Fundamental voice frequency during normal and abnormal growth, and after androgen treatment

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SUMMARY A simple instrument was shown to be suitable for clinical measurement of fundamental voice frequency. Basal frequency (SFF) and lowest frequency (LF) were determined in 374 normal subjects aged 6 years to adulthood. SFF fell between ages 8 and 10 years in boys (from 259 to 247 Hz), but not in girls (253 Hz). LF fell between ages 6 and 10 years in boys (from 234 to 203 Hz) and girls (from 230 to 218 Hz), and a sex difference appeared. In puberty, parallel to pubic hair (PH) development, a gradual fall of SFF and LF occurred in both boys (to 100 and 90 Hz, respectively) and girls (to 213 and 180 Hz). As a group, young hypopituitary children and girls with Turner's syndrome had a high SFF, and prepubertal boys with delayed maturation a low SFF. In some children with prenatal growth failure, SFF was abnormally high. The girls with Turner's syndrome exhibited a high, though individually variable, sensitivity of voice to androgen; their voices became lower before the appearance of any other masculinising effects. The instrument is useful for characterisation of growth failure syndromes and stages of puberty. It is particularly recommended for monitoring an undesirable effect on the voice during androgen treatment.

The development of the human voice as a function of age is characterised by changes in pitch, loudness, and variety of tone qualities. The pitch of speech or speaking fundamental frequency (SFF), being relatively simple to measure adequately, can be used as an indicator of voice maturity. In voice development three periods are of interest: infancy and childhood, puberty, and aging. Deviations from normal development have been reported in children with congenital malformations of the articulatory organs, e.g. in the cat cry syndrome (Vuorenkoski *et al.*, 1966), Down's syndrome (Weinberg and Zlatin, 1970), dysfunction of the central nervous system (Wasz-Höckert *et al.*, 1968), hypothyroidism (Vuorenkoski *et al.*, 1973), prenatal growth retardation (Vuorenkoski *et al.*, 1972), and in the absence of auditory feedback due to deafness (Elliott and Niemoeller, 1970; Mártony 1971).

This report describes the changes in pitch from childhood through puberty to adulthood, and the effects on pitch of some types of growth retardation, delayed pubertal development, and androgen treatment. Several techniques have been used for measuring the SFF (Luchsinger and Arnold, 1965;

Schultz-Coulon and Arndt, 1972); the most advanced is an automated computerised method (Vuorenkoski *et al.*, 1972; Hollien and Jackson, 1973). However, none of these techniques is suitable for routine clinical use. We report here a new, simple, and quick method which makes use of a small electronic device designed for developing an appropriate SFF in deaf children (Fig. 1; Mártony, 1972).

Subjects

Normal series. A total of 414 measurements were made on 374 healthy subjects aged 6–40 years, 178 males and 196 females (Table). The children and adolescents were studied in kindergartens and schools. The adult males were medical students and physicians. For adult females, members of a choir were chosen to obtain a better range of the female voice. The subjects were classed according to sex, and age or stage of pubic hair (PH) development (Tanner, 1962) (see Table). PH stages were used because they reflect the androgenic action, which also determines the pubertal voice change.

Only one measurement was made on each subject except in a group of 20 males who were tested at 11·7–13·5 years, and then 1·0 year and 1·5 years later

(Fig. 2). At the first recording 18 of them were at PH stage 1 (Table), 16 being at genital stage 2-3, and 2 at stage 1 (Tanner, 1962). A group of 20 girls were also tested at 11.7-13.5 years and 1.0 year later (Fig. 2). At the first recording 9 were at PH stage 1 (Table). In some cases the PH stage had not changed between recordings; the mean of the two values was then used for the statistics in the Table.

Abnormal series. This series included 141 patients seen at the endocrine clinic. To study the relation

between growth retardation and SFF, one or more measurements were made on 82 abnormally short children (height >2 SD below the mean for age) aged 6-12 years. 28 of them (22 girls) had a pre-natal growth disorder; 7 (4 girls) were cases of Mulibrey nanism (Perheentupa *et al.*, 1973), 12 were

Fig. 1 (a) Instrument for measuring speaking fundamental frequency.

(b) The contact microphone is applied to the throat below the larynx.

Table Speaking fundamental frequency (SFF) and lowest frequency (LF) of normal subjects according to sex and age or maturity (pubic hair stages 1-5 during puberty) (means $\pm$ SD).

Group	Boys				Girls			
	n	Age (yr)	LF (Hz)	SFF (Hz)	n	Age (yr)	LF (Hz)	SFF (Hz)
6 year old	38	6.4 $\pm$ 0.3	234 $\pm$ 22	261 $\pm$ 20	22	6.5 $\pm$ 0.3	230 $\pm$ 23	256 $\pm$ 16
8 year old	28	8.2 $\pm$ 0.4	221 $\pm$ 19	259 $\pm$ 20	32	8.2 $\pm$ 0.4	219 $\pm$ 17	253 $\pm$ 14
10 year old	32	10.5 $\pm$ 0.2	203 $\pm$ 23	247 $\pm$ 22	28	10.6 $\pm$ 0.2	218 $\pm$ 20	252 $\pm$ 17
PH 1	18	12.6 $\pm$ 0.4	210 $\pm$ 16	240 $\pm$ 16	9	12.3 $\pm$ 0.2	202 $\pm$ 29	238 $\pm$ 22
2	14	13.7 $\pm$ 0.6	189 $\pm$ 24	216 $\pm$ 26	14	13.3 $\pm$ 0.6	*205 $\pm$ 19	†239 $\pm$ 15
3	13	13.9 $\pm$ 0.5	154 $\pm$ 43	174 $\pm$ 44	19	13.2 $\pm$ 0.8	†203 $\pm$ 23	†237 $\pm$ 20
4	9	14.0 $\pm$ 0.4	112 $\pm$ 24	137 $\pm$ 23	21	14.8 $\pm$ 1.1	†191 $\pm$ 19	†220 $\pm$ 17
5	30	17.8 $\pm$ 0.7	90 $\pm$ 9	100 $\pm$ 7	30	17.6 $\pm$ 0.4	†180 $\pm$ 21	†213 $\pm$ 15
Adults								
Tenor and bass	20	25.5 $\pm$ 4.1	89 $\pm$ 5	101 $\pm$ 9				
Soprano					18	30.3 $\pm$ 7.5	†158 $\pm$ 19	†208 $\pm$ 24
Alto					19	31.8 $\pm$ 6.7	†146 $\pm$ 8	†187 $\pm$ 9

Statistical significance of differences is denoted by * $P < 0.05$ and † $P < 0.01$ between the lines for differences between groups above and below, and in front of a mean for female groups for differences from the corresponding male group.

girls with Turner's syndrome, and 9 (6 girls) miscellaneous cases unclassified except for a 6-year-old boy who had a 46,XY,r15 karyotype. 12 (3 girls) children had congenital growth hormone deficiency; of the boys, 1 also lacked thyroid stimulating hormone (TSH) and ACTH, and another lacked TSH. 42 (10 girls) were cases of familial short stature and/or delayed maturation.

In addition, the effect of androgen treatment on voice was studied in two groups of pubertal age. 38 girls with Turner's syndrome, aged 11–18 years, were tested before and/or after fluoxymesterone treatment, given at the time of the measurements in the dosage of 0.03–0.3 mg/kg, mean 0.11 mg/kg (dose increasing with age), daily for a period of 0.3 to 3.3 years to accelerate growth. 48 boys, aged 12–17 years, with delayed growth and maturation (lag in bone age 2.7 ± 0.8 years, mean $\pm$ SD) were tested before and/or after fluoxymesterone treatment, given in a dose of 0.06–0.26 mg/kg (dose increasing with age) daily for 0.3 to 1.7 years to hasten growth and maturation. 31 (23 at stage PH 1 and 8 at PH 2) were tested before the treatment. After treatment 17 boys were tested at stage PH 1, 25 at PH 2, 29 at PH 3, and 15 at PH 4. 2 boys at stage PH 1 and 3 boys at PH 2 had been off treatment for 0.4–0.6 years, and 13 boys each at PH 3 and PH 4 had been off treatment for 0.4–1.7 years.

Methods

SFF was measured with two different methods. In all the subjects measurements were made with the SFF indicator shown in Fig. 1 (made by AB Special Instrument, Stockholm). The contact microphone of the indicator is applied to the throat below the larynx, and during phonation a pointer indicates the fundamental frequency in the range 0–550 Hz. In practice the reading is accurate to the nearest 5 Hz. During speech the pauses, stops, voiceless consonants, and intonation cause the readings to fluctuate. Thus, for an exact reading, long vowels are required. In the beginning we asked the subject to say long vowels in a natural speaking voice. When, as was usual, the readings obtained during these different sounds varied less than ± 10 Hz of the value, this value was recorded as the SFF.

With some children, however, as seen in Fig. 4, the readings obtained in this manner at different times were variable. It was difficult to elicit a natural speaking voice because of excitement, low intelligence, or other reasons. We therefore asked the subject to say a standard sentence containing long vowels, making sure that he or she was relaxed and speaking in a natural voice. With this method reproducibility improved from the values given in Results.

We next asked the subject to glide the voice as low as possible for measurement of the lowest frequency (LF), and finally to glide as high as possible. The frequency of a voice break, if present, was thereby noted, and also the highest frequency (HF), usually > 550 Hz.

The reproducibility of the measurement was assessed with the following 'blind' methods. (a) One of us (V.V.) repeated the measurement in 60 normal 6 year olds after 3 weeks. (b) 3 of us (H.L.L., J.P., V.V.) separately on the same day tested 37 patients with different types of growth retardation. To validate the results obtained with the SFF indicator, a comparison was made with a more complex method. The group of 60 normal 10 year olds read into a tape recorder the first passage (30–40 s) of the tale 'The Princess and the Pea' (Andersen, 1835). The recordings were analysed at the Speech Transmission Laboratory with an automated computerised method (Vuorenkoski *et al.*, 1972).

Results

Reproducibility of analysis with SFF indicator. In the second analysis of 60 children the mean ($\pm$ SD) difference from the first analysis was 2.1 ± 5.4 Hz for SFF and 1.6 ± 6.8 Hz for LF. The differences between the readings obtained by the 3 investigators varied between 1.5 ± 9.2 Hz and 2.2 ± 13.6 Hz and were not significant.

Comparison of SFF indicator and computerised methods. The mean ($\pm$ SD) difference between the SFF values obtained from 60 children with the two methods was 2.0 ± 11.2 Hz, not significant.

Normal children before puberty (Table, Fig. 2). Children aged 6, 8, and 10 years were compared. Among the boys a significant difference was observed in SFF between the 8 and 10 year olds, while in LF all three groups were significantly different. Among the girls the only significant difference was in LF between the youngest and the next older group. HF was > 550 Hz in all the boys and girls, and none had a voice break. Two significant sex differences were observed: LF was lower in the boys at 10 years, and in all age groups the dispersion of SFF was wider in the boys.

Normal subjects during puberty (Table, Figs. 2, 3). Among the boys there was a continuous and steady lowering of both SFF and LF parallel to the PH stage. Between every two consecutive stages the difference was significant. A voice break was recorded in 2 of the 14 boys at PH2, in 7 of 13 at PH3, and in all the boys at PH 4 and 5. The mean level of the voice break was 240 Hz (range 170–350 Hz). HF

Fig. 2 Development of speaking fundamental frequency (SFF) and lowest frequency (LF) in males and females. Means $\pm$ SDs are indicated. For adult females, values for soprano and alto groups are given separately.

was >550 Hz in all boys at various PH stages except for 15 who were unable or refused to glide above the break level, and for 6 boys at PH stage 5 who reached an HF value of 400–500 Hz. Fig. 3 shows a steady but gradual change during PH development. Individual boys tended to maintain their relative positions in the distribution throughout puberty.

In the girls there was also a significant lowering of voice. A decrease was evident in both SFF and LF in our 12-year-old (PH 1) group, i.e. at the earliest pubertal stage before the appearance of PH. Then there was no further change until after PH 3. The HF remained >550 Hz throughout, and none of the girls had a voice break. Of the girls who were tested repeatedly, surprisingly few had a distinct lowering of the voice (Fig. 3). A significant sex difference was present at all stages except PH 1 both in SFF and LF. At PH 2–4 the dispersion was markedly wider in the males.

Normal adults. In the group of 20 adult males (no tenor/bass distinction was made) the voice was not lower than in the last pubertal group and the dispersion was narrow. A clear voice break was observed in all the subjects, with a mean level of 240 Hz (range 180–300 Hz). HF was >500 Hz in all. For the adult females with soprano voices, SFF was not significantly lower than in the last pubertal group, but in the LF there was a highly significant difference, perhaps because the adult females were a selected group of singers with some training. The altos had

Fig. 3 A longitudinal study of pubertal change in speaking fundamental frequency (SFF) and lowest frequency (LF) in a group of boys and girls.

significantly lower SFF and LF values than the sopranos and the PH 5 group, suggesting that the pubertal voice change is greater in some females than in others, but only a longitudinal study could show whether this is the case.

Abnormally short children (Fig. 4). The clinical impression was that a high-pitched voice was characteristic of Mulibrey nanism (Perheentupa *et al.*, 1970) and this was later confirmed with measurements (Vuorenkoski *et al.*, 1972). According to our

Fig. 4 Speaking fundamental frequency (SFF) in abnormally short children, ● male, ○ female. Subjects studied longitudinally shown with a line connecting the individual measurements. Mean $\pm$ 2 SD for normal children indicated by lines (sexes combined except for the Turner's syndrome group).

observations, however, the pitch is not constantly abnormal. While most Mulibrey children had an SFF at or above the upper limit of the normal range, some voices were below the mean for age.

The girls with Turner's syndrome tended to have voices of higher than normal pitch ($P < 0.05$, Fig. 6). The readings for some of the girls were variable; the

Fig. 5 Voice histories of 3 subjects. Case 1 had his puberty induced with high-dosage testosterone treatment. Case 2 increased her androgen dose accidentally. Case 3 had an insidious lowering of voice during androgen treatment given to accelerate growth. Normal mean $\pm$ 2 SD for the pubertal stages indicated by lines.

most extreme case (Fig. 4) being a girl with borderline intelligence.

In the miscellaneous group of *prenatal growth failure*, 2 children had abnormally high SFF values. The highest voice was in the boy with the karyotype 46,XY,r15, who had the severest growth failure of the series (height 6 SD below the mean for age). The other abnormal voice was of a girl with multiple minor malformations.

Of the *hypopituitary* children, the youngest ones mostly had high voices, but some of the older ones had borderline low pitch for bone age, though not for age. The 2 boys with TSH deficiency did not differ from the others.

Most of the children with *familial short stature* and/or *delayed growth* had SFF values below the mean for bone age. For the total group of 25 delayed boys at PH stage 1 and bone age ≥ 10 years (Fig. 6, not shown in Fig. 4), the difference from normal boys at the same stage was significant ($P < 0.005$). At PH stage 2 no such difference was present.

Androgen treatment. The very rapid effect of strong testosterone treatment on the voice is illustrated by Case 1 (Fig. 5). The sensitivity of the female voice to small doses of androgen is shown by Cases 2 and 3 (Fig. 5). Both had distinct lowering of the voice without the appearance of acne or clitoral enlargement. A gradual lowering of SFF, as occurred in Case 3, will not be heard by the unaided ear before the change is permanent.

In contrast to girls with untreated Turner's syndrome, those treated with fluoxymesterone had

as a group highly significantly lower SFF values than normal girls at the same PH stages (Fig. 6) because of too large doses of fluoxymesterone. This observation was made when the SFF indicator became available to us. Since then we have given 0.1 mg/kg or less daily to these girls; with this dosage the voice has remained unaffected.

The boys with delayed growth and maturation treated with similar small doses of fluoxymesterone tended to have significantly lower SFFs at stages PH 1 and PH 2 than the reference boys at the same stages (Fig. 6). However, the delayed boys of this group were not significantly different from delayed boys who were untreated. At stage PH 4 the delayed boys may have had voices that were higher than normal.

Discussion

Methodology. The ideal method for measurement of pitch is probably a computerised analysis of speech in a spontaneous situation. But until such a method is available to the clinician, use of the SFF indicator can be recommended. The results obtained with this instrument do not differ systematically from those obtained with a computerised method. A drawback of the indicator measurement is that its precision is rather low and in some subjects the readings fluctuate. About half of the variation observed for some age groups seems to be due to the method. Part of the low precision is caused by the unnatural testing situation, a problem which will diminish with accumulating experience of the observer.

Fig. 6 Speaking fundamental frequency (SFF) in a group of boys with delayed growth and maturation and a group of girls with Turner's syndrome, by pubic hair (PH) stage, before and after treatment with an androgen, fluoxymesterone. Significant differences between groups are indicated in the figure. Bars indicate mean $\pm$ SEM.

Normal development of pitch. The development of SFF before puberty was described in a cross-sectional study of 84 subjects, 3- to 13-year-old children or adults, from the St. Louis area by Eguchi and Hirsch (1969). They found a fall in the mean SFF, for the sexes combined, from 298 to 262 Hz between the ages of 3 and 7 years, but a further fall only after the age of 10 years. Interestingly, our data shows a significant sex difference before puberty: a lowering of both SFF and LF between 8 and 10 years in boys, in contrast to girls. This difference has not been reported by previous workers (Eguchi and Hirsch, 1969; Oordt and Drost, 1963). With regard to the absolute SFF values, ours were slightly lower than those of Eguchi and Hirsch; in general there was also good agreement with data published for children of isolated age groups (Fairbanks *et al.*, 1949a, b; Duffy, 1958; Naidr *et al.*, 1965; Michel *et al.*, 1966; Hollien and Malcik, 1967; Weinberg and Zlatin, 1970; Chevré-Müller, 1971). The reasons for the differences are presumably partly methodological, partly racial, linguistic, and cultural.

In most previous studies of the male pubertal voice change a serious shortcoming was that the deepening was correlated with chronological age only, and not with the stage of pubertal development. Yet the age range at the onset of puberty is as wide as the mean duration of pubertal somatic maturation, and consequently at certain ages the full scale of maturity is present (Tanner, 1975). As expected, a better correlation exists between the male voice change and bone age than between the voice change and age (Andersen, 1968). Tanner (1962) states that 'the male voice begins to deepen perceptibly during the period when the development of the penis is nearing completion', and 'gradualness makes voice deepening of little use for adolescence ratings'. We needed to confirm that the gradualness was not simply an apparent but erroneous result of the cross-sectional technique of study. Naidr *et al.* (1965) followed the voice, height, and laryngeal size in 100 boys from 11 to 15 years of age. Although pubertal stages were not recorded in this study, they concluded that the principal change in voice coincided with the greatest increase in height but was somewhat in advance of the increase in the size of the larynx.

Our findings confirm that the decrease in SFF does indeed occur gradually as correlated with the PH stages. Although the mean LF began to decrease earlier than the mean SFF, the greatest change occurred later in the mean LF (between PH 3 and 4) than in the mean SFF (between PH 2 and 3). In contrast to previous data, mature SFF and LF were already reached by our group aged 17.8 years. In our males the mature SFF was lower than in any other reports, 100 vs 120–133 Hz (for review, see

Hollien and Jackson, 1973). This is probably a real difference, associated with race, language, and culture.

Voice change also occurs in girls during puberty (Hollien and Paul, 1969). Notably, our data suggest that this change takes place in two steps: first early in puberty before the appearance of pubic hair, and then later after PH stage 3. The SFF values of our oldest pubertal group do not differ from those previously published for this stage (for review, see Hollien and Paul, 1969). According to Hollien and Paul, the adult female voice reaches stability during the immediate postpubertal period. Our finding of a significantly lowered LF in the adult groups must not be taken as evidence against that finding, because our female adult group were selected. The chronological, and possibly endocrinological and genetic, basis of the difference between soprano and alto voices would be an interesting, though difficult, subject to study.

Clinical value of pitch measurements. As pointed out by Tanner (1962), single measurements of pitch are of limited value in attempts to define the developmental stage of an individual because the voice change is gradual. However, these measurements do offer a useful additional parameter for following the development of an individual, normal or abnormal. Several workers have reported that the sensitivity of the female voice organ to androgen treatment, though individually variable, is higher than the sensitivity of other end organs (Timonen *et al.*, 1962; Bauer, 1963, 1968; Pfalz, 1967). The greatest clinical value of the measurement of SFF is probably in guarding against an undesired voice change during such treatment. Androgens form part of the physiological substitution therapy of females with ACTH deficiency, with adrenocortical failure and, perhaps with ovarian failure. Although the treatment is a matter of debate, androgens are used to promote growth in girls with Turner's syndrome (Perheentupa *et al.*, 1974). In our experience the voice is more sensitive to androgens than, for example, the skin or clitoris in these girls, and an irreparable voice change may be produced insidiously. We have made it a rule that every girl treated with androgens is to be followed with regular measurements of pitch.

Pitch measurement is an additional tool in the characterisation of growth failure and malformation syndromes. Voice abnormality is present in many of these conditions, and presumably has a variable basis: deviation in the size, spatial organisation, tissue structure or consistency, or differing development of the musculature etc. of the speech organ. A high pitch seems to be a frequent, though not constant, feature of prenatal growth failure

syndromes. It is one of the qualities typical of the voice in Mulibrey nanism (Perheentupa *et al.*, 1970, 1973, 1975; Vuorenkoski *et al.*, 1972). Young girls with Turner's syndrome tend to have high pitched voices, but no other unusual feature of the voice is typical. Our observation that young children with growth hormone deficiency (even for bone age) have a high voice pitch is expected, but we cannot account for the apparent normalisation of pitch in the older children of this group.

In boys with delayed growth and maturation the voice at PH stage 1 was like that of normal boys at PH stage 2, and notably the low pitch seemed to be a characteristic of this group even before puberty began. But an effort to correct the difference in voice maturity from other boys their age is not a tenable explanation for this observation.

References

- Andersen, E. (1968). Skeletal maturation of Danish school children in relation to height, sexual development, and school conditions. *Acta Paediatrica Scandinavica*, Suppl. 185, 97–99.
- Andersen, H. C. (1835). The Princess and the pea. *Fairy Tales*.
- Bauer, H. (1963). Die Beeinflussung der weiblichen Stimme durch androgene Hormone. *Folia Phoniatica*, 15, 264–268.
- Bauer, H. (1968). Die Beziehungen der Foniatrie zur Endokrinologie. *Folia Phoniatica*, 20, 387–393.
- Chevrie-Muller, C. (1971). Etude du fondamental de la voix parlée sur des groupes d'enfants de 3 ans à 5 ans et demi. *Journal Français d'Oto-Rhino-Laryngologie et Chirurgie Maxillo-Faciale*, 20, 451–455.
- Duffy, R. (1958). The vocal pitch characteristics of eleven, thirteen and fifteen year-old female speakers. Ph.D Thesis, State University of Iowa.
- Eguchi, S., and Hirsh, I. J. (1969). Development of speech sounds in children. *Acta Oto-Laryngologica*, Suppl., 257.
- Elliott, L. L., and Niemoeller, A. F. (1970). The role of hearing in controlling voice fundamental frequency. *International Audiology*, 9, 47–52.
- Fairbanks, G., Herbert, E., and Hammond, J. (1949a). An acoustical study of vocal pitch in seven and eight year-old girls. *Child Development*, 20, 71–78.
- Fairbanks, G., Wiley, J. H., and Lassman, F. (1949b). An acoustical study of vocal pitch in seven and eight year-old boys. *Child Development*, 20, 63–69.
- Hollien, H., and Jackson, B. (1973). Normative data of the speaking fundamental frequency characteristics of young adult males. *Journal of Phonetics*, 1, 117–120.
- Hollien, H., and Malcik, E. (1967). Evaluation of cross-sectional studies of adolescent voice change in males. *Speech Monographs*, 34, 80–84.
- Hollien, H., and Paul, P. (1969). A second valuation of the speaking fundamental frequency characteristics of post-adolescent girls. *Language and Speech*, 12, 119–124.
- Luchsinger, R., and Arnold, G. E. (1965). *Voice – Speech – Language*. Wadsworth, Belmont, California.
- Mártony, J. (1971). Pitch range of deaf children. *Proceedings of the Speech Symposium, Szeged, Hungary*, p. 171. Ed. by J. Hirschberg, Gy. Szépe, and E. Vass-Kovácz. Akadémiai kiadó, Budapest.
- Mártony, J. (1972). Visual aids for speech correction. *Proceedings of the International Symposium on Speech Communication Ability and Profound Deafness*, pp. 345–349. Ed. by G. Fant. Alexander Graham Bell Association for the Deaf, Washington.
- Michel, J. F., Hollien, H., and Moore, P. (1966). Speaking fundamental frequency characteristics of 15, 16 and 17 year-old girls. *Language and Speech*, 9, 46–51.
- Naidr, J., Zboril, M., and Sevcik, K. (1965). Die pubertalen Veränderungen der Stimme bei Jungen im Verlauf von 5 Jahren. *Folia Phoniatica*, 17, 1–18.
- Oordt, H. W. A. van, and Drost, H. A. (1963). Development of the frequency range of the voice in children. *Folia Phoniatica*, 15, 289–298.
- Perheentupa, J., Autio, S., Leisti, S., and Raitta, C. (1970). Mulibrey-nanism: dwarfism with muscle, liver, brain and eye involvement. *Acta Paediatrica Scandinavica*, 206, Suppl., 74–75.
- Perheentupa, J., Autio, S., Leisti, S., Raitta, C., and Tuuteri, L. (1973). Mulibrey-nanism, an autosomal recessive syndrome with pericardial constriction. *Lancet*, 2, 351–355.
- Perheentupa, J., Lenko, H. L., Nevalainen, I., Niittymäki, M., Söderholm, A., and Taipale, V. (1974). Hormonal therapy in Turner's syndrome, growth and psychological aspects. *Proceedings of the XIV International Congress of Paediatrics, Buenos Aires*, 5, 121–127.
- Perheentupa, J., Autio, S., Leisti, S., Raitta, C., and Tuuteri, L. (1975). Mulibrey nanism, review of 23 cases of a new autosomal recessive syndrome. *Birth Defects, Original Article Series*, XI, 3–17.
- Pfalz, R. (1967). Veränderungen an Hals, Nase und Ohr durch endokrine Erkrankungen. *HNO*, 15, 88–91.
- Pruszcwicz, A., Obrebowski, A., Jassem, W., and Kubzdela, H. (1973). Ausgeprägte akustische Merkmale virilisierter Mädchenstimmen. *Folia Phoniatica*, 25, 331–341.
- Schultz-Coulon, H.-J., and Arndt, H. H. (1972). Tonhöhen-schreibung in der phoniatischen Praxis. *Folia Phoniatica*, 24, 241–258.
- Tanner, J. M. (1962). *Growth at Adolescence*, 2nd ed. Blackwell, Oxford.
- Tanner, J. M. (1975). Growth and endocrinology of the adolescent. *Endocrine and Genetic Diseases and of Childhood Adolescence*, 2nd ed. Ed. by L. I. Gardner. Saunders, Philadelphia.
- Timonen, S., Sonninen, A., and Wichman, K. (1962). Endocrinological laryngopathy. *Annales Chirurgiae et Gynaecologiae Fenniae*, 51, Suppl. 107.
- Vuorenkoski, V., Lind, J., Partanen, T., Lejeune, J., Lafourcade, J., and Wasz-Höckert, O. (1966). Spectro-graphic analysis of cries from children with maladie du cri du chat. *Annales Paediatricae Fenniae*, 12, 174–180.
- Vuorenkoski, V., Lind, J., Wasz-Höckert, O., and Partanen, T. J. (1971). Cry score. A method for evaluating the degree of abnormality in the pain cry response of the newborn and young infant. *Speech Transmission Laboratory, Quarterly Progress and Status Report*, 1, 68–75.
- Vuorenkoski, V., Tjernlund, P., and Perheentupa, J. (1972). Auditory perception of voice qualities and speaking fundamental frequency in Mulibrey-nanism and in some other children with growth failure. *Speech Transmission Laboratory, Quarterly Progress and Status Reports*, 2–3, 64–74.

- Vuorenkoski, L., Vuorenkoski, V., and Anttolainen, I. (1973). Cry analysis in congenital hypothyroidism: an aid to diagnosis and clinical evaluation. *Acta Paediatrica Scandinavica*, **236**, Suppl., 27–28.
- Wasz-Höckert, O., Lind., J., Vuorenkoski, V., Partanen, T., and Valanne, E. (1968). *The Infant Cry: a Spectrographic and Auditory Analysis*. Clinics in Developmental Medicine No 29. Heinemann, London.
- Weinberg, B., and Zlatin, M. (1970). Speaking fundamental frequency characteristics of five- and six-year-old children with mongolism. *Journal of Speech and Hearing Research*, **13**, 418–425.
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