include female mutation. He experimented with establishing a model for female voices that correlated with Cooksey’s research. Initially, Baressi surmised that the distinction between the male and female transitional voice was found in the laryngeal cartilages, believing that while the male larynx both lengthened and thickened, the female larynx only lengthened.\textsuperscript{310} However, Kahane determined that a thickening in thyroid cartilage and lengthening of the

\textsuperscript{306} Gackle, 739.
\textsuperscript{307} Williams, 38.
\textsuperscript{308} Monks, 254.
\textsuperscript{309} Phillips, "Creating a Safe Environment for Singing."
superior cornu did occur in female pubertal larynges.\textsuperscript{311} Baressi perceived and proposed a limitation in tessitura and range previously undistinguished, but later confirmed by the work of Lynne Gackle.\textsuperscript{312} 313 Anxious to popularize new scientific data on female voice change; he delineated the stages for the prepubertal and post-pubertal female. Ultimately, Baressi distinguished two phases of female voice change (see Table 10).\textsuperscript{314}

**Table 10. Early distinctions in female adolescent voice change based on Baressi’s observations**

<table>
<thead>
<tr>
<th>First Developmental Stage</th>
<th>Second Developmental Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unchanged voice</td>
<td>Changing Voice</td>
</tr>
<tr>
<td>Husky tone, ability to sing in through an extended range</td>
<td>Similar range, huskiness subsides, tone begins to focus</td>
</tr>
</tbody>
</table>


*Lynne Gackle.* Lynne Gackle inadvertently began her path to becoming an eminent clinician on the development of female voice at the MENC National Conference Biennial Convention in 1984.\textsuperscript{315} Though interested in the subject of female vocal mutation, necessity prompted her to begin research in this field. Her work with girl choirs has enabled Gackle to gather observational evidence on the female adolescent voice. She partnered with other researchers to build upon previous studies and gain qualitative findings in support of her suppositions. Prior to designing a paradigm for the assessment of female mutation, Gackle together

\footnotesize{\textsuperscript{311} Kahane, 16-19.  
\textsuperscript{312} Friar, 28.  
\textsuperscript{313} Lynne Gackle, *Finding Ophelia’s Voice, Opening Ophelia’s Heart: Nurturing the Adolescent Female Voice* (Dayton, Lorenz Corporation, 2010), 14.  
\textsuperscript{314} Friar, 28.  
\textsuperscript{315} Gackle, 3.}
with Huff, Alderson, and Harrison constructed a list of symptomatic observations to assist teachers and trainers in identifying the female voice in transition (see Table 12).

**Table 11. Observational signs of female vocal mutational onset**

<table>
<thead>
<tr>
<th>Auditory and Kinesthetic Signs of Female Voice Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Increased breathy, husky, or horse voice qualities in both speaking and singing</td>
</tr>
<tr>
<td>2 Occasional voice <em>cracking</em> in speech</td>
</tr>
<tr>
<td>3 Lowering of mean fundamental frequency in the speaking voice</td>
</tr>
<tr>
<td>4 Decreased and inconsistent pitch range capabilities in singing</td>
</tr>
<tr>
<td>5 Decreased and inconsistent pitch range capabilities in singing</td>
</tr>
<tr>
<td>6 Increased incidence of abrupt register transition or <em>breaks</em> in singing</td>
</tr>
<tr>
<td>7 Generally uncomfortable singing or effortful phonation</td>
</tr>
</tbody>
</table>


In developing a model illustrating the female voice change, Gackle reflected the gradual shift in vocal character by referring to gradations of change as *phases* rather than *stages* or *periods*.\(^{316}\) According to Gackle, phasic adjustments occur in females more slowly than in males. She undertook a longitudinal study in order to delineate “predictability patterns” in female voice change (see Table 13).\(^{317}\)

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\(^{316}\) Gackle, 19.

\(^{317}\) Gackle, 19.
Table 12. Phases of female adolescent vocal development

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2A</th>
<th>Phase 2B</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepubertal Unchanged</td>
<td>Pre-Menarcheal Beginning of mutation</td>
<td>Post-Menarcheal Climax of Mutation</td>
<td>Young Adult</td>
</tr>
<tr>
<td>Singing Range: B3-F4</td>
<td>Singing Range: A3-G4</td>
<td>Singing Range: A3-F4</td>
<td>Singing Range: B3-F4</td>
</tr>
<tr>
<td>Speaking Range: C3-D#3</td>
<td>Speaking Range: Bb3-C#3</td>
<td>Speaking Range: A3-C3</td>
<td>Speaking Range: G3-Bb3</td>
</tr>
<tr>
<td>Lift Points: F3-A#3</td>
<td>Lift Points: F3-A#3, D4-F#4</td>
<td>Lift Points: D4-F#4</td>
<td></td>
</tr>
<tr>
<td>Vocal Character: • clear quality • like boys voice • no register breaks • flexible/agile</td>
<td>Vocal Character: • similar range to Phase 1 • register breaks • loss of upper range • may have difficulty in lower range</td>
<td>Vocal Character: • huskiness • 2 register breaks • easy low notes • discomfort in phonation • tessitura varies • breathiness or cracking</td>
<td>Vocal Character: • more richness in perceived quality • range increases • greater consistency in registers • decreased breathiness • some vibrato • greater flexibility • volume and resonance capabilities increase</td>
</tr>
<tr>
<td>Assigned Part: Soprano I</td>
<td>Assigned Part: Soprano I or I</td>
<td>Assigned Part: Soprano II or Alto</td>
<td>Assigned Part: Soprano I, II or Alto</td>
</tr>
<tr>
<td>Ages: Up to 8-10 or 11</td>
<td>Ages: 11-12 (13)</td>
<td>Ages: 12-14 (15)</td>
<td>Ages: 14-17 (18)</td>
</tr>
</tbody>
</table>


Note: *Lift points* is the term Gackle uses to denote the transition point the upper passaggio.  

**Choral Summary – Female Transition**

While less evidentiary information has been codified regarding the female changing voice, educational models are available to assist teachers and trainers. Curricula proactive in addressing mutational onset will likely serve to build
individual esteem in girls as they notice differences in their ability to sing. Additionally, insights into the self-concept of young singers reveal that “vocal identity” and esteem are undeniably bound. Gackle, Phillips, and Monks share the ideology that, through teacher education, successful “cultivation of the adolescent changing voice…” can be achieved.

Pediatric Singers and Vocal Ability

Ability has many meanings for young singers. To music psychologists like Sloboda, ability refers to skill acquisition and development. In music education parlance, ability, aptitude, and talent all denote specific implications regarding a child’s capability in music. However, the notion that “music ability cannot be defined solely in terms of productive competence” is one that serves well in training young singers.

The youngest singers display developmental competencies that will either demonstrate vocal pitch accuracy or not. If music educators teach singing in early childhood as a developmental behavior rather than an innate ability, it is likely there will be more successful singers. Music educators can mishandle distinguishing singing and ability. Children may not display the developmental coordination for accurate pitch singing up to 7 years old by Gordon's paradigm,

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320 Gackle, 119.
324 Welch, 706.
and even up to age 9. Davidson and other music educators state that singing is a learned skill. In order to train the youngest singers, neuromuscular facility must be gained. Patience is likely required with developing singers. If the expectations of pitch matching are present advance of developmental capability, negative labeling can result. O'Neill and Sloboda tested children ages 6-10 individually in the ability to discern melodic direction. Afterward, the children who failed felt less confident and their subsequent ability deteriorated. Because of results like this, it is incumbent upon voice trainers to develop schema that will offer the possibility for all children to feel successful.

Summary

Research in child development and the observations of pedagogic voice training paradigms offer complimentary insight into the musical capability and vocal development of young singers. Successful curricula for children and adolescents will likely contain strategies derived from a combination of both. Establishing training schema that incorporate; (1) knowledge in child developmental ability, aptitude, talent, and capability, (2) observational guidance of voice practitioners, and (3) understanding of the vocal mechanism as a developmental organ and instrument of phonation, will likely lead to authentic techniques that are both practical and successful.

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CHAPTER FOUR

Results

*Teachers and conductors who work with children must have the appropriate knowledge regarding voice use for the young and changing voice.*

Introductory Remarks

Just as singing is a learned skill, the teaching of singing is a learned skill as well. It is a vocation that likely begins with the best of intentions. However, teaching requires knowledge, often specific and detailed. Voice pedagogues can combine observational assessments of vocal machinations with scientific findings of anatomical structure and development to broaden their overall knowledge of the vocal instrument. Therefore, if power can be derived from knowledge, as stated in the maxim, synergy between scientific research and voice training approaches will likely result in more authentic teaching practices.

Synergy Between Voice Science and Pedagogical Observation

*Making Sound*

The abilities to phonate, speak, and sing are incidental capabilities of the larynx. The aryepiglottic sphincter (false folds) provides the first line of defense against foreign objects in the larynx. The vocal folds are the vibratory mechanism of sound. This glottis is the opening of the vocal folds — the midline at the point of phonation. The vibratory mechanism alone cannot make sound.

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329 Esther Jane Hardenbergh, "Resonance and the vocal tract" (lecture, Advanced Vocal Pedagogy, University of Miami, Coral Gables, FL, March 29, 2010).
Vibration is spurred with an influx of air (respiration) that creates the subgottal resistance necessary to incite the vocal folds into vibration.

Anatomical, physiological, anthropological, and sociological research revealed human beings’ need for communication. Human anatomy evolved into a physiology that enabled speech. Researching human speech led scientists to explore the supraglottal region of the pharynx, or the human vocal tract. The vocal tract, articulatory facility, and laryngeal decent all contribute to the acoustical resonance required for sound, speech, and singing. Teachers and singers who understand vocal tract resonance can best realize the phonatory capabilities of the voice. Hence, voice scientists interested in acoustics create studies whose results deepen our understanding of vocal acoustics. Since vocal tract length and breadth both affect the developing singer, especially during mutation, knowledge of vocal tract size, shape, and acoustical possibility can inform teaching practices. Information regarding expectant supraglottal resonance capability allows teachers to surmise resonance possibilities in children, by which they can train and attune their diagnostic ear toward a realistic sound.

*Prepubertal Physiology and Singing*

*Cartilages.* Babies are born with a thyroid cartilage that has a height of approximately 22 mm from superior cornu to inferior cornu. The average height an adult thyroid cartilage is a little more than twice that of an infant.330 The cartilaginous structure of the larynx grows gradually with the growth of the child

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330 Wysocki et al., 194.
until a hormonal influx at puberty accelerates this growth. Minute gradations of ossification are also thought to begin at puberty, culminating in the total ossification of the laryngeal cartilages as an adult between the ages of 26 and 53.  

At birth, vocal fold length is approximately the size of the infant’s thumbnail, or about 6-8 mm. Also, the infant larynx sits high in the neck, making the vocal tract smaller. Young laryngeal cartilages are not as thick as those of adults. This is not to say that the child’s vocal ability is weak due to a thinner cartilaginous façade; rather, this characteristic makes the child’s laryngeal structure more pliant. By about age ten, the cartilages are similar in thickness to those of the adult larynx.


Source: Data based on and adapted from the schema of Kahane, Titze, and Hartnick et al.

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The pediatric vocal fold begins to resemble that of the adult vocal fold by age 13. The adult fold is complex. Most voice scientists agree that it is principally a mucosal body comprised of three layers. Due to this common “three-layer” description, it is sometimes referred to as tri-laminate (see Table 13).

For voice pedagogues who teach children, it is important to understand the tri-laminate structure of the vocal fold and its evolution (see Table 14). The vocal fold or lamina propria is mono-layered at birth, but becomes bi-layered by 5 months. The bi-layered pediatric vocal fold has a superficial layer that is over five times as thick as the adult superficial layer; it will maintain this physiology up until age 7. Considering how children typically use their voices between 5 months old and 7 years of age, the extra collagen and elastin in the thicker pediatric vocal fold appears to offer protection from early childhood voice use. Collagen and elastin provide an elasticity that makes the vocal folds resilient, supple, and flexible. By seven years of age, the third layer of the lamina propria begins to form and the thick pediatric superficial layer begins to thin. Beginning at age 10, the physiology of the pediatric vocal fold starts to resemble that of the adult vocal fold; meanwhile, the vocal ligament (the thick, fibrous membrane in the intermediate and deep tissue of the lamina propria) begins to transition. The prepubertal vocal ligament originally mono-layered, becomes bi-layered in puberty.\textsuperscript{332} The transition of the lamina propria seems to antecede the

developmental requirements of childhood voice use and provides the physiological attributes that healthy vocal maintenance would likely necessitate.

Table 14. Developmental sequence of the pediatric lamina propria.

Parallels in Science and Pedagogy - Prepuberty

The possibility that pediatric vocal folds adjust to accommodate the requirements of developmental maturation can be good news for educators who
train child singers. This could mean that the child vocal mechanism is viable for the physical demands children tend to apply. Since the perception exists among a faction of voice pedagogues that children’s singing voices are fragile, potential physical evidence to the contrary is likely to be controversial.\(^{333}\)

Voice trainers tend to presume that the prepubertal voice is delicate due to the speculations and observations of voice theorists from the past 100 years.\(^{334}\) Though pediatric voice science may not be technologically ready to pinpoint the exact moment of mutational onset, recent histological findings regarding the pediatric vocal fold seem meaningful. Research in pediatric laryngeal physiology, therefore, impacts the field of pediatric pedagogy; current findings likely reinforce the charges of Cooksey, Gackle, and Smith & Sataloff for voice educators to know the instrument with which they work.

**Summations of Parallels in Voice Science and Prepubertal Observations**

In an effort to better assess the implications between scientific research and pediatric pedagogy, it may be useful to identify salient findings (see Table 15). Characteristics that voice trainers interpret as abnormal voice production may actually be developmentally normal. As reflected in Table 15, vocal qualities exist that may be explained by normal childhood growth. Whether or not areas of vocal concern are indicative of normal growth is not likely to be discerned by the aural evaluation of a voice teacher. Because of this, teachers tend to send students for whom they have concerns to be evaluated by an otolaryngologist. However, if the vocal folds are normal, that is, within expected healthy

\(^{333}\) Skelton, 537.
\(^{334}\) Skelton, 538.
parameters, the otolaryngologist will likely have nothing evidentiary to report.

This may be a source of frustration for teachers, especially if the observed vocal concern continues. Perhaps, an alternate plan for the vocal evaluation of pediatric singers should be considered.

**Table 15. Connections between voice science and pediatric pedagogy: Prepuberty**

<table>
<thead>
<tr>
<th>Vocal Concerns</th>
<th>Histological Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preschool children shouldn’t sing too…high, loud, long</td>
<td><strong>Vocal Ligament</strong>&lt;br&gt;• Children in early childhood have a vocal ligament that began to develop <em>in utero</em>.&lt;br&gt;• The vocal ligament supports the integrity of the vocal fold, similar to the steel belt reinforcement of a radial tire.</td>
</tr>
<tr>
<td>Chronic hoarseness</td>
<td><strong>Superficial Layer of the Lamina Propria</strong>&lt;br&gt;• The pediatric superficial layer is 5 times thicker than the adult superficial layer. &lt;br&gt;• The thicker superficial layer has groupings of collagen and elastin that act like &quot;water balloons&quot; buffering the impact of vocal fold adduction.&lt;br&gt;<strong>Omega-shaped epiglottis</strong>&lt;br&gt;• Common among young children, incidental and usually resolves.&lt;br&gt;• Noninvasive, however, size and shape of the epiglottis and the vocal tract may cause a &quot;muffling&quot; effect perceived as hoarseness.</td>
</tr>
</tbody>
</table>
| Escaping air in the sound                    | **Vocal Folds**<br>• The prepubertal vocal folds are short and thick; vocal fold thickness compromises glottal closure.<br>• The elastin and collagen groupings in the superficial layer can *clump* inconsistently affecting glottal seal.<br>**Muscular Process of Arytenoid Cartilages**<br>• The length of the muscle process is significantly shorter than an adult’s; causing a lack of muscular tension that can result in an incomplete glottal seal.  
**Posterior Glottal Chink (PGC)**<br>• PGC is a normally occurring phenomenon at the level of the glottis whereupon complete closure is prevented by a triangular gap. |

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335 Titze, 37.<br>336 Nita et al., 692
One consideration could be that vocal issues (i.e. breathiness or hoarseness) may actually begin with inefficient habits in speech rather than in singing. Speech is referred to as “mode” by speech pathologists or the most frequently used register in speech. Unlike otolaryngologists who evaluate physiology, speech pathologists evaluate modal behavior patterns. Succinctly, there are two types of modal speech; habitual pitch level and optimal pitch level. It is the habitual pitch level mode that can be problematic. The vocal range limitation in habitual pitch level speech, whether centered too high or too low compared to optimal pitch level speech, can result in dysphonic behaviors like hoarseness and fatigue. According to Morrison, frequent use of habitual pitch that is too low is the most common reason for vocal abuse pathology.

It could be said, then, that speech pathologists and voice teachers share a concern for vocal health and that both strive to resolve vocal faults. Since speech pathologists have been trained to assess patterns and habits in the production of speech sounds, their assessments may offer the insight sought by voice teachers. Also, if a speech pathologist suspects that physical evaluation is necessary, they will likely consult with an otolaryngologist in order to devise the appropriate therapeutic regimen.

For teachers who work with young singers, the speech pathologist could offer previously overlooked remediation. Speech therapy may resolve vocal issues heard by the voice teacher, not only to offer the possibility of mitigation,  

338 Morrison, 167.  
339 Morrison, 168.
but also to create new habits for speech that will likely result in overall improvement in vocal quality.

*Singing Through Mutation*

Though historically there existed a belief that the voice would be injured by continuing to sing through adolescence, current prevailing thought supports the opposite observation. Even some British cathedrals' current stance does not cite pedagogic reasons for cloistering boys in mutation; rather, some are fighting to maintain the aesthetic sound or culture that reflects their identities as performing entities. Contemporary technology will expose even one boy’s changing voice, making it impossible for boys in transition to be retained in cathedral choirs even as long as they had been previously. It is the preservation of the desired cathedral choir sound that continues the British tradition of exclusion of boys during their vocal transitions.340

*The Appearance of Mutation in the Pediatric Voice*

Puberty is a time of growth excitation. As a hormone-dependent structure, the larynx will likely be one of the first areas of the body in which changes are evidenced. Approximately six months prior to the initial growth signs of secondary sex characteristics (i.e. skeletal growth, increased body hair, menarche, breast development), an influx of hormones occurs that initializes the pubertal transition. Inconsistencies in vocal quality or production that were

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previously not present in a singer’s sound will likely be a teacher’s first clue to impending vocal transition.

Phasic Growth of Cartilages and Membranes

*Cartilaginous Growth Model for Male and Female Adolescents*

Laryngeal cartilage development has been observed in stages by researchers. It has been observed that the parameters by which measurements are assessed vary. For the purposes of this study, the measurements of Wysocki et al. will be used. Though parameters of measurement may vary between researchers, evidentiary growth comparisons should remain relative.

Comparing the average growth of the maximum height of the thyroid lamina between pubescent males and female shows differences, but differences within scientifically significant parameters are not exhibited (see Tables 16 and 17). However, a marked surge in growth excitation for both genders is evident between childhood and puberty (see Table 16, “Child” and “Pubescent”). Similarly, growth documented in the sagittal dimension of the cricoid cartilage indicates excitation for both genders also in childhood and puberty (see Table 17, “Child” and “Pubescent”). These findings illustrate in a compelling way the transition from childhood to adolescence.

**Table 16. Growth of thyroid cartilage lamina at maximum height.**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Infant (0-2 years)</th>
<th>Child (3-7 years)</th>
<th>Pubescent (8-12 years)</th>
<th>Adult (unspecified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>27.9 mm</td>
<td>34.8 mm</td>
<td>56.3 mm</td>
<td>54.9 mm</td>
</tr>
<tr>
<td>Female</td>
<td>23.5 mm</td>
<td>28.8 mm</td>
<td>42.8 mm</td>
<td>47.1 mm</td>
</tr>
</tbody>
</table>


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Wysocki et al., 197.
Table 17. Growth of sagittal dimension of cricoid cartilage.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Infant length (0-2 years)</th>
<th>Child length (3-7 years)</th>
<th>Pubescent length (8-12 years)</th>
<th>Adult length (unspecified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>13.9 mm</td>
<td>15.3 mm</td>
<td>25.5 mm</td>
<td>28.4 mm</td>
</tr>
<tr>
<td>Female</td>
<td>11.3 mm</td>
<td>12.0 mm</td>
<td>21.9 mm</td>
<td>26.7 mm</td>
</tr>
</tbody>
</table>


Fig. 37. Rima glottis (indicated by blue and green arrow).

Table 18. Elongation of sagittal midline of rima glottis (see Fig. 37).

<table>
<thead>
<tr>
<th>Sex</th>
<th>Infant (0-2 years)</th>
<th>Child (3-7 years)</th>
<th>Pubescent (8-12 years)</th>
<th>Adult (unspecified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>10.5 mm</td>
<td>12.0 mm</td>
<td>18.9 mm</td>
<td>29.6 mm</td>
</tr>
<tr>
<td>Female</td>
<td>7.3 mm</td>
<td>14.5 mm</td>
<td>18.3 mm</td>
<td>19.2 mm</td>
</tr>
</tbody>
</table>


Membranous Growth Differentiation by Gender

*Female.* Gender differentiation is principally evidenced in the growth of the rima glottis (which indicates the lengthening of the mucosal membranes or vocal folds) and not in the growth of the laryngeal cartilages. In females, the most growth in the vocal folds (indicated by the elongation of the rima glottis) is evidenced during two life stages; (1) the transitional period from infancy to child (see Table 18, “Infant” female and “Child” female) and (2) the transitional period from childhood to puberty (see Table 18, “Child” female and “Pubescent” female).
The physiological growth reported by Wysocki et al. seems to indicate a reasonably steady and consistent progression. Also, as previously stated, the duration of female voice change is accompanied by subtle growth permutations observed by girls in transition. Growth permutations observed by females seem proprioceptive. Both duration and cognition were noted in the work of Gackle and Monks. The findings of Wysocki et al., Gackle, and Monks led to the determination that the female voice change is period of transitional cognizant mutation; that is, females are believed to be cognizant of subtle and consistent physiological transitions in the larynx. Females can experience transitional cognizant mutation of the voice for a period of approximately two years.

**Table 19. Female voice change. ***Transitional, cognizant mutation.*

\[\text{Premutational Cognizance} \quad \text{Subtle Cognizant Growth Permutations} \quad \text{Emergence of Adult Vocal Fold Morphology} \quad \text{2-year transitional process}\]

*Male.* Substantial mutation in male vocal fold physiology is evidenced during two life stages; (1) the transitional period from childhood to puberty (see Table 18, “Child” male and “Puberty” male) and (2) the transitional period from puberty to adult (see Table 18, “Puberty” male and “Adult” male). Growth documented in transitional period (1) and transitional period (2) is appreciable.
Specifically, male vocal mutation has two overlapping phases that include irregular mutational events:

**Stage I. Early Mutational Onset.** This phase is the transitional period from “Child” to “Pubescent” (see Table 18). During early mutational onset, there are two areas of simultaneous growth in the laryngeal infrastructure:

(a) cartilaginous growth and

(b) membranous growth phase 1.

Membranous growth phase 1 is the first of two substantial growth phase events and occurs in the early onset of voice mutation.

**Stage II. Mid-Mutational Pivot.** Mid-mutational pivot occurs during the transitional period from “Pubescent” to “Adult” (see Table 18). During this stage, two observations occur:

(a) cartilaginous growth subsides

(b) membranous growth phase 2 occurs

Membranous growth phase 2 seems to coincide with mutational climax, which is a *pivot point* toward stabilization in the mutating voice. It is during the stage of Mid-mutational pivot, Cooksey’s stage of *mutational climax*, that voice trainers who work with they male transitioning voice may encounter a male singer with; (1) strengthened treble range (2) capability for greater volume and phrase sustainability (3) possibility for vibrato when previously none was present.342 This brief period in the male changing voice is likely the nearest contemporary example of the vocal production

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342 Craig Denison, "Male changing voice" (lecture, The boy’s changing voice: new dimensions, Villanova University, Villanova, PA, July 2011).
of the castrato. The greater respiratory power of an older boy in conjunction with incomplete vocal fold mutation (completion of Stage I growth only) may create a vocal sound similar to the male castrato based on physiology described by Abitbol et al.\(^{343}\)

**Table 20. Male voice change. Aperiodic, phasic mutation.**

<table>
<thead>
<tr>
<th>STAGE I</th>
<th>STAGE II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Mutational Onset</td>
<td>Mutational Pivot and Stabilization</td>
</tr>
<tr>
<td>Cartilage Growth</td>
<td>Cartilage Growth Subsides</td>
</tr>
<tr>
<td>Vocal Fold Growth Phase 1</td>
<td>Vocal Fold Growth Phase 2</td>
</tr>
</tbody>
</table>

The research of Wyscoki et al., Cooksey, and Gackle as well as the observations of leading practitioners led to an understanding of the male voice change that can be described as irregular or *aperiodic*. Additionally there is life stage growth complicated by phasic membranous transition. Research has led to the understanding of the male voice change as a period of *aperiodic, phasic mutation* (see Table 20). Males may experience aperiodic phasic mutation for a period of 6 months to 5 years. However, during voice change boys are typically only cognizant of overt growth events and observable pitch fluctuation in speech.

Gender differences in the prepubertal larynx are subtle, and the voices of

\(^{343}\) Abitbol et al., 426.
male and female children and are often said to be aurally indistinguishable. However, variances exist that can clarify adolescent mutation and gender differentiation. Both the male and female laryngeal structures transition through discernable phasic states. Voice change in female adolescents differs from that of male adolescents in that girls experience their voice change as a progression that is constant and durational, typically lasting two years. Boys tend not to be cognizant of their voice change as a consistent presence, but more as a series of aperiodic events that cause observable bursts in growth. The male voice change has two phases. Phase 1 occurs in early mutational onset, characterized by both cartilaginous growth and membranous development. As growth of the laryngeal cartilages begins to subside, a second considerable event occurs that is likely at the point of mutational climax.

Stabilization Through Growth: Consistency in the Muscular Process

The growth of the muscular process of the arytenoid cartilage was meaningful to researchers. Also, findings offered insights that could be relevant to voice pedagogues in developing a better understanding of the relationships among the machinations of the vocal folds, intrinsic muscles, and muscular processes in forming glottal closure. As stated previously, a short muscular process causes a propensity for laxity in the muscles compromising glottal closure. Upon reviewing research findings in the growth of the muscular process, it seems that the growth of the muscular process is steady and consistent (see Table 19). Steady growth in the muscular process likely creates stability between cartilaginous growth and membranous growth.
Table 21. Growth of muscular process of arytenoid cartilage.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Infant length (0-2 years)</th>
<th>Child length (3-7 years)</th>
<th>Pubescent length (8-12 years)</th>
<th>Adult length (unspecified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>4.8 mm</td>
<td>5.7 mm</td>
<td>9.8 mm</td>
<td>11.7 mm</td>
</tr>
<tr>
<td>Female</td>
<td>5.2 mm</td>
<td>5.6 mm</td>
<td>8.1 mm</td>
<td>9.9 mm</td>
</tr>
</tbody>
</table>


**Summation of Parallels in Voice Science and Adolescent Observation**

Current science provides voice teachers with the opportunity to gain insights into the development of the adolescent voice. Puberty can be taxing for adolescents — those who are pubescent are often behaviorally inconsistent, which seems to reflect the changes in their bodies and in their voices. Because of this, training adolescent singers can present situations in which teachers feel ill-equipped to succeed. However, the more that is understood about the changing voice, the better able teachers will likely be to develop effective practices (see Table 20).
### Table 22. Connections between voice science and pediatric pedagogy: Adolescence

<table>
<thead>
<tr>
<th>Physiological Characteristics of Adolescent Voice Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cartilages</strong></td>
</tr>
<tr>
<td>• Mutation of the laryngeal cartilages happens <strong>EARLY</strong> in mutation and includes:</td>
</tr>
<tr>
<td>o Thickening of walls and initial ossification creating ability for more tension in intrinsic musculature</td>
</tr>
<tr>
<td>▪ Pitch acuity</td>
</tr>
<tr>
<td>▪ Glottal closure</td>
</tr>
<tr>
<td>o Retraction of cornu for more compact structure</td>
</tr>
<tr>
<td><strong>Lamina propria</strong></td>
</tr>
<tr>
<td>• Major growth likely occurs mid transition during mutational climax</td>
</tr>
<tr>
<td>o <strong>EARLY</strong> in transition</td>
</tr>
<tr>
<td>▪ Areas of collagen and elastin group in to irregular regions</td>
</tr>
<tr>
<td>▪ Collagen and elastin regions form throughout layer</td>
</tr>
<tr>
<td>▪ These regions create lumps impacting adduction</td>
</tr>
<tr>
<td>o <strong>LATE</strong> in transition</td>
</tr>
<tr>
<td>▪ Collagen and elastin regions form long thin fibers</td>
</tr>
<tr>
<td>▪ The fibers integrate into the body of the lamina propria</td>
</tr>
<tr>
<td>▪ No more lumps</td>
</tr>
<tr>
<td><strong>Hormonal Influx</strong></td>
</tr>
<tr>
<td>• Responsible for mutational onset</td>
</tr>
<tr>
<td>o Aperiodic growth spurts, stages, or phases</td>
</tr>
<tr>
<td>▪ Female transition approximately 2 years</td>
</tr>
<tr>
<td>▪ Male transition 2-5 years</td>
</tr>
<tr>
<td>• Excessive hormonal presence in body creates dryness in mucosa</td>
</tr>
<tr>
<td>o Dryness causing swelling (edema) responsible for:</td>
</tr>
<tr>
<td>▪ Hoarseness</td>
</tr>
<tr>
<td>▪ Inconsistent glottal closure</td>
</tr>
<tr>
<td>▪ Air present in sound</td>
</tr>
<tr>
<td><strong>Vocal Ligament</strong></td>
</tr>
<tr>
<td>• Single band doubles by age 13 stabilizing vocal fold</td>
</tr>
<tr>
<td><strong>Muscular Process of Arytenoid Cartilages</strong></td>
</tr>
<tr>
<td>• Muscular process begins to lengthen for more complete glottal closure</td>
</tr>
<tr>
<td><strong>Posterior Glottal Chink (PGC)</strong></td>
</tr>
<tr>
<td>• PGC will likely resolve, though not always</td>
</tr>
</tbody>
</table>
CHAPTER FIVE

Vocal music is especially potent, emanating from deep within the human body itself rather than an external object. Being unmediated, singing is a peculiarly intense expression and exploration of the inner self. Crabbe, 2005

SUMMATION, CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

Summation

The purpose of this study was to determine if synergistic parallels existed between research findings in the voice science community and teaching practices in the voice pedagogy community. The results of this study indicate that there are salient connections between the two fields of study. These connections serve to both inform the vocal education community of current physiological findings for consideration in pedagogical practices and the voice community of the relevance of their research toward vocal health in singing.

This study surveyed amassed literature both concerning the evidentiary findings in voice science and the research-based, observational and suppositional paradigms practices of voice educators. Review of the literature was delineated by subject: (1) voice science and (2) voice pedagogy. Delineating the subject areas provided focused concentration on one area of consideration at a time. This approach enabled the rendering of progressive developmental timelines that would serve as the resource for ascertaining connections between the subjects.

An initial step in comparing the scientific and pedagogical literature was to
determine whether connections existed from which an authentic developmental
timeline could be created. Particular attention was paid to growth bursts in
laryngeal development and they were assessed for evidentiary meaning.
Research results determined to be compelling were extracted from studies and
presented in adapted tables. Compelling research findings were compared with
practical observations in order to interpret any meaningful parallels.

Conclusions

Based on this study, the following conclusions can be made (see Table 23):
1. New modalities in laryngeal assessment provide a more accurate picture
   of the pediatric vocal mechanism.
2. Scientific findings provide context for observational assessment of the
   pediatric singer.
3. Characteristics that seem or present as pathological may be
devolutional and normal.
4. The pediatric voice is pliant and resilient; therefore, it supports the way
   children and adolescents use their voices.
5. The mutational laryngeal structure will successfully accommodate shifts in
   coordination caused by adolescent growth events if adolescents sing
   through mutation.
6. The existence of both PVS (premenstrual vocal syndrome) and PGC
   (posterior glottal chink) provide insights into possible anomalous behaviors
in the pediatric female voice that are likely normal. In the case of PGC, this may be the case for some prepubescent males as well.

7. Physiological, cognitive, and emotional development is not exclusive of each other when determining strategies for voice training.

8. Female voice change is characterized by, (1) duration — a transitional time of about 2 years, and (2) cognizance — girls having awareness that something in their singing voice is different.

9. Male voice change is characterized by two overarching and overlapping growth cycles. During the first cycle both the cartilage and the vocal folds growth and during the second, the majority of considerable growth occurs in the vocal folds only. Within these stages, growth is sporadic and its timing is unpredictable, but sequential.

10. The influx of hormones is responsible for adolescent onset or the changing voice. In girls this begins sometime in the growth stage identified by Wysocki et al. as “child (age 3-7 years).” In boys, this begins sometime in the growth stage Wysocki et al. identify as “pubescent (age 8-12 years).”

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Table 23. Synergy between voice science and voice pedagogy.

Discussion

This study illustrates that there parallels that exist between voice science and voice pedagogy that are relevant to both fields. Through the review of the literature, it is clear that both research and opinion exists regarding the pediatric
voice, but the fields intersect infrequently. Voice pedagogues excel in their observational analysis of the developing vocal mechanism and so there seems to be a presumption that that is sufficient. Similarly, voice scientists’ research on the voice as a mechanism is seemingly divorced from the practical application for the voice teaching community. Though a movement exists through The National Center for Voice and Speech\textsuperscript{346} to open channels between voice science and voice pedagogues, this dialogue is new and not yet present in dialogues at the national level. Additionally, the Center’s educational offerings will likely attract a narrow sampling of vocal pedagogues and not the “average” voice trainer.

Voice teachers need to consult the latest findings in pediatric laryngology in order to create authentic practices for teaching the pediatric voice. It has been the habit of a faction of teachers to inject the field of pediatric voice training with supposition, conjecture, and opinion that is fear-based. The result of such speculation can lead to voice teaching that is inadequate and may cause the bad vocal habits they are intended to prevent.

The pediatric vocal mechanism can tolerate the act of singing in a manner that is similar to that of an adult. It is not the mechanism is that is the issue; rather it is cognitive developmental issues that affect vocal ability and capability. As identified by Gordon, Bluestine, Thurman & Welch, children may have developmental capability/ability landmarks or cognitive processes that either allow or impede melodic pattern comprehension. This will affect singing

ability/capability, not the vocal instrument itself, as long as the instrument is normal.

It is important to distinguish the act of singing from the sound produced by the pediatric mechanism and the adult mechanism. The pediatric and adult sound will be different because the morphological structure is different. However, because the morphological structure of the pediatric larynx and the adult larynx differ, that does not affect the mechanism’s tolerance for the act of singing. Both mechanisms are designed to tolerate the phonatory emissions expected of them, including singing. If a child can cry, then he can sing. If a child can yell, then she can sing — as long as the vocal mechanism develops normally; hence, the physical act of singing is somatic. Additionally, other physiological capabilities such as lung capacity, vocal fold length, vocal tract space (resonance), and speech behavior patterns will affect the sound produced by the pediatric vocal mechanism, but not the mechanism’s ability to produce sound.

Children can sing songs; that is, make accurate phonatory emissions that are representations of learned and recalled melodic patterns if (see Table 24):

1. The pediatric laryngeal structure is normal (soma).
2. They possess the developmental ability/capability to recall melodic patterns (process).
The child voice previously described as delicate by some conservative teachers, in reality is extremely resilient. The complex pediatric laryngeal structure is designed to accommodate excessive voice use. In the membranous structure of the vocal folds, a thick layer of clumps of collagen and elastin group together to form buoyant structure five times that of the adult layer. It is undoubtedly a structure designed to anticipate the demands of crying, yelling, and screaming. The cartilaginous structure is pliant and flexible. Its design seems to anticipate the developing physique of infants and young children and their activities level. The supple cartilages in the laryngeal structure are able to endure shock, and the actions of sucking and swallowing that are actions prevalent in early life.
Recommendations

The results of this study provide connections between voice science and voice pedagogy that may not have been previously identified. These connections are critical to voice professionals in comprehending the uniqueness of the pediatric vocal instrument. Once a practical and true understanding of the physiology of the pediatric voice is discerned, an authentic vocal curriculum for children and adolescents can be realized.

This study was intended to consult the work of choral pedagogues and expand upon their paradigms, framing this research within a specifically vocal context. Choral paradigms tend to guide repertoire and composition. In so doing, range expectations are offered. This study intended only to delineate the scientific research in order to gain an accurate assessment the developmental stages of the voice in childhood and adolescence.

Studies in the relationship between singing in adolescence and adolescent identity were of particular interest to this research. Further studies in this regard would be beneficial. It was observed that there are studies in the development of both male and female identity during adolescence. While complete investigation of this topic was beyond the scope of this initial study, it is nonetheless topical. Just as males and females have divergent pages in vocal mutation, they experience the impact of identity differently. Up until adolescence, children have a sense of who they are. That is, they have the voice they have always known. This knowledge of self is questioned when the voice they know is changing and will ultimately not longer exist. For females, it seems that cognizant transitional
mutation reflects a durational aspect to this identity crisis. Since they are aware of voice change while it is happening, females are consistently faced with their evolving identity and the questioning of who they are. For males, the abrupt nature of aperiodic phasic mutation may not represent a consist reminder of identity shift or loss, but seems to create an urgency in boys to know who they will be; that is, *when will the man emerge…and who will I be until then?*

The vocal mechanism, whether pediatric, adolescent, adult, or aging is an instrument that evolves with human beings as they grow, change, and age. During the continuum of a human being’s vocal life, excitations in growth punctuate the evolving voice, sometimes upsetting this continuum. The voice is resilient and practical in its morphology. As it develops, the body prepares the way for the subsequent life stage, providing the opportunity for the voice to remain healthy and the voice user to enjoy the capabilities of it for a lifetime.

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abduct. To move apart.

adduct. To bring together.

anterior. Toward the front.

arytenoid cartilages. Paired cartilages at the posterior of the laryngeal structure to which the vocal folds are attached.

aryepiglottic schincter. First line of defense against foreign objects in the larynx. False folds, situated above the true vocal folds.

Bernoulli’s principle (effect). If the energy in a confined fluid stream is constant, an increase in particle velocity must be accompanied by a decrease in pressure against the wall.

ciliated. Possessing hair or cilia.

circumpubertal. Occurring around the time of puberty.

collagen. Structural protein in connective tissue.

columnar. vertical

conus elasticus. Fiberelastic membrane extending from the vocal folds to the cricoid cartilage.

cricoid cartilage. A solid ring of cartilage located below the thyroid cartilage.

cricothyroid muscle. Paired intrinsic laryngeal muscle used primarily to control pitch.

diaphragm. A large, dome-shaped muscle at the bottom of the ribcage that bisects the torso. It is the primary muscle of inspiration.

elastin. Fibrous and elastic protein-type in connective tissue.

epiglottis. Leaf-shaped cartilage that covers over the larynx during swallowing.

epithelium. The cover of body surfaces.

esophagus. Tube leading from the bottom of the pharynx to the stomach transporting food.

extrinsic muscles of the larynx. The strap muscles in the neck that stabilize the laryngeal structure and adjust its height.

endoscope. A lighted instrument or speculum.

glottal chink. Posterior opening in the glottis during adduction of the vocal folds.

hormones. Substances produced in the body that affects organs and bodily functions.

hyoid bone. An omega-shaped bone that is not directly articulated to another bone. It is attached to the laryngeal structure through muscles and related structures.

histology. Microscopic structure of tissues.

in utero. Before birth.

in vivo. In the living body.

in vitro. Outside the living body.

inferior. Below

interarytenoid muscle. An intrinsic laryngeal muscle that connects the two arytenoid cartilages.

intercostal muscles. Muscles between the ribs.

intrinsic. Contained within the structure.

intrinsic laryngeal muscles. Muscles within the larynx that are responsible for the lengthening and shortening of the vocal folds, as well as their adduction and abduction.

intubation. Insertion of a tube in trachea.
**lamina propria.** The tissue layers below the epithelium. In the adult vocal folds, it consists of a deep, intermediate and superficial layer.

**laminate.** Protective layer or surface.

**laryngeal prominence.** The “notch” of the thyroid cartilage at its midline that forms the Adam’s Apple.

**laryngeal sphincter.** The closure created by the action of the epiglottis in order to protect the airway.

**laryngologist.** Physician specializing in the disorders of the larynx and voice.

**laryngoscopy.** A visual examination of the vocal folds.

**larynx.** An organ of the body found in the neck that house the vocal folds.

**lateral.** To the side; away from midline.

**lateral cricoarytenoid muscle.** Intrinsic laryngeal muscle. One of the paired muscle set (the other being the interarytenoids) responsible for the adduction of the vocal folds.

**ligament.** Short of tough fibrous membranes.

**medial.** Toward the midline or center.

**morphology.** Study in the form of an organism.

**morphometric.** Measurements of the external shape of a structure.

**mucosa.** The covering of the surfaces of the respiratory system, including the, nasal cavities, larynx and lower airways.

**muscle.** Band of fibrous tissue that has the ability to contract, producing movement.

**muscle fiber.** A lone, thin cell; the basic unit of the muscle that is excited by a nerve ending.

**mutation.** The action or process of changing structure.

**neural.** Of or relating to the nervous system.

**ophthalmology.** The branch of medicine that deals with anatomy and physiology of the eye.
optical coherence tomography. A modality that measures infrared light backscattered from within tissue thus providing a cross-section of images resembling vertical sections of tissue structure.

otolaryngologist. Physician whose expertise deals with the ears, nose, and throat.

otologist. An otolaryngologist whose specializes in the ear.

palpate. Examine by touch.

passaggio. The transition between registers in the voice.

pathology. Abnormality

pediatric. Dealing with children.

perturbation. Slight disturbance in predicted behavior.

pharynx. Located in the posterior of the oral cavity between the larynx and the velum.

phonation. The generation of sound using the vocal folds.

plastination. Method of preservation in which tissue is dehydrated in acetone and preserved in epoxy resin.

posterior. Toward the back.

posterior cricoarytenoid muscle. Paired intrinsic laryngeal muscle that engages to achieve abduction of the vocal folds.

premenstrual vocal syndrome. A syndrome that generally begins 4-5 days in advance of menstruation, characterized by vocal fatigue, decreased range, and loss of certain harmonics.

prepubertal. Prior to the onset of puberty.

progesterone. A steroid hormone that stimulates the uterus for pregnancy.

proprioceptive. Awareness of one’s own as in limbs and musculature as pertains to movement.

pubertal. Achieving the age of sexual maturity and reproductive capability.
registers. Pitch regions in the singing voice that may require technical adjustments.

Reinke’s space. Part of the lamina propria, it is synonymous with the superficial layer.

Resonance. Enhancement or reinforcement of sound due to shape and size of the vocal tract.

Respiration. The incitation of airflow through the vocal folds.

saggital. The division of the right and left side through the anatomical plane.

squamous. Scaly.

stratified. Arranged in thin layers.

stroboscopy. A technique that pulses interrupted light to simulate slow motion.

strobovideolaryngoscopy. Utilizing the technique of light pulsation to achieve a detailed assessment vocal fold oscillation in slow motion.

subglottal. Below the level of the glottis.

superior. Above

supraglottal. Above the level of the glottis.

testosterone. Hormone generated by the body responsible for emergence of male sexual characteristics, including growth in the larynx.

thyroarytenoid muscle. Also the vocal fold; paired intrinsic muscle of the larynx constituting the body of the vocal fold. Attached at the laminate of the thyroid cartilage and the vocal process of the arytenoids.

transoral. Through the mouth.

trilaminar. Three organic layers.

ultrasonography. Imagining of deep structures of the body by recording echoed pulses of sonic waves.

velum. The region of the soft palate; found posteriorly in the oral cavity.

videoendoscope. Lighted instrument with videographic capability.
**vocal folds.** The system in the larynx that consists of paired layers of tissue, which produce sound through oscillation.

**vocal ligament.** Part of the lamina propria; consists of its deep and intermediate layers.

**vocal tract.** The supraglottal cavities that facilitate vocal resonance, which include the pharynx and the mouth.

**vocalic.** Having to do with vowels and vowel shapes.

**vocalis muscle.** The medial aspect within the thryroarytenoid muscle.
BIBLIOGRAPHY


