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Original Article

Correlation between Fundamental Speech Frequencies (F0) and Serum Testosterone Levels in Patients with Puberphonia Attending a Tertiary Care Hospital

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Abstract

Background: voice in humans is susceptible to the hormonal changes throughout life right from the puberty until old age. Thyroid, gonadal, and growth hormones have varied impact on the structure and function of the vocal apparatus. Voice changes are observed during physiological states such as puberty and menstruation. Puberphonia is defined as an inappropriate use of high-pitched voice beyond pubertal age in males which is usually seen in the immediate postpubescent period when the male vocal mechanism has undergone significant changes in size and function caused by hormonal changes. Endocrine evaluations in puberphonia by astute clinical observers who make out the changes in the voice are required to develop a system of diagnosis and assessment of prognosis.

Aim of the study: The aim of the study was to analyze the relationship between serum testosterone levels and fundamental frequencies (F0) of patients with puberphonia.

Materials and Methods: A total of 43 patients aged between 14 and 18 years with puberphonia were included in the study. They were subjected pubertal history taking and an ENT evaluation with a stroboscope to obtain visual assessment of the vocal cords. The mucosal wave, vibratory symmetry, and amplitude; type of glottic closure; hyperfunction; arytenoids movement and symmetry; ventricular movement, etc., were evaluated using stroboscopy including patient's fundamental frequency (F0) during sustained phonation. The relationship between circulating levels of serum testosterone and the fundamental frequencies of puberphonia patients was analyzed. Serum testosterone was evaluated by quantitative high-performance liquid chromatography-tandem mass spectrometry method in this study. Serum levels of testosterone more than 165 ng/dL in children aged 14–15 years; testosterone levels higher than 619 ng/dL in children aged 15–16 years; and higher than 733 ng/dL in children aged 16–17 years were taken as abnormal. All the data were analyzed using standard statistical methods.

Observations and Results: Among the 43 patients, the incidence was equal in all age groups between 14 and 17 years. There was no statistical significance in relation to socioeconomic status, the presence of secondary sexual features, personality, and parent domination among the groups. However, residing in urban locality was statistically significant over residence in the rural locality among the patients with puberphonia with $P = 0.042$ and 0.038, respectively. The overall F0 mean value for the study group was 196.56. The relationship between mean F0 values and mean serum Testosterone levels were analyzed using Chi-square test and observed that there was statistical significance between the values in all the age groups of the study ($P < 0.05$).
Conclusions: There was a negative relationship between circulating levels of serum testosterone and fundamental frequency (F0). Higher testosterone levels are indicating lower fundamental frequency, although the magnitude of the relationship was larger than previously observed studies in literature. It is thought that male voices may have deepened over the course of evolution to signal dominance and/or to increase the speaker's attractiveness. Findings confirm that vocal frequencies may provide an honest signal of the speaker's hormonal quality.

Key words: Frequency, Hormone and vocal cords, Puberphonia, Speech therapy, Voice

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INTRODUCTION

Voice is an important component that imparts self-confidence and socially acceptable behavior of an individual. The quality of the voice is an essential component of the self-assessment tool and reduces the social and physiological handicap of an individual.[1]

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The pitch of the voice is considered as the main factor influencing the perception of the gender based on the voice.[2] The relationship between voice and hormones was appreciated even in the medieval era. In earlier centuries, in Central Asia and European countries, it was a practice to castrate young male singers with exceptionally good voice to prevent the cracking of their voice during puberty, giving them a long professional life. This practice was prevalent in 17th and 18th centuries and the popular castrated stars during that era include Baldassare Ferri (1610–1680) and Alessandro Moreschi (1858–1922).[3] The physical properties of speech include the voice (audible sound waves), pitch (rate of vibration of the vocal folds), resonance (quality and depth invoice), intonation (variation of pitch without distinguishing of words), tone (pitch variation with distinguishing of words), intensity (pressure of sound), timbre (characteristic tone or quality), and articulation (production of vowels and consonant sounds).[4] The fundamental frequency (F0) corresponds to the number of vocal fold vibration cycles per second (Hz) and perceived as the pitch of the voice. The vocal cords in females are short and thin, leading to fast vibration, giving a higher pitch to their voice. There are changes in the F0 with age with the first change happening at puberty in males. Thereafter, with advancing age, the pitch gets reduced in females and increases in males. The short vocal tract in the females gives the voice a higher resonance than male voice.[5] Voice is an important secondary sexual characteristic giving an independent imprint to the character and personality of an individual. The deep influence of sex hormones on the characteristics of voice is mediated by the hormonal receptors present within the vocal folds and apparatus.[6] The sexual differences about the voice change are observed during puberty.[7] Increased testosterone and dihydrotestosterone in males lead to increased bulk of laryngeal muscles and ligaments. This leads to drop in the higher octaves in the pitch of voice and frequent cracking. Puberphonia is defined as an inappropriate use of high-pitched voice beyond pubertal age in males which is usually seen in the immediate postpubescent period when the male vocal mechanism has undergone significant changes in size and function caused by hormonal changes. The patients resent with a complaint of a high-pitched voice which is deemed inappropriate for their age and sex. The incidence of puberphonia in general population is 1 in 900,000.[8] The most common symptoms are pitch breaks, hoarseness, breathiness, difficulty in vocal projection, and visible laryngeal muscle tension. The various theories put forth in literature[9] regarding the development of puberphonia are increased laryngeal muscle tension causing laryngeal elevation, embarrassment of the newly achieved vocal pitch, failure to accept the new voice, social immaturity, etc. In elderly males, the levels of estrogen play an important role in influencing the voice. In a study conducted in an elderly population compared the voice characteristics in patients with and without hypogonadism the patients with low estrogen levels, there was an increase in the mean fundamental frequency and a shift of the frequency ranges with alterations in the highest and lowest frequencies.[10] In the case of females, the elevated levels of estrogens and progesterone have no or minimal effect on the voice during puberty. The importance of hormonal influence on the female voice is appreciated during the cyclical changes of the menstrual cycle. The voice changes associated with the premenstrual syndrome are grouped under dystrophia premenstrualis.[11] During this period, the classical manifestation is the difficulty in singing high notes. There is also laryngeal edema due to the high estrogenic state before the ovulation. The slight drop in pitch of voice after menopause may be due to a relative excess of androgens. Other voice changes observed after menopause include huskiness, vocal fatigue, and inability to reach high harmonics which are appreciated more in professional singers and teachers. Hormone replacement therapy has shown to reverse most of the observed voice changes in postmenopausal females.[12] The present study was conducted with an aim to analyze the relationship between salivary testosterone hormone levels and their fundamental frequencies in patients with puberphonia.

Type of Study

This was a prospective cross-sectional and analytical clinico-physiological study.

Period of Study

The period of study was from October 2016 to September 2018 (2 years).

Institute of Study

This study was conducted at Government Medical College, Anantapur.

MATERIALS AND METHODS

In this prospective study conducted in the department of ENT of a tertiary hospital over a period of 2 years, 43 patients with history of high-pitched voice (perceptually) and found to have high F0 (Fundamental Frequency) on Multi-dimensional Voice Program (Kay Pentax) were diagnosed as puberphonia and were included in the study. All the patients were aged between 14 and 18 years.

Inclusion Criteria

(1) Patients aged between 14 and 17 years were included. (2) All the patients were males. (3) Patients with fundamental frequency (F0) >200 KHZ were included. (4) Patients

consenting to collect blood samples for estimation of early morning serum testosterone levels were included.

Exclusion Criteria

(1) Patients <14 years and >17 years were excluded. (2) Patients with vocal cord lesions were excluded. (3) Patients with a history of surgeries on the throat were excluded. All the patients were subjected to detailed pubertal history taking by a physiologist, and an ENT evaluation by an ENT surgeon with a stroboscope was done using Kay Pentax 9105 System. Stroboscopy was used to obtain a visual assessment of the vocal cords. The stroboscopic evaluation provided measures of vibratory behavior of the vocal folds such as presence or absence of mucosal wave, vibratory symmetry, and amplitude; type of glottic closure; hyperfunction; arytenoids movement and symmetry; ventricular movement, etc. Stroboscopy also yielded a measure of the patient's fundamental frequency (F0) during sustained phonation. The relationship between circulating levels of serum testosterone and the fundamental frequencies of puberphonia patients who recorded their voices and provided blood samples at 9 am on a single day was studied. Serum testosterone was evaluated by quantitative high-performance liquid chromatography-tandem mass spectrometry method in this study. Serum levels of testosterone more than 165 ng/dL in children aged 14–15 years; testosterone levels higher than 619 ng/dL in children aged 15–16 years; and higher than 733 ng/dL in children aged 16–17 years were taken as abnormal. All the data were analyzed using standard statistical methods.

OBSERVATIONS AND RESULTS

A total of 43 patients with a diagnosis of puberphonia and evaluation were included in this study. The incidence of age groups and demographic data was analyzed and found that the incidence was equal in all age groups among the children aged between 14 and 17 years and not statistically significant ($P < 0.05$ was taken as significant) [Table 1]. Similarly, socioeconomic status, presence of secondary sexual features, personality, and parent domination were also not significant statistically. However, residing in urban locality was statistically significant over residence in the rural locality among the patients with puberphonia with $P = 0.042$ and 0.038, respectively [Table 1].

Stroboscopy findings among the patients with puberphonia in this study showed normal features in regard with a mucosal wave, vibratory symmetry, and amplitude, type of glottic closure, arytenoids movement symmetry, and ventricular movement. Fundamental frequency (F0) showed variable expression and was tabulated in Table 2. The overall F0 mean value for the study group was 196.56.

Table 1: The age incidence and demographic data of patients with Puberphonia (*n*=43)

Observation	Number	Percentage	*P* value
Age group (years)			
14–15	17	39.53	Not significant
15–16	15	34.88	
16–17	11	25.58	
Socioeconomic status			
Low	9	20.93	Not significant
Middle	20	46.51	
High	14	32.55	
Residence			
Urban	26	60.46	0.042 (significant)
Rural	17	39.53	
Sibling status			
First	7	16.27	0.038 (significant)
Second	22	51.16	
Third	14	32.55	
Other secondary sexual features			
Present	39	90.69	Not significant
Absent	4	09.30	
Personality			
Timid	20	46.51	Not significant
Introvert	6	13.95	
Extrovert	17	39.53	
Parental domination			
Mother	24	55.81	Not significant
Father	19	44.18	

The relationship between mean F0 values and mean serum testosterone levels was analyzed using Chi-square test and observed that there was statistically significant difference between the values in all the age groups of the study ($P < 0.05$) [Table 3].

DISCUSSION

Voice production in humans is a complex function depending on multiple systems such as properly functioning neurological system, the respiratory system and an anatomically sound, and physiologically active upper airway tract. Production of normal voice is possible only with the coordination of complex systems such as various laryngeal muscles. There should be a temporary cessation of the vital functions of the upper aerodigestive tract such as breathing and deglutition.[7] The larynx *per* se being a dynamic structure alters its shape and lumen by a system of articulated cartilages controlled by the vagus nerve. Voice is produced by the vibration of a closed glottis during expiration. The expiratory blast of air from the lungs induces a vibration in the vocal cords producing voice which, in turn, gets articulated in the lubricated supralaryngeal airway to form speech. Any change in any of these systems brought about by endocrine disorders would have an impact on the physiology of voice production. The characteristics of speech include the voice (audible sound waves), pitch

Table 2: The incidence of F0 ranges in the study group (*n*=43)

Frequency (KHz)	14–15 years (17)		15–16 years (15)		16–17 years (11)		Overall mean
	Number of patients	Mean F0	Number of patients	Mean F0	Number of patients	Mean F0	
100–150	4	123.30	2	121.45	1	119.40	
150–200	7	168.95	6	157.35	5	155.50	
200–250	5	215.55	3	205.20	3	240.30	
>250	1	265.40	4	253.15	2	261.25	
Mean F0		193.30		184.28		194.11	196.56

Table 3: The correlation between F0 and testosterone levels in the study groups (*n*=43)

Age groups (years)	Mean values of F0	Mean testosterone levels (ng/dL)	*P* value
14–15 (17)	193.30	194	0.035
15–16 (15)	184.28	658	0.045
16–17 (11)	194.11	759	0.371

(rate of vibration of the vocal folds), resonance (quality and depth invoice), intonation (variation of pitch without distinguishing of words), tone (pitch variation with distinguishing of words), intensity (pressure of sound), timbre (characteristic tone or quality), and articulation (production of vowels and consonant sounds).[4] The fundamental frequency (F0) corresponds to the number of vocal fold vibration cycles per second (Hz) and perceived as the pitch of the voice. The vocal cords in females are short and thin, leading to fast vibration, giving a higher pitch to their voice. There are changes in the F0 with age with the first change happening at puberty in males. Thereafter, with advancing age, the pitch gets reduced in females and increases in males. The short vocal tract in the females gives the voice a higher resonance than the male voice.[5] Voice is considered by many as an important secondary sexual characteristic which gives an independent imprint to the character and personality of an individual. The profound influence of sex hormones on the characteristics of voice is mediated by the hormonal receptors present within the vocal folds and apparatus.[6] There are certain sexual differences in the voice change observed during puberty.[10] Increased testosterone and dihydrotestosterone in males lead to increased bulk of laryngeal muscles and ligaments. This leads to a drop in the higher octaves in the pitch of the voice and frequent cracking. In elderly males, the level of estrogens has a major influence on the voice rather than the prevailing androgens. A study done in an elderly population compared the voice characteristics in patients with and without hypogonadism. In patients with low estrogen levels, there is an increase in the mean fundamental frequency and a shift of the frequency ranges with alterations in the highest and lowest frequencies.[11] Whereas in females the higher levels of estrogens and progesterone have minimal effect on the voice during puberty. The importance of hormonal influence on the female voice is appreciated during the cyclical changes of the menstrual cycle. The voice changes associated with the premenstrual syndrome are grouped under dystrophia premenstrualis.[12] The classical manifestation is the difficulty in singing high notes during the premenstrual period. There is laryngeal edema due to the high estrogenic state before the ovulation. However, the relative excess of androgens after menopause may lead to a slight drop in the pitch of the voice. Other voice changes observed after menopause include huskiness, vocal fatigue, and inability to reach high harmonics. These changes are appreciated more in professional singers and teachers who use the voice for a living. Hormone replacement therapy has shown to reverse most of the observed voice changes in postmenopausal females.[13] Testosterone is the major androgenic hormone. It is responsible for the development of the male external genitalia and secondary sexual characteristics. In females, its main role is as an estrogen precursor. In both genders, it also exerts anabolic effects and influences behavior. In males, testosterone is secreted by the testicular Leydig cells and to a minor extent, by the adrenal cortex. In premenopausal women, the ovaries are the main source of testosterone with minor contributions by the adrenals and peripheral tissues. After menopause, ovarian testosterone production is significantly diminished. Testosterone production in testes and ovaries is regulated through pituitary-gonadal feedback involving luteinizing hormone and to a lesser degree, inhibins, and activins. Most circulating testosterone is bound to sex hormone-binding globulin (SHBG), which in males also is called testosterone-binding globulin. A lesser fraction is albumin-bound and a small proportion exists as a free hormone. Historically, only the free testosterone was thought to be the biologically active component. However, testosterone is weakly bound to serum albumin and dissociates freely in the capillary bed, thereby becoming readily available for tissue uptake. All non-SHBG-bound testosterone is, therefore, considered bioavailable. In male children around puberty, larynx undergoes deep modifications resulting in voice mutation. The vocal folds suffer a pronounced growth, doubling in size. As a result, voice decreases one octave, and the adult

voice is established. In women, whereas this growth is less significant, and voice decreases only two to three notes around 12–14-year-old.[14,15] These voice changes, along with all the other secondary sexual characteristics, allow the differentiation of gender through voice, something that does not occur during childhood.[15] These changes take few months to 1 year and the male child's voice may become mildly rough, weak, and unstable, with some variations and bitonality, but tending to low sounds.[15] If this mutation does not occur correctly and adequately, a mutational dysphonia or puberphonia occurs. The cause is rarely organic, and it is usually part of the psycho-emotional sphere. Mutational dysphonia may be didactically classified into prolonged, incomplete, excessive, premature, retarded, and mutational falsetto.[14] Among them, the mutational falsetto is considered the most frequent, representing 2% of the functional dysphonia.[15] In this study, an attempt was made to find the relationship between the serum testosterone levels and fundamental frequency of puberphonia patients which is an effect of the mutational failure of the larynx. Stroboscopy findings among the patients with puberphonia in this study showed normal features kin regard with a mucosal wave, vibratory symmetry, and amplitude, type of glottic closure, arytenoids movement symmetry, and ventricular movement. Fundamental frequency (F0) showed variable expression and was tabulated in Table 2. The overall F0 mean value for the study group was 190.56. The relationship between mean F0 values and mean serum testosterone levels was analyzed using Chi-square test and observed that there was statistical significance between the values in all the age groups of the study ($P < 0.05$) [Table 3]. A study with 10 teenagers with mutational falsetto in pre- and post-therapy conditions showed mean F0 values of 221 Hz and 119 Hz, respectively. These values are very close to those found in this study 190.56.[16] It is thought that male voices may have deepened over the course of evolution to signal dominance and/or to increase the speaker's attractiveness.[17] Findings confirm that vocal frequencies may provide an honest signal of the speaker's hormonal quality.

CONCLUSIONS

There was a negative relationship between circulating levels of serum testosterone and fundamental frequency (F0). Higher testosterone levels indicating lower fundamental frequency, although the magnitude of the relationship was larger than previously observed studies in literature. It is thought that male voices may have deepened over the course of evolution to signal dominance and/or to increase the speaker's attractiveness. Findings confirm that vocal frequencies may provide an honest signal of the speaker's hormonal quality.

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