A Roentgencephalometric Investigation of the Effect of Adenoid Removal upon Selected Measures of Velopharyngeal Function

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Velopharyngeal closure, a feature necessary for the production of non-nasalized speech, is accomplished by velar movement in a posterosuperior direction accompanied by pharyngeal wall movement primarily in a mesial direction. The target of this posterosuperior velar movement is the posterior pharyngeal wall. In children, this target area is covered by a mass of lymphoid tissue, the adenoids. When adenoid tissue is present it provides a more anterior cushion against which velopharyngeal closure is achieved, thereby decreasing anterior-posterior pharyngeal depth (*9, 16*). By virtue of the presence of adenoid tissue, therefore, the distance the velum must traverse in order to effect velopharyngeal valving is decreased.

Extirpation of adenoid tissue, a common surgical procedure in children, results in an abrupt change in pharyngeal architecture which is manifested by increased anterior-posterior pharyngeal depth. The end result is a greater distance the velum must traverse in order to obturate the velopharyngeal port. If normal oral-nasal resonance balance is to be preserved, this abrupt change in pharyngeal dimensions should necessitate a change in the mode of velopharyngeal function from the pre- to the postoperative state. In other words, the velopharyngeal mechanism must have the basic physiological potential and must adapt to this sudden increase in pharyngeal depth. If this potential is not present and these adaptations are not made, hypernasal speech will, in all probability, result.

In some children, such as those with a congenitally short velum or excessively deep pharynx, the adenoid pad serves as an essential aid in velopharyngeal closure. In these children, adenoidectomy might result in irreversible hypernasality. Cases of this nature have been reported, and the resultant hypernasality is usually attributed to the unmasking of regional growth disturbances or congenital palatopharyngeal insufficiency by the adenoidectomy (*4, 5, 6, 13*). In these cases, the velopharyngeal mechanism apparently lacks the physiological potential to adjust to this change in pharyngeal dimensions.

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Three studies have previously attempted to describe the effect of adenoid removal upon velopharyngeal function. Wallner et al. (*17*) stated that greater velar excursion is required to effect velopharyngeal closure postoperatively. All 31 subjects investigated in his study were found to be accomplishing "effective velopharyngeal closure" one month postoperatively. Subtelny and Koepp-Baker (*16*) also found that the velum must traverse a greater distance to effect closure postoperatively. In addition, they stated that 1) greater muscular activity on the part of the velum is required to compensate for the increased pharyngeal dimensions; 2) the amount of velar tissue affecting closure is reduced postoperatively; and 3) subsequent to adenoid removal velopharyngeal closure must be more posteriorly located. Fletcher (*4*) contends that adenoid removal in children causes a directional shift in velar movement from the typical posterosuperior direction to a more posterior direction. None of these studies presents basic data, and their results are presented in a subjective manner. In addition, these studies, with the exception of Fletcher's (*4*), failed to control various crucial variables (e.g., subject age) and neglected to examine many of the parameters of velopharyngeal function.

An investigation designed to provide a detailed, objective and clear description of the effect of adenoid removal upon velopharyngeal function was clearly indicated. The purpose of this investigation was to answer the following questions: What changes occur in pharyngeal dimensions and velopharyngeal function as a result of adenoid removal, and to what extent are these changes related? In addition, a quantitative description of the physiological capacity of the normal velopharyngeal mechanism to adjust to the anatomical effects of adenoid removal has possible clinical application. Data on the normal mechanism would hopefully provide the information needed to more accurately predict the ability of the mechanism of marginal or questionable integrity to adjust to this surgical procedure.

Procedure

Subjects. Fifteen subjects, eleven male and four female adenotonsillectomy and selective adenoidectomy candidates, ranging in age from four to seven years, were selected for this study. Criteria for subject acceptance were that each subject achieve velopharyngeal closure during the preoperative (upon admission to hospital) and postoperative (four to six weeks subsequent to surgery) visit, as demonstrated by the following: 1) cephalometric evidence of velopharyngeal closure during sustained production of /s/; and 2) an oral-nasal resonance balance not rated hypernasal by a panel of judges.

Equipment. Lateral cephalometric x-rays were taken with a Universal X-ray Unit (Model 3325). The headholder was a Wehmar Cephalostat. Cassettes for the film were Radelin (TF-2) High Speed, plastic coated with an intensifying screen.

Cephalometric Procedures. Two lateral cephalometric x-rays, one at physiological rest and one during sustained production of /s/, were taken of each subject during the preoperative visit; the same procedure was used during the postoperative visit. A composite of the two preoperative and two postoperative X-rays on one subject is presented in Figure 1.

Measurement Procedures. Tracings from the x-rays were made on acetate transparencies, and all measurements were taken from these tracings. All linear measurements were made correct to the nearest one-half millimeter. Angular measurements were made correct to the nearest whole degree. Area measurements were made with a compensating polar planimeter correct to the nearest square millimeter.

The linear, angular, and area measurements made on the two preoperative and two postoperative lateral x-rays for the eleven male and four female subjects are illustrated schematically in Figure 2. Measurements taken were as follows:

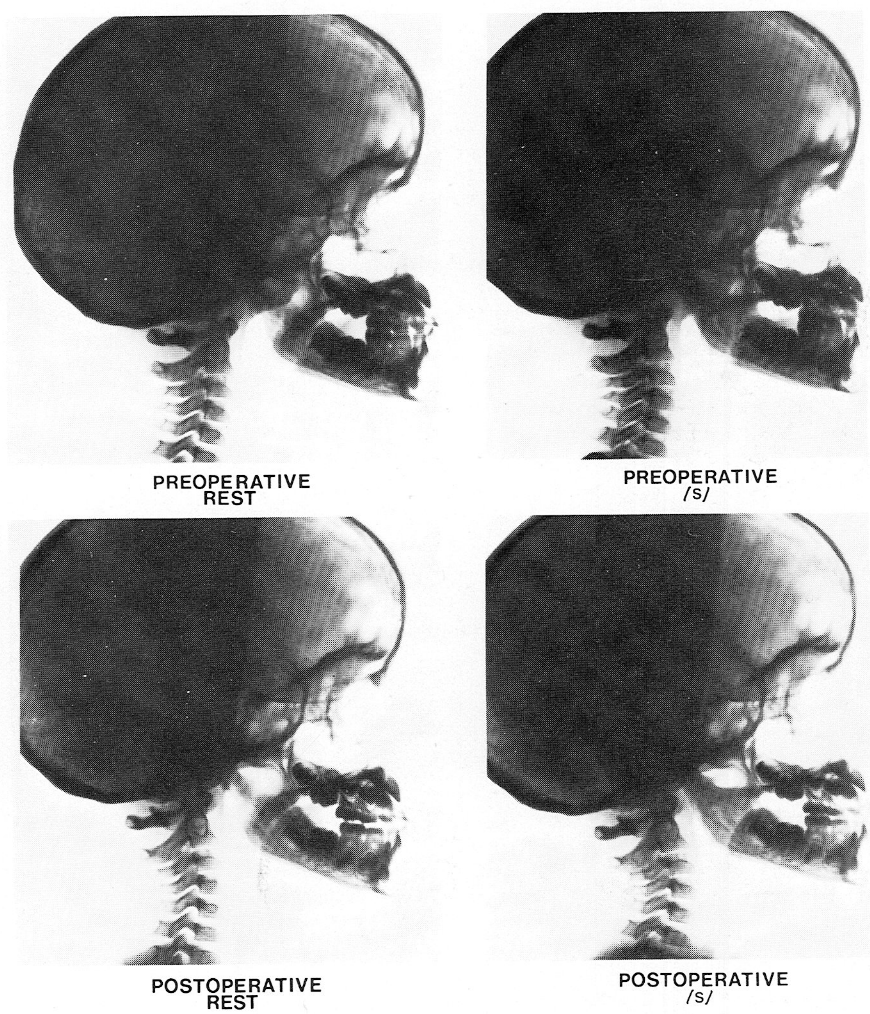

FIGURE 1. Two preoperative and two postoperative cephalometric radiographs of one subject during physiological rest and during sustained production of /s/.

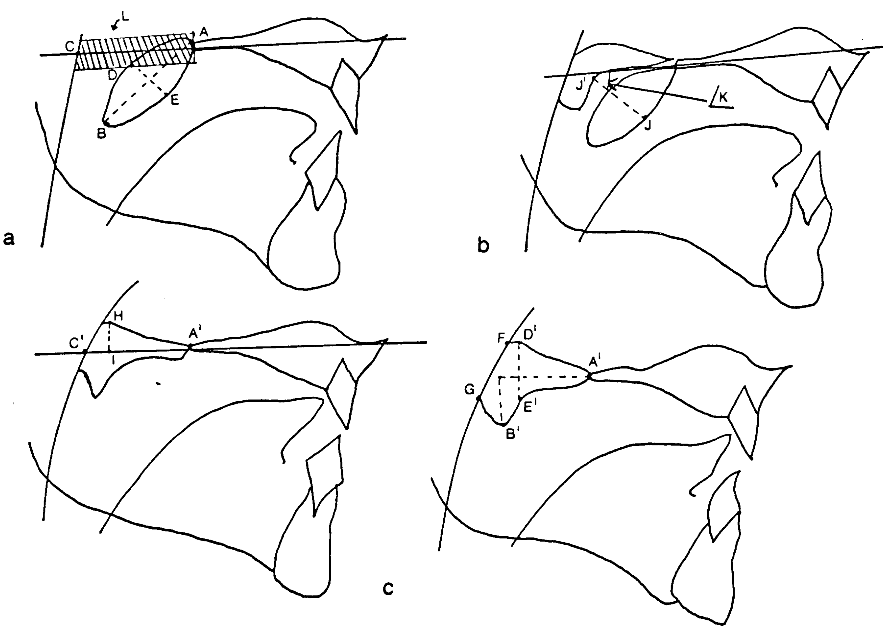

FIGURE 2. Velopharyngeal measurements: a. During rest (AB: velar length; AC: soft tissue pharyngeal depth; DE: velar thickness; L: area of velopharyngeal closure); b. From rest to function (JJ': velar mobility; K: angle of velar movement); c. During function (A'C': soft tissue pharyngeal depth; HI: height of velopharyngeal closure; A'B': velar length; D'E': velar thickness; FG: amount of velopharyngeal contact).

1. Velar length (rest-AB) (function-A'B'). Midline distance is measured from the posterior nasal spine to the tip of the uvula.
2. Velar thickness (rest-DE) (function-D'E'). The thickness at the thickest section of the velum is measured on a line perpendicular to the midline.
3. Velar mobility (JJ'). Velar mobility is defined as the linear distance traversed by the midpoint of the oral surface of the resting velum to the midpoint of the levator dimple during function.
4. Angle of velar movement (K). Angle of velar movement is defined as the angle formed by the intersection of the palatal plane with a line connecting the midpoint of the oral surface of the resting velum and the midpoint of the levator dimple during function.
5. Amount of velopharyngeal contact (FG). Amount of contact is measured from the superior to the inferior points of contact between the velum and the posterior pharyngeal wall during function.
6. Height of velopharyngeal closure (HI). Height of closure is measured (on a line perpendicular to the palatal plane) from the palatal plane to the superior-most point of the nasal surface of the velum during function.
7. Soft tissue pharyngeal depth (rest-AC) (function-A'C'). Depth of the pharynx is measured along the palatal plane from the posterior nasal spine to the posterior pharyngeal wall.
8. Area of velopharyngeal closure (L). This area is determined by measuring the area encompassed anteriorly by a line perpendicular to the palatal plane registered at the posterior nasal spine, posteriorly by the posterior pharyngeal wall, superiorly by a line drawn five millimeters above and parallel to the palatal plane, and inferiorly by a line drawn five millimeters below and parallel to the palatal plane.

Those measures derived from the above were as follows:

9. Need ratio (AC/AB). The need ratio is computed by dividing soft tissue pharyngeal depth at rest by resting velar length.
10. Change in velar length (A'B'-AB). This is the change in velar length from rest to function.
11. Percent of velar stretch ($\frac{A'B'-AB}{AB} \times 100$). The percent of velar stretch is determined by

dividing the change in velar length by resting velar length and multiplying that value by 100.
12. Posterior pharyngeal wall movement (AC-A′C′). The distance that the posterior pharyngeal wall moves from rest to function is computed by subtracting soft tissue pharyngeal depth during function from soft tissue pharyngeal depth at rest.

Reliability. In order to assess inter-judge measurement reliability, x-rays of five subjects were randomly selected. A second judge repeated all tracings and measurements made by the principal investigator. For preoperative measures, the coefficients of reliability ranged from r = .852 to 1.000 ($\overline{X}$ = .956); postoperative coefficients of reliability ranged from r = .674 to .992 ($\overline{X}$ = .938). With one exception (postoperative velar length during function, r = .674), the coefficients indicate inter-judge reliability to be sufficiently high for the purposes of this study.

Results and Discussion

Mean Differences Between Pre- and Postoperative Measures. Means and standard deviations for all cephalometric measures are presented in Table 1. To determine if significant differences existed between the means of each pre- and postoperative measure, a t-test for paired observations was employed. Results of the t-test are presented in Table 2.

All measures of pharyngeal dimensions (soft tissue pharyngeal depth, area of velopharyngeal closure, need ratio) increased significantly ($p < .01$) as a result of adenoid removal. It was previously stated that extirpation of adenoid tissue results in increased anterior-posterior pharyngeal depth. Results of this investigation support this statement. It is interesting to note that postoperative need ratio increased to 97.33%. Subtelny (15) stated that ratios greater than 70% indicate an unfavorable relationship between velar length and pharyngeal depth. Had these children been born with pharynxes of these dimensions, they could be considered to have an anatomical characteristic of congenital palatopharyngeal insufficiency (C.P.I.).

There were significant ($p < .01$) differences between the pre- and postoperative means of most measures of velopharyngeal function. The differences between the pre- and postoperative means of the following measures were significant: velar length during function; velar thickness during function[1]; velar mobility; height of velopharyngeal closure; and percent of velar stretch. The differences between the pre- and postoperative means of angle of velar movement, amount of velopharyngeal contact, and posterior pharyngeal wall movement were not significant.

All subjects met the physiological and perceptual criteria of velopharyngeal closure postoperatively in spite of increased pharyngeal dimensions. Therefore, it seemed logical to expect some changes in velopharyngeal function if the mechanism were to adjust to its new environment. Subtelny and Koepp-Baker (16) and Wallner et al (17) found velar mobility to increase postoperatively;

[1] Velar thickness is traditionally measured at the thickest point of the velum. There are some inherent dangers in this approach since the thickest portion of the velum might vary from rest to function. In addition, changes in the convexity of the velum may cause apparent changes in velar thickness as viewed on a lateral radiograph, which in fact do not exist. Hence, the difference between the pre- and postoperative means of velar thickness during function might be an artifact.

TABLE 1. Means and standard deviations for all preoperative, postoperative, and change cephalometric measures.

Measure		Preop.	Postop.	Change
Soft tissue pharyngeal depth at rest	$\bar{X}$	19.667	27.567	7.900
	s	7.941	4.873	5.764
Area of velopharyngeal closure	$\bar{X}$	204.000	297.333	93.333
	s	76.139	39.545	71.281
Need ratio	$\bar{X}$	70.867	97.333	24.467
	s	25.779	12.687	21.430
Velar length at rest	$\bar{X}$	27.567	28.267	0.700
	s	2.485	2.492	1.279
Velar thickness at rest	$\bar{X}$	8.600	9.233	0.633
	s	1.502	1.193	1.302
Velar length during function	$\bar{X}$	31.067	36.167	5.100
	s	4.942	5.147	4.124
Velar thickness during function	$\bar{X}$	8.733	10.533	1.800
	s	2.060	2.256	1.878
Velar mobility	$\bar{X}$	8.300	10.933	2.633
	s	2.783	2.389	2.793
Angle of velar movement	$\bar{X}$	44.333	45.667	1.333
	s	22.718	9.499	19.465
Height of velopharyngeal closure	$\bar{X}$	4.033	8.067	4.033
	s	2.100	2.896	2.271
Amount of velopharyngeal contact	$\bar{X}$	12.100	9.300	-2.280
	s	4.327	3.858	5.473
Change in velar length	$\bar{X}$	3.500	7.900	4.400
	s	4.031	3.592	4.310
Percent of velar stretch	$\bar{X}$	12.667	27.800	15.133
	s	13.839	11.602	15.702
Soft tissue pharyngeal depth during function	$\bar{X}$	20.100	26.433	6.333
	s	7.419	5.046	4.821
Posterior pharyngeal wall movement	$\bar{X}$	-0.433	0.733	1.167
	s	2.802	1.374	2.380

results of this investigation support their contention. Subtelny and Koepp-Baker further stated that amount of velopharyngeal contact decreases postoperatively; although a decrease did occur in the amount of velopharyngeal contact from the pre- to the postoperative state, this decrease was not found to be significant. Fletcher's (4) finding that the angle of closure becomes more acute postoperatively is also not supported by this investigation. As far as can be ascertained, the other significant differences between the pre- and postoperative means of velopharyngeal function have not been previously reported.

One interesting change in velopharyngeal function was seen in the height of velopharyngeal closure. Height of closure increased 100% or six millimeters postoperatively, this change being significant at the .01 level of confidence. Although electromyographic instrumentation was not employed in this investigation, it can be postulated that this increase in height of closure might be due to greater muscular effort on the part of the palatal levators. An alternate explanation of this significant increase in height of closure is the lack of the previously inhibiting mass of adenoid tissue.

Another parameter of velopharyngeal function measured in this investigation was percent of velar stretch. Pruzansky and Mason (11), in a cephalometric study of 110 C.P.I.'s, found that the velum increased in length 25.8% from rest to /s/. Simpson and Austin (14), in a cephalometric study of 20 normal adults found the velum to stretch slightly over 20% from rest to /s/. Colton (2), in a cephalometric study of 20 normal adolescents, found the velum to stretch slightly over 15% from rest to /s/. The present investigation found that postoperative velar stretch was 27.8%, this increase being significant at the .01 level of confidence. It is interesting to note that the preoperative percent of velar stretch was below the values found by both Simpson and Austin (14) and Colton (2). This is probably due to the fact that velar movement was inhibited preopera-

TABLE 2. Results of the t-test to determine significant differences between the pre- and postoperative means of all cephalometric measures.

Measure	t
Soft tissue pharyngeal depth at rest	-5.3083*
Area of velopharyngeal closure	-5.070*
Need ratio	-3.898*
Velar length at rest	-2.120
Velar thickness at rest	-1.884
Velar length during function	-4.789*
Velar thickness during function	-3.711*
Velar mobility	-3.651*
Angle of velar movement	-0.265
Height of velopharyngeal closure	-6.877*
Amount of velopharyngeal contact	1.981
Change in velar length	-3.953*
Percent of velar stretch	-3.728*
Soft tissue pharyngeal depth during function	-5.088*
Posterior pharyngeal wall movement	-1.898

*Significant at the .01 level.

tively by the presence of adenoid tissue. More interesting, however, is the fact that postoperative percent of velar stretch was slightly higher than the same measure taken on a group of C.P.I.'s by Pruzansky and Mason. The children in the present study cannot be classified as C.P.I.'s since none displayed hypernasality and all achieved velopharyngeal closure. Nevertheless, the group under study acquired pharyngeal dimensions of C.P.I. proportions as a result of adenoid removal. However, they were able to successfully offset the combination of "adult-like" pharyngeal dimensions with "child-like" velar dimensions by increased velar mobility, increased height of velopharyngeal closure, and increased percent of velar stretch.

RELATIONSHIPS WITHIN THE CHANGED VELOPHARYNGEAL MECHANISM. The correlation coefficients for the changes among velopharyngeal measures from the pre- to the postoperative state are presented in Table 3. Due to the large number of correlations computed, a $p < .01$ level of significance was employed.

None of the relationships between changes in pharyngeal dimensions and changes in velopharyngeal function from the pre- to the postoperative state reached statistical significance. In other words, changes in pharyngeal dimensions were not accompanied by systematic and predictable changes in any of the measures of velopharyngeal function.

Several significant relationships among changes in velopharyngeal function did, however, emerge. The change in velar length during function was related to the change in velar mobility ($r = .766$, $p < .01$), angle of velar movement ($r = .691$, $p < .01$), and percent of velar stretch ($r = .923$, $p < .01$). The relationship between the change in velar thickness during function and height of velopharyngeal closure was $r = .604$ ($p < .01$). The change in velar mobility was related to the change in percent of velar stretch ($r = .734$, $p < .01$). The relationship between the change in the angle of velar movement and percent of velar stretch was $r = .782$ ($p < .01$). The change in amount of velopharyngeal contact was related to the change in posterior pharyngeal wall movement ($r = -.604$, $p < .01$).

One of the more intriguing relationships that emerged among changes in measures of velopharyngeal function was the following: As amount of contact decreased from the pre- to the postoperative state, the amount of posterior pharyngeal wall movement increased. This suggests that as the amount of contact between the velum and the posterior pharyngeal wall became more tenuous, the movement of the posterior pharyngeal wall was increasingly required. Many researchers have found that the posterior pharyngeal wall of normal subjects does not move anteriorly to a significant degree during speech (*1, 3, 18*). Haggerty and Hill (*7*) found more anterior movement of the posterior pharyngeal wall in cleft palate subjects than in normal subjects. It appears, then, that the group of subjects under investigation adapted to a change in amount of velopharyngeal contact by means of posterior pharyngeal wall movement, an adaptation not unlike the type one would expect to find in a cleft palate of C.P.I. population.

The relationship between change in percent of velar stretch and two other

TABLE 3. Correlation matrix of the changed linear, angular and area measurements.*

	1 Soft tissue pharyngeal depth at rest	2 Area of velopharyngeal closure	3 Need ratio	4 Velar length at rest	5 Velar thickness at rest	6 Velar length during function	7 Velar thickness during function	8 Velar mobility	9 Angle of velar movement	10 Height of velo-pharyngeal closure	11 Amount of velo-pharyngeal contact	12 Change in velar length	13 Percent of velar stretch	14 Soft tissue pharyngeal depth during function	15 Posterior pharyngeal wall movement
1	1.000														
2	.730	1.000													
3	.973	.756	1.000												
4	.226	.137	.037	1.000											
5	.292	.076	.330	-.060	1.000										
6	.384	.321	.363	-.006	.666	1.000									
7	.532	.571	.421	.442	-.003	.261	1.000								
8	.440	.502	.459	.002	.432	.768	.332	1.000							
9	.010	-.024	-.080	.564	-.306	-.619	.318	-.338	1.000						
10	.143	.485	.099	.434	.198	.339	.604	.435	.088	1.000					
11	-.110	.035	.029	-.422	.490	.176	-.326	.281	-.250	-.105	1.000				
12	.301	.266	.336	-.291	.655	.955	.119	.734	-.760	.196	.294	1.000			
13	.294	.302	.358	-.362	.662	.923	.061	.742	-.782	.192	.374	.991	1.000		
14	.843	.779	.877	.035	.377	.378	.548	.656	.090	.288	.219	.352	.378	1.000	
15	.493	-.047	.374	.293	-.106	.169	.256	-.092	-.145	-.113	-.604	.075	.005	.027	1.000

*Correlation coefficients equal to or greater than .592 are significant at the .01 level.

changes in measures of velopharyngeal function reached statistical significance and deserve mention. As percent of velar stretch increased from the pre- to the postoperative state, velar mobility increased and angle of velar movement decreased. Although it has previously been stated that angle of velar movement does not change significantly from the pre- to the postoperative state, "angle" does change significantly and systematically in relation to change in percent of velar stretch. Increase in percent of velar stretch from the pre- to the postoperative state is accompanied by increased velar mobility and decreased angle of velar movement. As the angle of velar movement becomes more acute (decreases), the velum must travel more posteriorly toward the posterior pharyngeal wall. This change in direction requires increased velar mobility and, hence, increased velar stretch.

PREDICTION OF POSTOPERATIVE AMOUNT OF VELOPHARYNGEAL CONTACT. To determine whether postoperative amount of velopharyngeal contact (postoperative success) could be predicted from preoperative measures, the relationship between all preoperative measures and postoperative amount of velopharyngeal contact was examined. The correlation coefficients are presented in Table 4. It appears that no preoperative measure correlated significantly with postoperative amount of contact.

Postoperative amount of contact is one of the major criteria in defining success of adenoid removal in terms of future speech adequacy; the presence of contact between the velum and the posterior pharyngeal wall indicates the individual to be achieving velopharyngeal closure, a requisite for normal speech production. At present, no data exists which could enable a clinician to predict postoperative success from preoperative measures. Neither the results of previous studies nor the results of this investigation indicate that amount of velopharyngeal contact can be predicted preoperatively using those measures employed in this investigation.

General Discussion

Congenital palatopharyngeal insufficiency (C.P.I.) is generally defined as hypernasal speech in the absence of an overt cleft. Anatomical characteristics of this syndrome may include: 1) congenitally short velum; 2) excessively deep pharynx; 3) midline defects of the hard palate; 4) cervical spine anomalies; and 5) any combination of the preceding (*10, 12*). C.P.I. is often unmasked later when adenoids atrophy or are surgically removed. Individuals with anatomically inadequate velopharyngeal mechanisms often attempt to compensate physiologically although usually unsuccessfully) for this inadequacy by means of adjustments, e.g., anterior movement of the posterior pharyngeal wall and/or increased velar stretch.

The most salient finding in this investigation was the "C.P.I.-like" anatomic and physiologic characteristics of the postoperative group. Preoperatively, the need ratio (ratio of velar length to pharyngeal depth) was within normal limits. Postoperatively, however, the need ratio increased significantly to a value indicating excessive pharyngeal dimensions. Another interesting "C.P.I.-like"

TABLE 4. Correlation coefficients between postoperative amount of velopharyngeal contact and all preoperative measures.*

Preoperative Measure	Postoperative Strength of Closure
Soft tissure pharyngeal depth at rest	-.014
Area of velopharyngeal closure	-.037
Need ratio	.069
Velar length at rest	.313
Velar thickness at rest	-.502
Velar length during function	-.288
Velar thickness during function	.279
Velar mobility	-.335
Angle of velar movement	.100
Height of velopharyngeal closure	.030
Amount of velopharyngeal contact	.109
Change in velar length	-.160
Percent of velar stretch	-.131
Soft tissue pharyngeal depth during function	-.057
Posterior pharyngeal wall movement	.110

*$r = \geq .592$ ($p < .01$)

characteristic of the postoperative group was their increase in percent of velar stretch to a value greater than that found in an actual C.P.I. group. Finally, results indicate that anterior movement of the posterior pharyngeal wall increased as postoperative amount of velopharyngeal contact became more tenuous. A compensation of this type is not uncommon in the inadequate velopharyngeal mechanism.

The postoperative group was similar to a C.P.I. group in that they possessed excessively deep pharynxes and made velopharyngeal compensations typical of those with inadequate mechanisms. However, cephalometric evidence confirmed the success of their compensations, and they displayed no hypernasality. For these reasons, it is felt that the postoperative group did not fit the pure definition of C.P.I. They merely possessed one similar anatomical characteristic and displayed two unusual changes in velopharyngeal function, posterior pharyngeal wall movement when amount of contact decreased and percent of velar stretch greater than that found in the C.P.I. population.

Results of this investigation indicate that children adapt physiologically to the anatomical effects of adenoid removal in the following ways: 1) increased velar mobility; 2) increased height of velopharyngeal closure; 3) increased percent of velar stretch; and 4) anterior movement of the posterior pharyngeal wall when amount of velopharyngeal contact becomes tenuous. These adjustments are apparently necessary to successfully offset the postoperative imbalance between pharyngeal depth and velar length. It must be kept in mind, however, that the conditions present in the postoperative group are probably temporary and constantly changing. This postoperative imbalance will, in all probability, eventually normalize, assuming normal postoperative craniofacial growth.

Summary

Pre- and postoperative lateral x-rays were taken of 15 candidates for adenoid removal, ranging in age from four to seven years. Cephalometric measurements were taken during rest and during function (/s/). The postoperative group acquired pharyngeal dimensions of C.P.I. proportions as a result of adenoid removal. However, all subjects achieved velopharyngeal closure and displayed no hypernasality following this surgical procedure, indicating success in terms of speech. The success in their adaptation can be attributed to the following: 1) increased velar mobility; 2) increased height of velopharyngeal closure; 3) increased percent of velar stretch; and 4) anterior movement of the posterior pharyngeal wall when amount of velopharyngeal contact became tenuous. The normal velopharyngeal mechanism has the capacity to successfully overcome the imbalance between pharyngeal dimensions and velar length caused by adenoid removal. The normal mechanism overcomes this imbalance by means of compensations, some of which are typical of the inadequate mechanism.

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