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The Effects of Age on the Voice, Part 1

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The normal aging process affects human function profoundly. Some aging effects on the voice are obvious. Hearing even a few words over a telephone usually allows us to know whether we are speaking with a child or an adult. Frequently, we also can identify a speaker as elderly. Some of the phonatory characteristics associated with advancing age are inevitable, but others may be modified through medical intervention or through voice training. Laryngologists, speech-language pathologists, and voice teachers should be familiar with many of the more important, clinically relevant age-related changes that occur in the human voice.

ANATOMY AND PHYSIOLOGY: AN OVERVIEW

Embryologically, the larynx develops most of its anatomic characteristics by the third month of fetal life. At birth, the thyroid cartilage and hyoid bone are attached to each other. The laryngeal skeleton then separates, and the slow process of ossification (cartilages turning to bone) begins.[1] The hyoid bone starts to ossify by 2 years of age. The thyroid and cricoid cartilages ossify during the early 20s, and the arytenoid cartilages ossify in the late 30s. Except for the cuneiform and corniculate cartilages, the entire laryngeal skeleton is ossified by approximately age 65. In the infant, the epiglottis is bulky and omega shaped; it does not open to its normal adult configuration until puberty. At birth, the angle of the thyroid cartilage is about 110° in the male and 120° in the female. These relationships also remain fairly stable until puberty. At birth, the larynx is located high in the neck, resting at about the level of the third cervical vertebra (C3). It descends to about the level of C5–C6 by the age of 5 and continues gradual descent, lying at about the level of C6–C7 between ages 15 and 20. Descent continues throughout life in both sexes. As the larynx descends, vocal tract length relationships change, and average vocal pitch tends to become lower. In infancy, the membranous and cartilaginous portions of the vocal folds are equal in length; by adulthood, the membranous portion accounts for approximately three fifths of vocal fold length. Total vocal fold length is 6 to 8 mm in the infant, but increases to 12 to 17 mm in the adult female, and to 17 to 23 mm in the adult male. The dimensions of all other aspects of laryngeal anatomy increase, as well.

First vocalizations sometimes occur prior to birth, although the birth cry is normally the first sound uttered. Its frequency averages about 500 Hz (one octave above middle C). At this time, laryngeal mobility is limited primarily to vertical movements, and the appearance of the larynx is very similar to that of primates (monkeys). As the child grows, mean fundamental frequency of speech drops gradually, and by 8 years of age, it is approximately 275 Hz. Until puberty, male and female fundamental frequencies are about the same. During childhood, the physiologic frequency range (the highest and lowest sounds the child can produce) remains fairly constant. However, musical frequency range increases; that is, the child becomes able to produce musically acceptable sounds throughout an increasing percentage of his frequency range. Thus, between ages 6 and 16, the important developmental changes are not absolute range (constant at about 2½ octaves), but rather improved control, efficiency, and quality. Recognizing this principle is helpful in structuring training of young voices to strengthen and take advantage of the natural developmental process, rather than concentrating too heavily and too early on exercises that are designed to stretch the extremes of range. Such exercises may be damaging, especially to fragile young voices.

Puberty provides particularly challenging problems. Voice changes during puberty are caused by major alterations in laryngeal anatomy that occur coincident with the development of other secondary sex characteristics. Male vocal folds grow 4 to 11 mm, or as much as 60% in length, while female vocal folds grow 1.5 to 4 mm, or as much as 34%.[2] The connective tissue layers of the vocal folds develop progressively throughout childhood. The superficial and intermediate layers are well defined with a mature vocal ligament by age 16.[3]

The time of onset and duration of voice mutation vary somewhat from study to study and depend, to some extent, on the techniques used to measure and define voice change. Puberty usually begins between ages 8 and 15 in American females and between ages 9½ and 14 in American males. It is usually complete by age 12 to 16½ in females and by age 13½ to 18 in males.[4] Voice mutation is most active between ages 12½ and 14, and is usually complete in both sexes by age 15.[5] Mutational voice usually lasts about 1½ years but can last as long as 3 years.[6] Voice mutation occurs because of laryngeal growth. The angle of the male thyroid cartilage decreases to 90°, while the female thyroid cartilage remains at 120°. In both sexes, the epiglottis flattens, grows, and elevates; laryngeal mucosa becomes stronger and thicker. During puberty, the female voice usually drops about 2.5 semitones and averages roughly 220 to 225 Hz when voice change is complete. The male voice drops approximately one octave, averaging about 120 to 130 Hz by age 18 years.

The vocal tract is altered at many levels during puberty. Tonsil and adenoid tissues atrophy and partially disappear. This may relieve nasal obstruction and changes oropharyngeal and nasopharyngeal resonance. The basic contours of the pharynx can be fully developed as early as age 9, but the vocal tract continues to grow in length and circumference through puberty and into adulthood. Full growth is usually not complete until age 20 or 21. These changes can be demonstrated by examining the three lowest formant frequencies. Adult females average 12%, 17%, and 18% higher than adult males; and prepubescent children average 20% higher than adult females.[7] Dental development is completed during young adulthood, and jaw alignment may change. Tongue position and mouth opening can be influenced by discomfort and limitations of the temporomandibular joint complex that develop as a result of dental malalignment or injury. Usually, it is best to address dental and orthodontic problems as early as possible; and when considering the voice as well, it is always advantageous to treat the underlying causes of poor vocal technique before injurious compensatory mechanisms develop. The "power source" of the voice reaches its full potential as the chest enlarges and thoracic and abdominal musculature strengthens. Muscular strength and stamina peak usually during young adulthood.

From young adulthood to old age the respiratory system undergoes marked anatomic and physiologic changes, including decreased force and rate of contraction of respiratory muscles,[8] stiffening of the thorax,[9] and loss of elasticity of lung tissues.[10] These changes result in a progressive decline in respiratory function with increasing age after maturation in both men and women. Specific functional losses include decreased elastic recoil of lung tissues, reduced vital capacity, increased residual volume, and decreased expiratory/inspiratory reserve volume. Forced expiratory volume and airflow rate also

decline with aging.[11] These changes in respiratory function impact speech breathing in both men and women beginning during middle age, although the pattern and extent of those changes varies by gender. For instance, both genders show larger lung volume excursions and higher percent vital capacity/syllable measurements with advanced age, although these changes appear to arise from different mechanisms. In men, such changes may be linked with inefficient laryngeal valving resulting from glottal gaps that develop with aging. In women, it is speculated that age related changes in valving at the level of the velopharynx, tongue, or lips might account for observed changes. Alternatively, declines in laryngeal agility in elderly women as the larynx moves in and out of the airway during speech production may be responsible.[12]

The larynx also undergoes extensive anatomic and physiologic change during adulthood.[13] Cartilages undergo ossification and calcification,[14] intrinsic muscles atrophy,[15] and joints erode.[16] Age related changes in the epithelium of the vocal folds are somewhat in dispute. Several investigators report thickening; others have found no evidence of change with aging. It also has been suggested that the epithelium increases in thickness in males up to age 70 and decreases with further aging. In women, the epithelium may progressively increase with aging, particularly after age 70.[17] A variety of changes in the lamina propria have been documented, including thickening/edema of the superficial layer, degeneration/atrophy of elastic fibers, and declines in the number of myofibrils.[18] Allah et al. studied fibroblasts in macula flava and Reinke's space of vocal folds in newborns, adults, and geriatrics. They reported age-related differences in fibroblasts in the vocal fold in the mucosa, particularly the vocal ligament. Filho et al studied histologic vocal fold changes associated with aging in ten male and ten female cadavers. They noted decreased thickness of the lamina propria and decreased epithelial cell density as a function of age.[19] In elderly men, the mucosa stiffens and increases in viscosity in comparison with women and younger men, resulting in decreased ease of phonation.[20] Changes in the larynx from young adulthood to old age are generally more extensive in men than in women, with the possible exception of muscle atrophy about which there is little information on gender differences.[21]

Microscopic changes noted in the superficial layer of the lamina propria in mice include a relative reduction in hyaluronic acid and elastin, with an increase in collagen. In addition, there is an increase in the density and ratio of collagen and reticular fibers which are arranged in thick, disorganized bundles.[22] Histologic examination of aged human vocal folds has shown a decrease in the total number of cells, reduction in the intracellular organelles responsible for protein synthesis, and reduced production of extra cellular matrix (ECM) from these cells. The superficial layer of the lamina propria increases in thickness and is more edematous in both men and women, with a change in viscoelastic properties.[23] Changes within the cricoarytenoid joint include surface irregularities and disorganization of collagen fibers.[24] Laryngeal cartilages stiffen with progressive calcification and/or ossification.

A great deal of work, summarized by Thomas et al., has revealed changes in the musculature of the aging larynx, which contribute significantly to presbyphonia.[25] Several skeletal muscle changes are known to occur with aging. Although many of these also apply to the thyroarytenoid muscle (TA), there are also notable differences. Sarcopenia refers to the loss in muscle mass, strength, and quality often observed with aging. Because the loss in muscle mass is gradual, there is little noticeable loss in function, until the loss extends beyond threshold levels. At this point, functional abilities decline noticeably. Sarcopenia is likely the result of metabolic, neurologic, hormonal, and environmental factors.

The TA extends from the thyroid cartilage anteriorly to the vocal process and fovea oblonga of the arytenoid cartilage. It is often thought of as being made up of a medial vocalis and more laterally positioned thyromuscularis. The latter probably plays a role in the rapid shortening of the vocal fold, while the vocalis is likely involved in fine tuning tension along the focal fold edge and in providing lateral resistance during vocal fold contact. Contraction of the TA results in thickening and stiffening of the vocal fold, and a corresponding "loosening" of the lamina propria. Compared with limb skeletal muscle, the TA differs in several ways including fiber size, contractile protein profiles, mitochondrial content, and aging patterns. Similar differences also have been found in other laryngeal muscles.

The TA in humans contains type I, IIX, and IIA fibers, as well as "hybrid fibers." Furthermore, it has been suggested that the fast and slow fibers are arranged along a gradient, with the medial aspect composed of fast fibers. This unique composition, which results in a rapidly contracting, fatigue resistant muscle well suited for the TA's role as a muscle of respiration, airway protection, and voice production, is unusual compared with limb skeletal muscle. Elevated levels of mitochondria have been noted in the posterior cricoarytenoid, cricothyroid and thyroarytenoid muscles compared with limb skeletal muscle. This feature may increase resistance to fatigue and facilitate the continuous action required by these muscles for respiration. The TA is richly innervated by the recurrent laryngeal and superior laryngeal branches of the vagus nerve. Motor units are small, with each motor neuron innervating only a few fibers. Laryngeal sensory information is received through mechanoreceptors, chemoreceptors, taste buds, and free nerve endings.

Although loss of muscle mass with aging in the human TA was identified as early as 1941,[26] and confirmed in subsequent studies, patterns of fiber loss have not been defined clearly. In older rats, a reduction in force, speed, and endurance has been identified. Changes in the innervation of the TA with age also have been noted. Although there appears to be no net loss of myelinated or unmyelinated fibers with age, there is an increase in myelin-abnormal and myelin-thinning fibers, suggesting an active process of degeneration/regeneration. In the superior laryngeal nerve, there is a reduction in the size and number of myelinated fibers, which correlates with the documented reduction in laryngeal sensitivity with age. Metabolic changes have also been noted in the aging TA. Mitochondrial DNA mutations consisting of the 4977-base pair deletion have been identified, and these are thought to result in the increased production of injurious free radicals. Expression of this mutation appears to increase with age, producing dysfunctional mitochondria that may negatively affect contractile properties of the TA. In addition, laryngeal blood flow decreases by ~50% in older rats, with a possible reduction in oxygen, and accumulation of cellular waste products. The influence of hormones on vocal maturation, and in senescence, is recognized widely, and appreciated clinically. However, the mechanism of action of these hormones remains poorly understood.[27]

From a vocal fold function perspective, the issue of glottal gaps and aging is interesting to consider. Historically, complete glottal closure has been regarded as a characteristic of normal phonation in young adults. However, based on recent research, it is evident that, at high pitch and/or soft loudness levels, glottal gaps of varying configurations are commonplace in young adults of both genders.[28] With aging, men demonstrate an increased incidence of glottal gaps, presumably as a consequence of vocal fold atrophy. In contrast, young and elderly women do not differ in the overall incidence of glottal gaps. However, they do demonstrate different glottal gap configurations as a function of age. Young women overwhelmingly demonstrate posterior chinks, while elderly women display gaps more anteriorly in the glottis. Stroboscopic studies indicate that vocal fold movement patterns in elderly women are altered. Specifically, greater aperiodicity, reduced amplitude of vibration, and reduced mucosal wave have been observed.[29] Pontes et al. studied retrospectively 100 laryngeal images of young adults and older adults. They documented differences in older patients including increased prevalence of vocal fold bowing, vocal processes prominence, glottic proportion, phase and amplitude asymmetry, and tremor.[30]

Marked anatomic changes in the supraglottic vocal tract have been reported from young adulthood to old age. Facial bones continue to grow during this period,[31] although the magnitude of that growth (3%5%) is relatively modest. Changes in facial muscles include decreased elasticity, reduced blood supply, atrophy, and collagen fiber breakdown.[32] The temporomandibular joint (TMJ) undergoes extensive changes with aging including thinning of articular discs, reduced blood supply, and regressive remodeling of the mandibular condyle and glenoid fossa.[33] However, age-related changes in the TMJ can be difficult to distinguish histologically from a TMJ that is involved pathologically.[34] The oral mucosa loses elasticity with aging and thins, with deterioration of attachments of epithelium and connective tissue to bone.[21] However, there is some disagreement as to whether these changes reflect normal aging or result from drugs, disease, or pathological conditions.[35] Dental structures also are altered with aging, although tooth loss itself is not an inevitable consequence of aging.[36] Changes in the tongue epithelium include thinning and

fissuring of the tongue surface.[37] Pharyngeal and palatal muscles also have been reported to undergo age-related degenerative changes.[38] From a functional perspective, loss of salivary function can produce symptoms of oral dryness, dysphagia, and oral discomfort in the elderly; susceptibility to oral infection also is reported to increase.[39] The elderly have been reported to experience significant declines in tongue strength, although endurance remains relatively unaffected.[40] Lingual pressure reserves during swallowing also decline with aging, although maximum tongue pressures during swallow events remain stable from young adulthood to old age.[41]

NOTES

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Dr. Kost did her undergraduate studies and residency at McGill University in Montreal. She completed a fellowship in Voice and Head and Neck Oncologic Surgery at the Institute of Laryngology and Otology in London England under the stewardship of Sir Donald Harrison. She is a Professor of Otolaryngology at McGill University and is the Director of the Voice and Dysphagia Laboratory at McGill University. Areas of special interest include Head and Neck Oncology, Airway problems, and Voice. She is the past president of the Otolaryngology division of the McGill Med-Chi Society, and sits on several local committees associated with McGill university.

Dr. Kost has an ongoing interest in Global health. She worked in the Canadian Arctic for over 20 years, performed the first surgical procedure in Northern Quebec and played an instrumental role in repatriating medical and surgical services to Nunavik in Northern Quebec. In 2014 and 2015, Dr. Kost participated in 2 humanitarian medical missions in remote villages of the Himalayas in Nepal accessible only by foot, with no running water and no electricity. In addition to practicing medicine, she provided teaching and instruction to local healthcare providers.

Dr. Kost has been, and continues to be heavily involved in the Canadian Society of Otolaryngology-Head and Neck Surgery and has served as chair of Bylaws, Regional Representative of Quebec, and President of the Canadian Society of Otolaryngology-Head and Neck Surgery Fund. In 2013, she served as the President of the Canadian Society of Otolaryngology-Head and Neck Surgery Society—the second female president of the society since its birth in 1946. She established the Women in Otolaryngology (WIO) section of the Canadian Society of Otolaryngology-Head and Neck Surgery in 2013, went on to form a committee, secure funding for the WIO, and serve as its chair from 2013–2017. She continues to serve as chair of the Laryngology committee within the Society.

Dr. Kost has also served as President of the American Society of Geriatric Otolaryngology (ASGO) from 2012 to 2014 and as program chair for 5 years from 2007–2012. In addition, Dr. Kost has been an active member of the American Academy of Otolaryngology-Head and Neck Surgery, and several of its committees including the Geriatric Otolaryngology Committee from 2006–2016, and again from 2018 onwards, the International Committee from 2013–2017, the International Steering Committee from 2017 to the present, and as Representative to the Voice Committee from 2017 to the present. She served as the chair of the International Otolaryngology Committee for the year 2016–2017. Dr. Kost was nominated to the Council of the prestigious American Laryngological Association in May 2019.

Dr. Kost is involved in both basic science and clinical research focused on voice, voice disorders and singing. She teaches medical students, as well as residents and is the Director of the Laryngology Fellowship at McGill University. She served as an examiner for the Royal College of physicians and Surgeons of Canada for 7 years, and continues to work with the Royal College as part of a team restructuring the Otolaryngology training program in Kuwait, where she also functions as an international examiner.

Dr. Kost has published extensively on voice and tracheostomy, which was the subject of her Triological thesis in 2005. She is the first Canadian female to be inducted into the Triological Society. Dr. Kost is a member of over a dozen medical societies, including the American Laryngological Society. Dr. Kost is the author of several publications in peer-reviewed journals and over 20 book chapters on airway and voice. She has edited or co-edited 3 textbooks on Geriatric Otolaryngology, and sits on the editorial boards of four peer-reviewed otolaryngology journals. She is the associate editor of the 'Clinics in Geriatric Otolaryngology' section of the ENT Journal, and in October 2019 was appointed Associate editor of Laryngology for the Otolaryngology-Head and Neck Surgery Journal. Dr. Kost has given over 400 presentations on voice and tracheostomy around the world as a keynote speaker, invited lecturer/professor or guest speaker.

Dr. Kost is the recipient of the Birkett prize in Otolaryngology, the Teacher of the Year Award in Otolaryngology in 2002 and 2009, the Recognition of Service and Commitment Award from the Canadian Society of Otolaryngology-Head and Neck Surgery Society in 2009, and the Distinction Award

of Otolaryngology from the American Academy of Otolaryngology-Head and Neck Surgery in 2014. In September 2016, Dr. Kost was awarded the Helen B Krause Trailblazer Award from the Women in Otolaryngology of the American Academy of Otolaryngology-Head and Neck Surgery.

Robert T. Sataloff, MD, DMA, FACS, is Professor and Chairman, Department of Otolaryngology-Head and Neck Surgery and Senior Associate Dean for Clinical Academic Specialties, Drexel University College of Medicine. He is also Adjunct Professor in the departments of Otolaryngology—Head and Neck Surgery at Thomas Jefferson University and the University of Pennsylvania, as well as Temple University and the Philadelphia College of Osteopathic Medicine; and on the faculty of the Academy of Vocal Arts. Additionally, he is Director of Otolaryngology and Communication Sciences Research, Lankenau Institute for Medicine Research. Dr. Sataloff is also a professional singer and singing teacher, and he served as Conductor of the Thomas Jefferson University Choir over a period of nearly four decades. He holds an undergraduate degree from Haverford College in Music Theory and Composition, graduated from Jefferson Medical College, Thomas Jefferson University, received a Doctor of Musical Arts in Voice Performance from Combs College of Music; and he completed his Residency in Otolaryngology—Head and Neck Surgery and a Fellowship in Otology, Neurotology and Skull Base Surgery at the University of Michigan. Dr. Sataloff is Chairman of the Boards of Directors of the Voice Foundation and of the American Institute for Voice and Ear Research. He also has served as Chairman of the Board of Governors of Graduate Hospital; President of the American Laryngological Association, the International Association of Phonosurgery, and the Pennsylvania Academy of Otolaryngology—Head and Neck Surgery; and in numerous other leadership positions. Dr. Sataloff is Editor-in-Chief of the *Journal of Voice*, Editor-in-Chief of *Ear, Nose and Throat Journal*, Associate Editor of the *Journal of Singing*, and on the editorial boards of numerous otolaryngology journals. He has written approximately 1,000 publications, including 62 books. His medical practice is limited to care of the professional voice and to otology.