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Changes in the male voice at puberty: vocal fold length and its relationship to the fundamental frequency of the voice

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Abstract
Ultrasound measurements of the vocal folds were taken for a number of boys passing through puberty. The boys were grouped according to their pubertal stage as defined by Tanner and there was a gradual increase in the length of the vocal folds as puberty progressed. The fundamental frequency of the boys' speaking voice was recorded via laryngography and a good correlation between the length of the vocal folds and the frequency of the voice was seen. The sudden drop in frequency seen between Tanner stages 3 and 4 did not correlate with similar changes in the length of the vocal folds at this time but stroboscopic findings suggest a change in the structure and mass of the vocal folds at this time of maximum frequency change.

Key words: Voice; Puberty, Vocal fold

Introduction

The pitch of the male voice lowers during puberty. This change is a gradual process but a relatively sudden decrease in the fundamental frequency occurs between Tanner's pubertal stages 3 and 4 corresponding to the time of other maximum bodily changes (Harries *et al.*, 1996). Previous work has shown that the vocal folds do increase in length as a child progresses through to adulthood, but is the fall in pitch directly due to this elongation? In the larynx it is known that dynamically the pitch of the voice *increases* as the vocal folds lengthen by the action of the cricothyroid muscle, which rotates the cricoid cartilage on the fixed thyroid cartilage, thus stretching the vocal folds; this forms the basis of laryngeal framework operations designed to elevate the pitch (type IV thyroplasty). This increase in the fundamental frequency on lengthening therefore seems to be the opposite of what happens during puberty where an increase in length is accompanied by a decrease in the fundamental frequency.

Changes which take place during puberty in the various organs of phonation include an increase in breathing capacity with both the length and the circumference of the chest increasing (Polgar and Weng, 1979). The neck increases in length and width which leads to a relative descent of the larynx and a subsequent enlargement of the vocal tract (the conduit from the vocal folds to the openings of the mouth and the nose), thus enlarging the resonatory system. Growth of the paranasal sinuses also enriches the vocal quality, the tonsils and the adenoids atrophy to a degree, and the cavernous tissue of the nasal turbinates develop (Weiss, 1950). The vibratory source, the vocal folds, is therefore only one of several parts of the vocal apparatus which undergo a change in size during the course of pubertal development but the fundamental frequency of the voice is directly related to the vibration of these folds (Abberton *et al.*, 1989).

The aim of this study was to measure the length of the vocal folds during each stage of puberty as defined by Tanner (Tanner, 1962), and to correlate this with the fundamental frequency of the boy's voice at that stage. Is there a relatively sudden increase in the length of the folds that would explain the similar drop in pitch seen between stages 3 and 4, or does the length change gradually and the sudden change in frequency happen as a result of some other change in the larynx?

Subjects and methods

A total of 26 male volunteers were recruited from a local High School for boys. All were in the third year i.e. between 13 and 14 years of age at the first recording. Prior permission was obtained from the headmaster and parents, and ethical approval was obtained. Boys were seen at three monthly intervals

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over a 12-month period (0, three, six, nine and 12 months). Recordings at each visit were divided into three broad categories:

(1) Endocrine and physical examination

Clinical assessment of the stages of pubertal development was performed using the Tanner classification, hereafter referred to as 'G' staging. This describes a scale of 1 to 5 representing the prepubertal boy through to the fully mature adult man.

(2) Laryngographic recordings

Recordings were carried out in a sound-treated audiology booth using the laryngograph (portable laryngograph processor) and the measurements analysed on an IBM PC/AT computer with PCLX system. Recordings were documented on uniaxial, chromic, high-bias Sony tapes of each boy speaking his own name and then reading the phonetically recognized passages 'Arthur the Rat' and 'The Rainbow Passage'. The mean speaking fundamental frequency was obtained at each visit.

(3) Ultrasound measurements

Readings were taken during 'gentle respiration' when the vocal folds are at their resting length and tension. A 7.5 MHz linear array machine was used with three recordings taken at each visit and the mean value obtained. It is the membranous part of the vocal cord (also termed the vocal fold) that vibrates during phonation. This can be clearly defined from the cartilaginous posterior third of the vocal cord which has a brighter signal and does not vibrate during voice production. The vocal fold was measured rather than the vocal cord length (as this would also have included the cartilaginous vocal process) and the anterior measuring point taken as the inner surface of the thyroid cartilage (Figure 1).

Videolaryngoscopy and stroboscopy were performed on each boy at each visit to ensure that the vocal folds were healthy. Attendance was good with only eight missed recordings out of a total of a possible 130 data readings (i.e. $26 \times 5 = 130$; 94 per cent attendance rate).

Results

The results show a gradual increase in the length of the vocal fold through the Tanner stages of pubertal development. There is a relatively sharp fall in the fundamental frequency of the boy's voice that is not mirrored in the recordings of length. The relationship between the length of the vocal fold and the frequency of the speaking voice shows a power relationship with a very good correlation ($r = 0.8$).

Stroboscopic recordings did not show any evidence of pathology of the vocal folds but there was a subjective change in the mucosal wave pattern between 'G' stages 3 and 4. Boys in stages 1, 2 and 3 had a mucosal wave similar to that seen in a

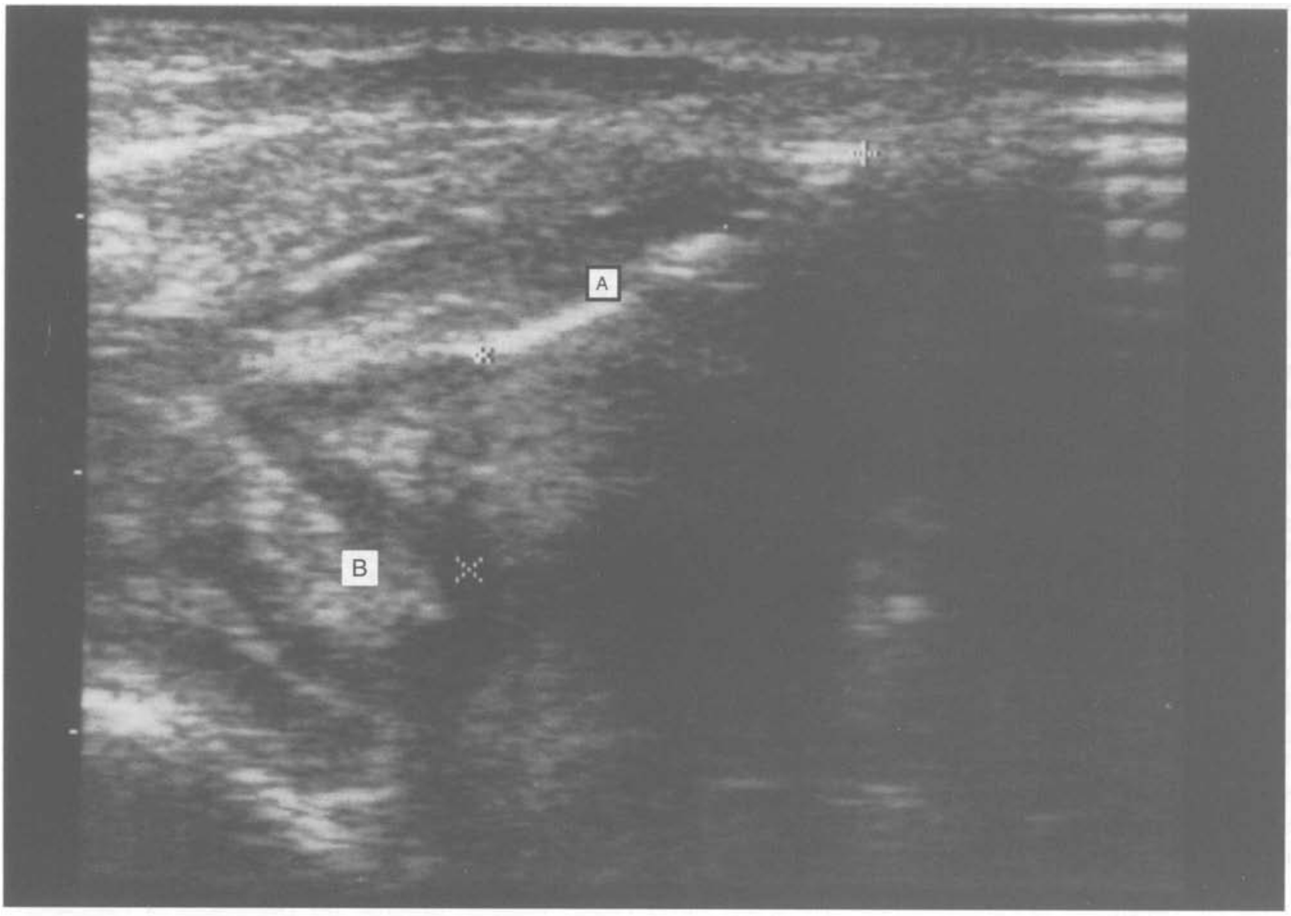

Fig. 1

Ultrasound of vocal cords showing vocal fold [A] and arytenoid cartilage [B].

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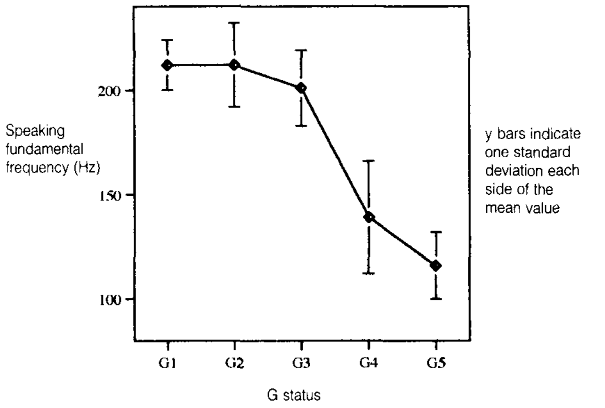

FIG. 2
Fundamental frequency of the male speaking voice versus Tanner "G" status

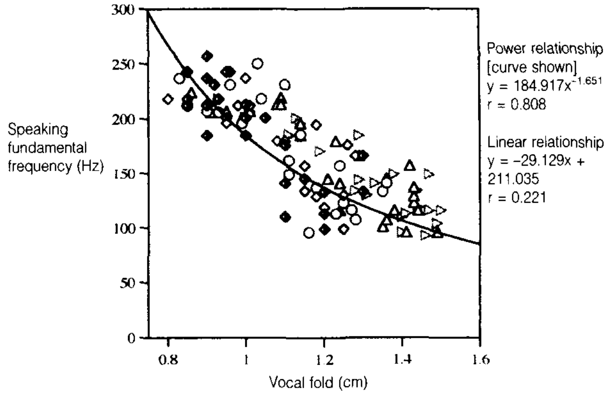

FIG. 4
Vocal fold length versus fundamental frequency of the male speaking voice.

dennervated vocal fold (sometimes referred to as flaccid flap) whilst boys in stages 4 and 5 appeared to have the mucosal wave pattern associated with an adult larynx. These findings are only subjective, however, and until there is a method of quantifying the mucosal wave pattern any conclusions drawn from this are conjecture only.

Discussion

Previous studies of the male pubertal voice have correlated the voice changes with chronological age rather than with pubertal stage (Pedersen *et al.*, 1985). The range in the age of onset, and the tempo of development through puberty is so variable that in our opinion this study is made clinically more relevant by comparing boys at the same pubertal stage.

Hertz described a laryngeal ultrasonographic method for studying the vibratory movements of the vocal folds (Hertz *et al.*, 1970). This technique is suitable for the larynx due to the different sonographic signals of air, soft tissue and cartilage, especially in infants before ossification of the thyroid cartilage occurs (Garel *et al.*, 1992).

The vibrating source essential for voice production is the vocal cords which consist of a posterior cartilaginous and an anterior membranous component. The posterior component is the vocal process of the arytenoid cartilage whilst the anterior membranous component is termed the vocal fold. The vocal fold is 1.3–2.0 mm in newborns increasing to 14.5–18.0 mm in adult males (Kahane, 1982). This is similar to our findings in this study. There is no sex difference under the age of 10 years.

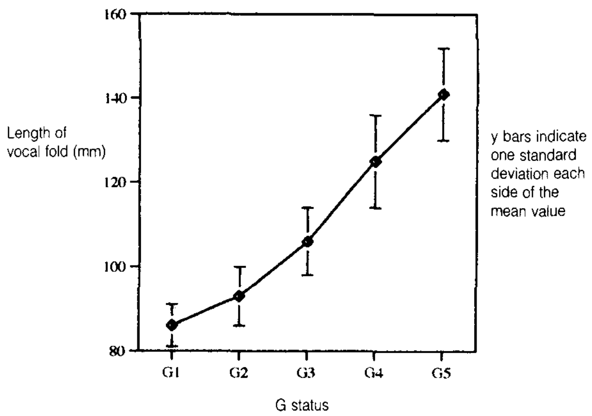

FIG. 3
Vocal fold length versus Tanner "G" status.

Hirano studied the fine structure of the vocal fold and found that it was a five layered structure (Hirano *et al.*, 1981). Superficially lies the squamous epithelium followed by the lamina propria (which has three layers), and then the deeper vocalis muscle. These different layers behave like three relatively independent masses, with the epithelium and the superficial layer of the lamina propria forming one semi-fluid layer termed the 'cover', the intermediate and deep layers of the lamia propria forming a stiffer layer, the 'vocal ligament', and the vocalis muscle the 'body' of the vocal fold. If any of these layers changes in mass, stiffness, or geometry then the vibratory pattern of the vocal fold changes.

Hirano also noted that there is a differentiation of the vocal ligament in the male between 12 and 16 years (Hirano *et al.*, 1981), as the layered structure forms. Voice maturation is therefore associated not only with an increase in length of the vocal fold but also with changes of its inner structure. The visual change in the stroboscopic signal noticed may reflect the development of the five-layered structure described above but we have no quantitative data to support this as stroboscopic evaluation is at the moment subjective.

Clinical conditions that change the mass of the vocal folds also lead to a change in the fundamental frequency of the voice. Reinke's oedema, where the subepithelial layer increases in mass, is associated with a drop in pitch of the voice (Bennett *et al.*, 1987) but the opposite is seen in asthmatics on steroidal inhalers where the raised frequency of the voice has been attributed to a decrease in mucosal oedema (Clarke *et al.*, 1992). The increase in the fundamental frequency of the voice seen with old age has also been explained by the change in the structure and mass of the vocal folds (Shindo and Hanson, 1990).

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Conclusions

(1) There is an increase in length of the vocal folds through each pubertal stage.

(2) A relatively sudden drop in fundamental frequency is seen between Tanner stages 3 and 4.

(3) This sudden drop is not directly due to an increase in length of the vocal folds.

(4) There is a subjective opinion that the mucosal wave changes between Tanner stages 3 and 4 could reflect the maturation of the five-layered fold but at present this is conjecture only.

(5) We postulate that changes in the mass of the vocal fold and the differentiation of its layers could be the critical change causing the relative sudden drop in fundamental frequency of the male voice during puberty.

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