A Functional Study Of The Palatal And Pharyngeal Structures

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Recent contributions to orthodontic literature have criticized the static approach of examining a denture at rest, with the teeth artificially articulated by means of plaster casts. It is becoming increasingly evident that more consideration must be paid to the role of the musculature.[1] Functional aberrations can create severe morphological disturbances of concern to the orthodontist. Mastication, though important, is not the sole functional entity. Of equal or greater importance are the functions of deglutition, respiration and speech. Perverted perioral muscular activity during swallowing can create severe malocclusions or make existing malocclusions more severe. Relatively little objective research has been done in this field, but it seems logical that abnormalities in respiration and speech may be as important as improper mastication and deglutition by virtue of the muscular forces involved. Speech problems in particular are of concern to the orthodontist. Whether they are causative or resultant of the abnormal morphology conferred by the dental malocclusion, the fact remains that a high percentage of orthodontic patients do have speech defects. In many instances, the parent will say that this is the reason that the child is brought for his initial orthodontic examination. Mouth breathing, hypernasality, and sibilant defects are common sequelae of the Class II, Division 1 malocclusion. In congenital cleft palate patients, speech problems are compounded and the occlusion may or may not be a factor. Because of the difficulty of studying normal speech physiology, controversy exists over the relative importance of the teeth and investing tissues, palatal contour, lip activity, velopharyngeal valving, etc. in the production of normal speech sounds. Since 1950, a series of cephalometric-roentgenographic studies of normal and cleft palate subjects has been directed by Graber at Northwestern University Cleft Lip and Palate Institute. In the past two years, an extensive study of basic normal speech function has been carried out through the support of the United States Public Health Service Research Grant D-405. The project is designed to give an objective, descriptive analysis of the function of the "normal" velopharyngeal mechanism during the instant of production of each of the various types of consonant sounds in American English. The present report summarizes these previous and presently continuing investigations.

In 1950, Williams made a roentgenographic study of vowel sounds in

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thirty non-cleft individuals between twenty-two and thirty-five years of age.[2] This was primarily a study of soft-tissue physiology during vowel tone production, similar to the study done in 1927 and reported by Dr. G. O. Russell in 1931.[3] With improved roentgenographic equipment, finer analysis of soft tissue movements was possible. He noted that the function of the velopharyngeal valve is related directly to tongue function. During the production of the prolonged vowel tones, Williams failed to find any compensatory pharyngeal activity. That is, the position of the posterior pharyngeal wall remained relatively stable at rest and during function. In 1953, Carpenter reported his study of twelve cleft palate patients ranging in age from fifteen to thirty-nine years.[4] These were postoperative subjects with fairly good speech and slightly nasal voice qualities. He repeated the study of Williams. In addition, he added the consonant *k* and had each patient blow into the calibrated manometer tube. The level of air pressure was recorded for each test element. Carpenter found significantly more anterior movement of the pharyngeal wall during production of the consonant sound *k*, and he noted some anterior movement of the posterior pharyngeal wall in the cleft palate cases during vowel production that was not present in the normal sample.

In 1954, Wildman did a detailed metric analysis of a velopharyngeal closure and correlated this directly with nasal emission, as measured on a specially constructed nasometer employing a Marey tambour.[5] Nasal emission was highly correlated with the size of the pharyngeal port. The study corroborated Carpenter's observations of compensatory movement of the posterior pharyngeal wall in cleft palate subjects. Wildman observed a difference in tongue and palate position and the extent of posterior movement of the soft palate in cleft palate subjects, when compared with the normal profile roentgenograms in Williams' study.

In 1951, McDonald and Koepp Baker had reported a tendency in cleft palate patients to talk with the dorsum of the tongue held high in the back of the mouth.[6] They expressed the belief that this was a major cause of hypernasality, nasal emission, and faulty articulation, and that the elevated mandible and the malposed tongue were part of this subnormal functional activity. Objective investigation was done by McKee to test this thesis and was reported in 1955.[7] McKee noted that the tongue position was lower than normal in cleft palate patients. During phonation, these patients elicited a definite posterior movement not found in comparable normals. McKee's investigation also showed greater extent of movement of the hyoid bone during production of speech sounds. Jo Subtelny further corroborated the findings of McKee on the lack of the highriding tongue in a more detailed study.[8] In 1956, Senty, using the new stereocephalostat and a high speed rotating anode radiation source, obtained under the United States Public Health Grant D-280, studied for the first time short duration speech sounds such as *p* and *k*.[9] His analysis of the speech function of seventeen normal speech subjects pointed out the importance of the adenoid tissue as a factor in velopharyngeal function. With this improved methodology, he was able to show anterior movement of the posterior pharyngeal wall even in normal subjects. The frequency of anterior movement was correlated with the sounds being produced and the intensity of the sounds.

In 1957, companion studies by Anderson[10] and Nohrstrom[11] compared soft tissue changes during speech and swallowing functions for cleft palate and for normal subjects. Their investigations showed that the degree and even the mode of velopharyngeal valving was significantly different for deglutition, as compared with speech. The peristaltic-like action during the act of swallowing for both the normal and cleft palate subjects showed a constant and maximal activity of the tongue, soft palate and associated structures. A much more refined level of muscle specificity was involved in the speech act in both subjects. A significant finding was the fact that some vela, inadequate to supply velopharyngeal valving for speech in cleft palate subjects, showed adequate closure during the swallowing act.

This series of studies indicates the need for a more detailed and limited investigation of the many variables with the use of the new and improved roentgenographic equipment now available. The following is a preliminary report of such a study now underway at the Northwestern University Cleft Lip and Palate Institute.

Present Study

The purpose of the present investigation is to objectively describe and analyze the function of the velopharyngeal mechanism during the instant of production of each of various types of consonant sounds.

A method was developed through a series of preliminary studies on normal subjects using high-speed, fine-focus roentgenographic equipment modified by an instantaneous timer switch and special patient-positioning devices. After the methodology and research plan had been developed and tested through a series of fifty pilot investigations on each of the consonant sounds in American English, this second phase study was initiated. It was limited to the investigation of the velopharyngeal function during the instant of production of the labial sounds *p, b, f, w,* and *m,* since the pilot studies had indicated that the most consistently reliable result could be obtained on these sounds. The purpose of this second phase investigation was to describe functional and morphological changes of the soft palate and related structures from rest position to the instant of production of each of these sounds. The second phase study sample was made up of forty-four young adult subjects from nineteen to thirty-five years of age. Each subject had normal articulation patterns for speech and normal voice quality. Twenty-two of the subjects were male and twenty-two were female. All were college students enrolled at Northwestern University at Evanston or Loyola University, Chicago.

Procedure

After preliminary speech, hearing, and voice tests each subject was positioned in a head-holder designed to standardize all technical variables, to eliminate random movement during the test run and to permit accurate duplication for cross-sectional and longitudinal studies. A Lyshholm-Schoenander polarizing grid and a one and one half millimeter aluminum filtration screen were used to improve soft tissue disclosure and to give added protection to the subjects. Six exposures were taken on each subject in the series, one for the rest position, and one each for the instant of production of the constant sounds *p, b, f, w,* and *m.* Each exposure was taken at a speed of 1/20 of a second at 200 milliamps, and 95 Kvp. Ionization chamber tests indicated .075 to .090 roentgens per test sound which is far below even minimal hazard conditions. Soft tissue visualization was improved through the use of a barium disclosing solution painted on the lips and tongue of each subject. (Figure 1)

Certain additional controls were used in order to eliminate other possible

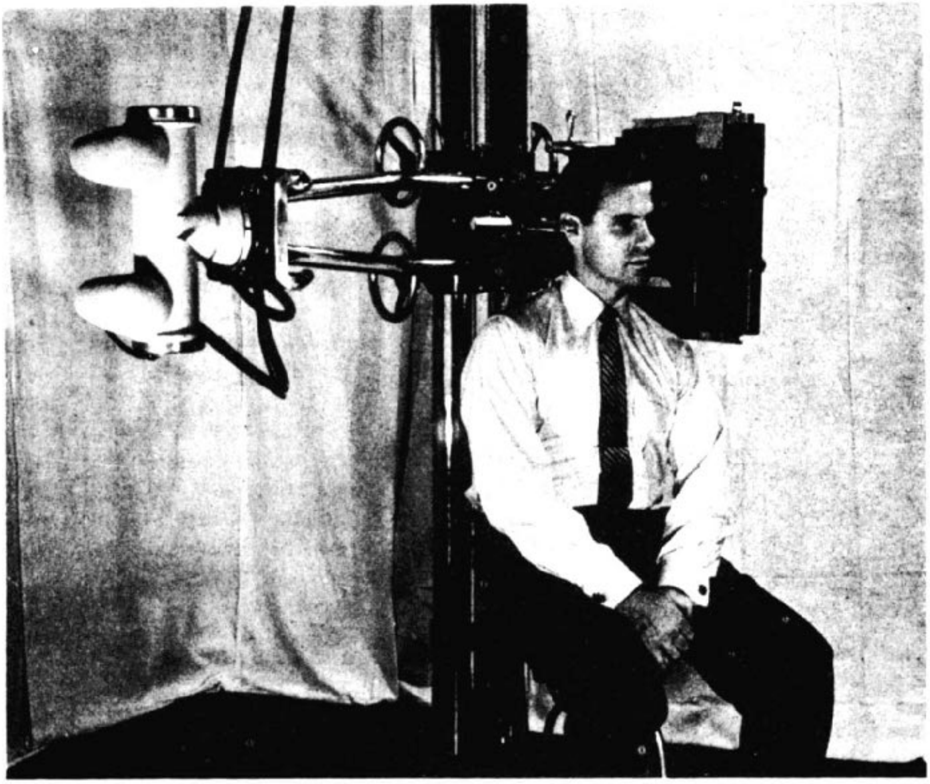


Fig. 1 Stereocephalostat, using high speed rotating anode radiation source and instantaneous exposure mechanism.

variables in the production of the speech sounds. A standard carrier phrase "Now I say the word" was used in each case followed by a nonsense syllable initiated with the test sound. In order to eliminate the possible effect of the vowel tone upon the palatal position of the consonant sound tested, four different vowel sounds were used after the test sounds. The vowels selected for this purpose were *e* as in the word *see, a* as in the word *father, a* as in the word *caught,* and *oo* as in the word *new*. In order to control possible differences in the force of the speaker's voice, an Altec 660B microphone attached to a PT-6 Magnicorder hi-fidelity tape reproduction system was placed exactly six inches from the lips of each subject. (Figure 2) Each subject monitored the force of his voice so that a VUmeter on the recorder peaked at -3 on the test syllable. Each subject repeated the carrier phrase and test syllable three times, monitoring the force of their voices. The exposure was timed to coincide with the lip articulation of the consonant sound being tested. Tape recordings were made of the entire procedure and each subject, and were played back to double-check the timing of each exposure. This was possible because the sound of the cathode-ray discharge was audible on the tape. Cases with imperfect timing were eliminated from the study sequence.

The salient structures were traced directly on the headplate by each investigator. Following this, superimposed

Fig. 2 Subject positioned by calibrated ear-rods and orbitale markers. The high-fidelity Altec 660B microphone is mounted exactly six inches from the lips at rest.

tracings of all test exposures were made. (Figure 3) Different colors were used for each test sound to prevent confusion in interpretation. Accurate millimetric measurements were made of the outline of the velum along the superior border, from the posterior nasal spine to the uvula. The velum was divided into quadrants for all tracings. Posterior pharyngeal wall contiguent structures were outlined. Specific measurements were made of the length of contact of the pharyngeal wall and the velum and of the extent of forward movement of the sphincter complex. The height of the velum during function was determined with reference to the palatal plane. Data were compiled on master charts and subjected to biometric analysis in an attempt to answer the following questions:

1. How long was the palate at physiologic rest and what changes occur in palatal length during function?
2. Which quadrant of the palate most consistently contacts the posterior wall during velopharyngeal valving for speech?
3. What is the length of upward and backward movement of the palate at each quadrant and at which quadrant does the greatest extent of movement take place?
4. How high does the soft palate rise during speech?
5. What is the midpoint of closure of the velopharyngeal valve?
6. What is the consistency of complete or incomplete valving for the various test sounds?
7. What is the superior-inferior extent of contact of the velum and posterior pharyngeal wall at the moment of contact?
8. With what frequency does forward movement of the posterior pharyngeal wall take place?
9. Is there a consistency to the morphology of these structures during speech or is there a difference for each of the test sounds?

Data and Interpretation

With regard to changes in the length of the palate from rest to functional positions for speech, Figure 4 shows the findings for the forty-four cases in this investigation. It is obvious from this figure that there is a significant increase in the length of the palate from rest to the functional position. As Figure 4 illustrates, the length of the palate at rest ranges from 32 to 49 mm. In contrast, the range for the *p*, *b*, and *f* sounds which, by their nature require the firmest velopharyngeal closure, was from 45 to 70 mm. In the study sample, Case Three and Case Forty-two illustrate the extreme changes in palatal length from rest to

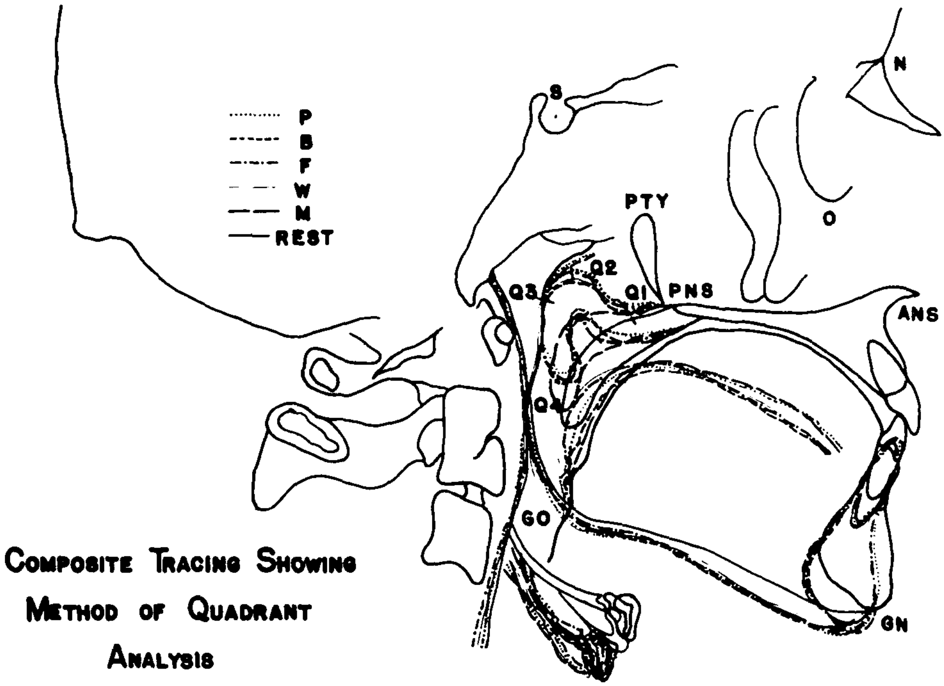


Fig. 3 Typical cephalometric lateral tracing showing palatal, tongue, postpharyngeal wall, mandibular and hyoid bone positions for each of the six test elements. The superior surface of the soft palate has been divided into quadrants to permit a more definitive study of palatal function.

functional position. At rest, the palate of Case Three measured 32 mm. in length. In function, on the *p* and *b* sounds, the same palate measured 57 mm. In Case Forty-two, the palate which measured 32 mm. at rest, changed to a length of 62 mm. on a *p* sound and 63 mm. on the *b* sound. In all cases, the changes in length for the *p, b,* and *f* sounds were closely similar. Changes in length on the *w* sound were also similar but tended to be somewhat less than for the other three sounds. Of significance was the increase in palatal length found during the production of the *m* sound. Although the *m* sound is made by emitting air through the velopharyngeal port, the palate does assume a close-ready position of closure which is actually more similar to closed position than the rest position. This fact is objectively substantiated by this and other measurement findings. These measurement changes in length are not interpreted as meaning actual incremental increase, but rather as evidence of the incorporation of tissue elements from the lateral pharyngeal walls.

A highly significant finding resulted from the measurement of the quadrant of contact of the palate with the postpharyngeal wall during speech function. Although in the past it has generally been assumed to be the middle third of the palate which effects the velopharyngeal seal, this evidence showed conclusively that for young adults it is the third quadrant which effects this seal. The third quadrant was involved in the seal in 100% of the cases for the study sample. Quad-

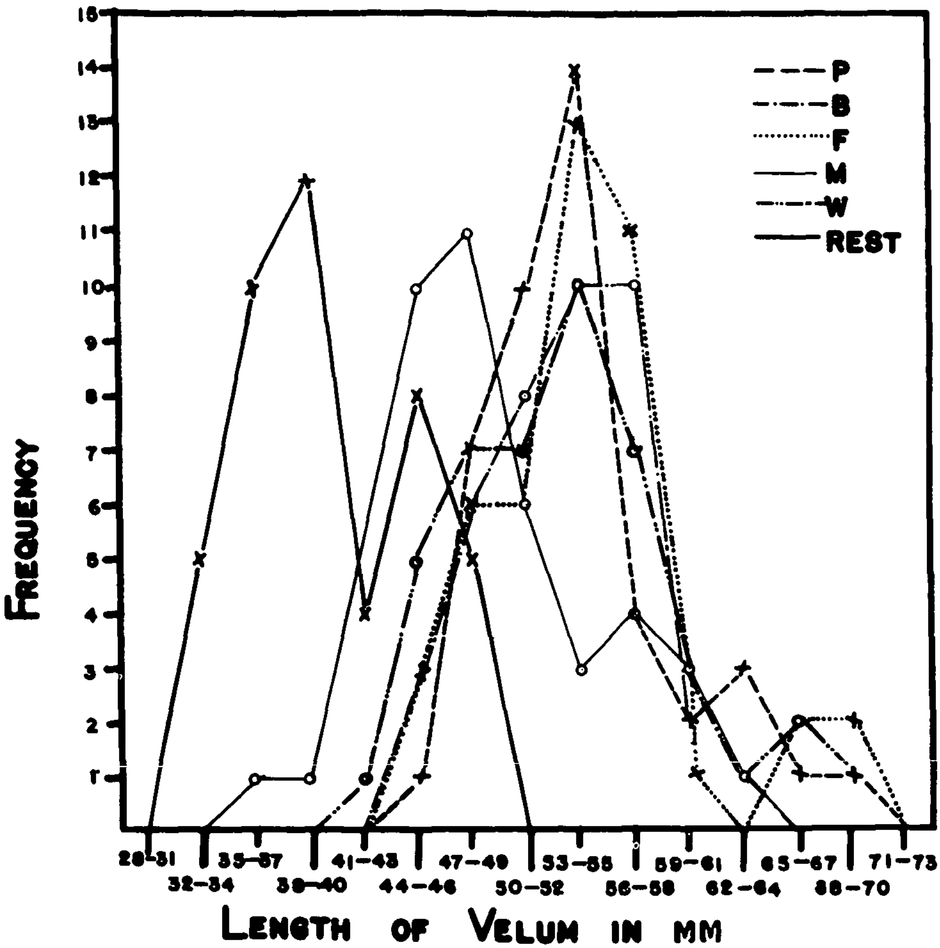


Fig. 4 The resting lengths and functional increments for all cases are plotted on this graph. Note the significant increase in palatal length for all test sounds.

rant four was also involved in the seal in 27% of the cases. Figure 4 illustrates typical quadrant division in contact found in the study.

Table 1 shows the findings regarding the extent of upward and backward movement of the palate at each of the quadrants measured. A consistent finding in this data indicates that Q2, the midpoint of the palate, shows the greatest extent of upward and backward movement from rest to closed position. Despite the magnitude of movement at Q2, the region of the midpoint of the palate was not involved in actual contact with the posterior pharyngeal wall. The second most extensive upward and backward movement was found in Q3, which was involved regularly with velopharyngeal seal. A wide range of angular measurements was found illustrating the direction of movement of the palate of each subject. Table 2 lists the angles described by the intersection of Line Q2 at the palatal plane. The wide range of measurements may be attributed to individual differences of cranio-facial morphology. In all cases, direction of movement was upward and backward.

EXTENT IN MM OF UPWARD & BACKWARD MOVEMENT OF THE SOFT PALATE

Quadrant	*Phonation*	*Mean*	*S.D.*	*Range*
Q1........	P	6.0	2.06	3.0- 9.0
Q1........	B	6.1	2.25	3.0-10.0
Q1........	F	6.0	2.35	2.0-10.0
Q1........	PBF	6.0	2.22	2.0-10.0
Q1........	W	5.8	2.56	2.0- 9.0
Q1........	M	3.9	2.00	1.0- 8.0
Q2........	P	16.2	3.41	10.0-27.0
Q2........	B	16.2	3.40	9.0-23.0
Q2........	F	16.2	3.01	9.0-23.0
Q2........	PBF	16.2	3.27	8.0-27.0
Q2........	W	15.4	3.18	8.0-22.0
Q2........	M	10.2	3.01	2.0-17.0
Q3........	P	14.2	3.42	7.0-20.0
Q3........	B	14.1	3.02	8.0-20.0
Q3........	F	13.7	2.81	6.0-19.0
Q3........	PBF	14.0	3.10	6.0-20.0
Q3........	W	13.6	3.61	6.0-20.0
Q3........	M	9.7	3.38	2.0-17.0
Q4........	P	10.0	3.77	2.0-19.0
Q4........	B	10.0	3.38	4.0-16.0
Q4........	F	9.6	3.23	3.0-16.0
Q4........	PBF	9.9	3.46	2.0-19.0
Q4........	W	9.5	3.15	3.0-17.0
Q4........	M	6.7	3.32	1.0-13.0

Table 1 The greatest upward and backward movement occurs at Q2, or the midpoint of the superior palatal surface. Movement at Q3 was only slightly less, but uniformly contacted the postpharyngeal wall.

Figure 5 shows the findings regarding the high point of the soft palate during speech and the midpoint of closure. It is significant that in all sounds, particularly the nasal, the high point was above the level of the floor of the nasal cavity. The same figure shows that the midpoint of closure is somewhat below the level of the palatal plane, but the high point of the actual seal in most cases approximated the level of the nasal floor. This has clinical implications regarding the placement of the prosthetic speech bulb and the attachment of the pharyngeal flap in certain surgical procedures in cleft palate rehabilitation.

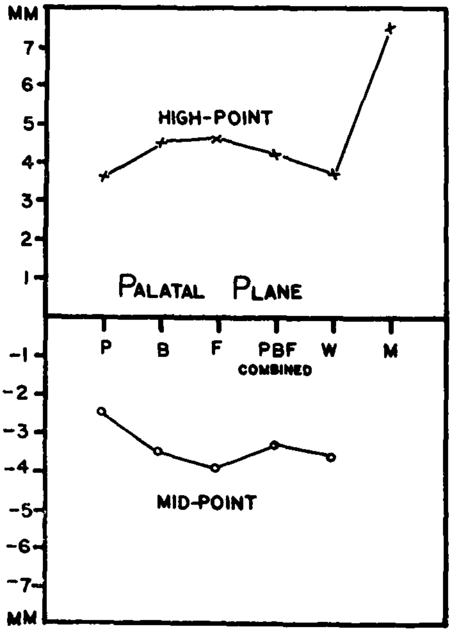
The pharyngeal valve was consistently closed for the consonants *p*, *b*, *f*, and *w*. This finding is at variance with other studies, using more static roentgenographic techniques.

The superior-inferior extent of con-

ANGLE DESCRIBED BY MID-POINT OF PALATE IN FUNCTION

Phonation	*Mean*	*S.D.*	*Range*	*Mode*	*Number*
P ...	56.0	5.68	26-76	52	42
B ..	52.6	5.07	24-73	58	44
F ..	52.8	5.09	23-71	58	44
W ..	51.6	2.69	23-73	48	44
M ..	44.2	2.44	27-66	41	43

Table 2 Quadrant markings at rest and during phonation for each sound were joined. The intersection of these lines with the palatal plane formed the recorded angles. The relatively small standard deviations for w and m suggest greater constancy of position for these consonants, but the broad ranges reduce the significance of any interpretation.



HIGH-POINT & MID-POINT OF PALATAL CLOSURE

Fig. 5 The highest point of palatal elevation (Q2) was consistently above the floor of the nasal cavity. The midpoint of velopharyngeal valving was 2.4 mm. below the nasal cavity floor. This is higher than generally described.

Distance of Velum Contact

Phonation	*Mean*	*S.D.*	*Range*	*Number*
Pa ..	8.94	3.93	2.0-17.0	42
Ba ..	9.85	3.96	3.6-20.0	42
Fa ...	11.06	4.43	4.0-21.0	41
Wa ..	10.40	4.48	3.8-18.0	40

Table 3 Palatal postpharyngeal wall contiguity during consonant phonation.

tact on these sounds ranged from 2 to 21 mm. Table 3 shows the range, mean and standard deviation for the sample. Despite the broad range, there is a relatively narrow standard deviation and closely similar mean length of contact for different test sounds.

The posterior pharyngeal wall moves forward in more than 50% of the cases. Dramatic constrictor activity assisting in normal velopharyngeal valving was observed in at least four patients. Figure 6 is an example of extreme anterior movement of the so-called "Passavants pad". These findings were interpreted as indicating that, at least in some cases, normal velopharyngeal valving was assisted by significant, superior constrictor activity. However, in the majority of these cases, the anterior component was minimal.

From observation of the consecutive headplates on each individual case, it is obvious that a high degree of consistency of morphology of the velopharyngeal structures is found during the act of speech. There appear to be varying soft tissue contours from case to case, but, despite this, precise measurements of the valving act, as reported above, show a close similarity for all cases.

Summary and Conclusions

A review was given of the series of related research studies on speech

Fig. 6 Dramatic "Passavant's pad" activity, white female, with normal speech. This anterior bulging of the postpharyngeal wall was evident for all test exercises in this subject.

physiology carried on by the Northwestern University Cleft Lip and Palate Institute. In general, these studies indicated that anterior movement of the posterior pharyngeal wall is more common in cleft palate than in normal subjects during the production of speech sounds. Studies involving consonant sound elements did show some pharyngeal activity even for normal subjects. It was objectively established that nasal emission and hypernasality were highly correlated with the size of the velopharyngeal port. Aberrant tongue position in function was noted in the cleft palate cases. Metric analysis showed that tongue position was actually lower in the cleft palate than in the normal subjects. The principal variation from normal activity in the tongue function of cleft palate patients was in the nature of a posterior positioning. Other studies showed a significant difference in velar valving for deglutition as compared with speech.

A research study based upon these previous investigations was outlined. Using high speed roentgenographic equipment, the soft tissue morphology of normal subjects was studied during the instant of production of various consonant sounds (*p, b, f, w, m*). Biometric analysis was made of the roentgenographic findings and the following conclusions were drawn: the soft palate increases significantly in length from the rest to functional position. It is the third quadrant of the palate which consistently effects the velopharyngeal seal for normal young adults. The greatest extent of the upward and backward movement of the palate takes place at the midpoint of the posterior superior surface of the palate. The mean extent of movement at this point is approximately 16 mm. The high point of the soft palate is consistently found to be 4 to 5 mm. above the level of the palatal plane during valving. For the nasal sound "m", the high point was found to be 3 to 4 mm. higher than for the remaining consonant test elements. The high point of the soft palate was never involved in actual velopharyngeal seal. The midpoint of closure during velopharyngeal seal is normally 3 to 4 mm. below the palatal plane. The high point of seal is found approximately at the level of the palatal plane. The velopharyngeal valve is consistently closed for all of the consonant sounds during normal speech production. The palate assumes a close ready position of velopharyngeal closure even for the nasal sounds. Slight anterior movement of the posterior pharyngeal wall is seen in over 50% of the normal cases. Dramatic anterior movement occasionally occurs in normal subjects. Metric analyses show that there is a consistent pattern of velopharyngeal valving for speech for normal subjects.

The orthodontist, as well as the prosthodontist and speech therapist, should profit from a better appreciation of normal speech physiology.

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