Prosthetic Treatment for Palatopharyngeal Incompetence: Research and Clinical Implications

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Palatopharyngeal function during speech has been studied relative to the physiology of speech, direction of air flow, oral breath pressure, nasal sound power level, acoustic output, and perceptual characteristics of speech. Despite varied research efforts, including speech analysis and synthesis, understanding remains incomplete and a clinical need to clarify the effect of palatopharyngeal opening and nasal resonance upon speech perception persists. This investigation was based upon the premise that information germane to the major area of interest could be contributed through a multidimensional study of cleft palate subjects speaking with and without nasopharyngeal obturation.

From a research viewpoint, cleft palate speakers with normal articulation who have been successfully fitted with prostheses provide an excellent opportunity to investigate the selective effect of nasopharyngeal opening upon speech function. By pairing observations of speech produced with the nasopharynx open and functionally occluded, speech function can be evaluated under two experimental conditions existing in the same subject. As a result, control over many variables such as differences in articulatory skill is possible. Moreover, this control yields information which cannot be attained by studying grouped cleft palate data. In the latter instance, speakers can differ from each other in many respects other than in regard to palatopharyngeal function. In broad aspect, then, the purpose of this investigation is to make a comparative analysis of each cleft palate subject speaking with the nasopharynx open and with the nasopharynx functionally occluded.

From a clinical viewpoint, comparative study of speech produced with and without prosthesis provides a realistic measure of the relative speech improvement achieved by prosthetic fitting. By further subgrouping

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This paper was supported at the Eastman Dental Center by Public Health Service Research Grant #DE-01837, from the National Institute of Dental Research.

and analysis of data, comparisons between successful and unsuccessful speakers can be made from phonetic, physiologic, and prosthetic aspects. Information derived by such comparisons contributes to the understanding of the basis for satisfactory and unsatisfactory speech production after prosthetic fitting.

Further clinical treatment of the unsuccessful speaker wearing a prosthesis may involve simple modification of the prosthesis, speech training, surgery, combinations thereof, or disregarding prosthesis as the method of physical management because successful prosthesis cannot be constructed and/or maintained. In the latter instance, surgical correction of palatopharyngeal incompetence would be indicated. Intelligent decisions pertaining to further treatment of an individual speaker cannot be made unless the basis for prosthetic failure is fully comprehended.

Understanding the 'why' of speech failure with prosthesis is not easy, because unsatisfactory speech may be explained by various factors, existing in isolation or in complexly interrelated combinations. The prosthesis may fail to provide adequate nasopharyngeal obturation, defective articulatory behavior may persist after prosthetic fitting, or palatopharyngeal features in a given patient may vitiate successful prosthetic construction. When these factors are considered, it becomes evident that considerable information is required to determine the basis for an individual's failure in speech. Requisite information would seem to involve evaluation of articulatory behavior with and without the prosthesis, appraisal of obturation adequacy, detailed study of palatopharyngeal features with and without prosthesis, and analysis of physiological factors other than nasopharyngeal relationships which may influence the character of speech produced.

Clinical as well as research interest in palatopharyngeal physiology as it pertains to speech encouraged this investigation. The goals of the study are: a) to evaluate changes in physiological relationships associated with prosthetic placement; b) to define modifications in speech associated with prosthetic placement; c) to differentiate successful and unsuccessful prosthetic fitting from speech, prosthetic, and physiological viewpoints; d) to study, in a select group of subjects, the effect of nasopharyngeal opening and nasality upon speech intelligibility. Information necessary to fulfill these objectives was supplied by combined speech, cephalometric, and oropharyngeal examinations.

Procedure

Subjects. Twenty-three cleft palate speakers served as subjects in this study. All of the subjects were older adolescents or adults who had received prosthetic treatment for palatopharyngeal incompetence at the University of Illinois Cleft Palate Center, Northwestern University Cleft Lip and Palate Institute, or the Eastman Dental Center, Rochester, New York. All subjects were fitted, prosthetically, for the first time during late adolescence or adulthood. Each subject had been wearing a prosthesis for a minimum of two years. None of the subjects had a hearing loss defined as greater than 20 dB in the better ear at speech frequencies of 500, 1000, and 2000 cps.

Subjects differed in regard to original cleft morphology, present status of palatal repair, and dental condition. Four subjects had complete bilateral clefts of the lip and palate, ten had complete unilateral clefts of the lip and palate, and nine had posterior clefts of the palate. Two subjects had posterior clefts of the palate which were unoperated, all others had received surgical treatment for palatal repair. Three subjects had all upper anterior teeth missing; the remaining 20 subjects had either a full complement of teeth or just one missing incisor in the maxillary anterior dentition. Dental occlusion varied from severe Class III to normal occlusal relationships. These enumerated facts provide evidence that considerable heterogeneity in palatal condition and dentofacial morphology was present. As a result, prosthetic needs for palatopharyngeal obturation and cosmetic improvement varied markedly.

SPEECH RECORDING. Speech samples were recorded by the Ampex Recorder, Model 601 with an Electro-Voice, Model 647 microphone. All speech samples were recorded once with and once without the prosthesis for each of the 23 speakers. Recorded speech material included a continuous speech passage which served as stimulus material for judgmental ratings of nasality and articulatory skill and PB (phonetically-balanced) word lists used for intelligibility measures. Words were presented to the subject, one at a time with five-second intervals between items.

AUDITING SPEECH. The tapes were played over the Ampex Model 620 amplifier-speaker in a sound-treated room for evaluation by a panel of three speech clinicians who were experienced in the area of cleft palate. The auditing procedure for the word test was designed to measure the relative success of speakers in producing identifiable consonants. The specific procedure used in intelligibility testing and in analysis of test results has been described previously (*9*). In simple terms, the words and sounds comprehended by the listeners were compared with the words and sounds intended by the speaker. Analysis of the test results yielded percentage scores for word intelligibility and for intelligibility of respective phonetic categories.

Recorded material for nasality and articulation judgments was randomized in order of presentation so that speech samples recorded for the same subject with and without prosthesis did not follow in consecutive order. Auditors had no knowledge of the nasopharyngeal status (obturated or unobturated) which existed at the time recordings were made.

Procedure for evaluation of the continuous speech sample was designed to gain separate ratings of the degree of nasality and articulatory proficiency. A four-point scale was used for both judgments. The continuous speech passage was played once for nasality rating and then once again for articulation rating. Numerical ratings from the three auditors were then totaled to obtain a single rating of nasality and a single rating of articulatory proficiency. The total range of scores extended from 3 (with each judge rating 1) to 12 (with each judge rating 4). Higher numerical ratings indicated progressively greater degrees of nasality and progressively poorer articulation.[1]

CEPHALOMETRIC ANALYSIS. Duplicate cephalometric x-ray films were secured for each subject under two conditions: with the prosthesis in situ and without the prosthesis. For each condition, films were obtained during rest, with the teeth in occlusion and during the sustained phonation of /u/. Films were traced and a detailed analysis undertaken to specify lip, tongue, hyoid bone, velar, and mandibular positions. A description of each individual measurement is included in the tables reporting measurement results. Reference points and lines used for measurements of tongue and hyoid positions and for measurements of lip and mandibular positions are illustrated respectively in Figures 1 and 2.

In order to describe the relevant features in the palatopharyngeal region, measures were made from films secured without prostheses. Velar length and the angular position of the velum in reference to the palatal plane were defined by analysis of films secured in rest position. Films secured during vowel production were measured to define, anteroposteriorly, the palatopharyngeal aperture and the position of the velum in reference to the palatal plane during function. The difference between the angular position of the velum at rest and its position during function was individually determined to indicate the degree or range of velar movement demonstrated during function.

Reference points, lines, and angles used for measurements of the palatopharyngeal region are illustrated in the left portion of Figure 3. Procedures for specification of the carrier and pharyngeal section of the prosthesis are illustrated in the right portion of Figure 3.

Results

CENTRIC POSITION. On the basis of heterogeneity in sample characteristics previously described, lip measures in particular would be expected to show marked individual variation. This expectation is supported by the comparatively large standard deviations reported for lip measures made with subjects in centric position (Table 1). Considerable variation in lip postures was found to occur under both conditions with and without prosthesis.

[1] For clarity of interpretation, cumulative scores of 3, 4, 5, and 6 were assigned values of 1, 2, 3, and 4 and were considered to indicate slight nasality (or articulatory distortion), generally not perceptible to the layman. Cumulative scores of 7, 8, and 9 were assigned values of 5, 6, and 7 and were considered to indicate moderate nasality (or articulatory defectiveness), consistently perceptible to the layman. Cumulative scores of 10, 11, and 12 were assigned values of 8, 9, and 10 and were considered to indicate hypernasality (or severe articulatory defectiveness), constituting a serious communication problem.

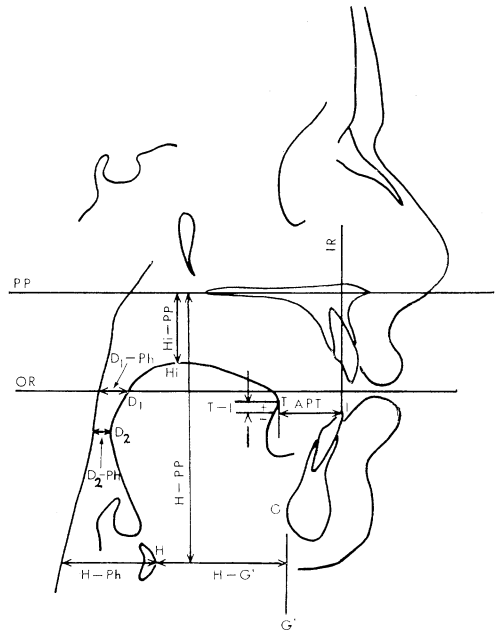

FIGURE 1. Cephalometric tracing illustrating reference points and lines used for measurements of tongue and hyoid positions. H, anterior superior most point of the body of the hyoid; Hi, highest point of tongue; T, anterior superior most point of the tongue tip; D_1, dorsal aspect of tongue on oral reference line; D_2, posterior most point of tongue in reference to posterior pharyngeal wall; I, lower incisor edge; G, genial tubercle-posterior most point of mandibular symphysis.

Reference lines: PP, palatal plane—anterior nasal spine to posterior margin of hard palate; OR, oral reference—parallel to palatal plane from point bisecting lip aperture; H-ph, hyoid pharyngeal—parallel to palatal plane, from point H to posterior pharyngeal wall; IR, lower incisor reference—perpendicular from palatal plane to lower incisor edge; G′, tangent from genial tubercle constructed perpendicular to palatal plane.

Despite the variation in lip measures noted, *t* values derived by paired observation showed that prosthetic placement had a significant effect upon upper lip posture, although no change in the angular position of the lower lip was indicated. As a consequence of prosthetic placement, the upper lip was found to assume a more protrusive position in its angular relationship to the palatal plane, in its linear relationship to the lower facial plane, and in its linear anteroposterior relationship to the lower lip. Thus, in the anteroposterior aspect, a more normal and harmonious posture of the upper lip was found to be associated with prosthetic insertion.

However, vertical measurements of the lip showed that, when the prosthesis was in situ, the upper lip was further removed from the lower lip. A significantly larger lip aperture was evident, indicating that the protruded upper lip failed to assume a normal vertical relationship to the lower. On the basis of these findings, it is suggested that the favorable

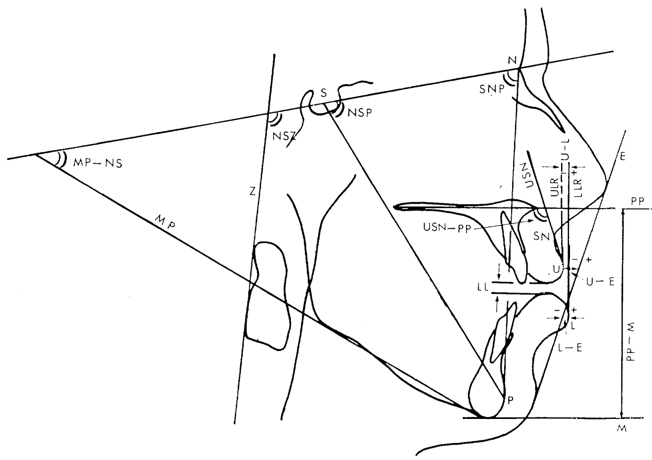

FIGURE 2. Cephalometric tracing illustrating reference points, lines, and angles used for measurements of lips and mandible. S, sella—midpoint of sella turcica; N, nasion—point of juncture between frontal and nasal bones; P, pogonion—anterior most point of the skeletal chin; SN, subnasion—juncture of columella and lip; U, anterior most point of upper lip; L, anterior most point of lower lip.

Reference lines: PP, palatal plane—anterior nasal spine to posterior margin of hard palate; MP, mandibular plane—inferior most point of mandibular symphysis, along lower border of mandible to intersect NS line; ULR, upper lip reference—perpendicular from Point U, anterior most point of upper lip to palatal plane; LLR, lower lip reference—perpendicular from point L, anterior most point of lower lip to palatal plane; USN, angular position of upper lip, point U, anterior most point of upper lip, to point SN, subnasion; E, lower facial plane—tip of the nose to soft tissue pogonion; M, tangent—inferior most point of the mandible parallel to palatal plane; Z, tangent—posterior border of second cervical vertebra to intersect NS line.

Angles: SNP, sella-nasion-pogonion; NSP, nasion-sella-pogonion; MP-NS, mandibular plane-nasion-sella; USN-PP, upper lip-palatal plane; NSZ, nasion sella—Z tangent to cervical vertebra.

upper lip protrusion may be accomplished by some accompanying sacrifice in vertical relationship. This interpretation is particularly appropriate for certain subjects with repaired lips which were vertically deficient. A second factor contributing to the larger lip aperture with the prosthesis in situ seems to be related to a lower mandibular position. Linear measures made from the palatal lane to the lower border of the mandible showed a significantly lower mandibular position was associated with prosthetic placement.

In summary, the larger lip aperture in centric position associated with prosthetic insertion may be accounted for by a possible combination of factors: a more protruded posture of the upper lip, a lower posi-

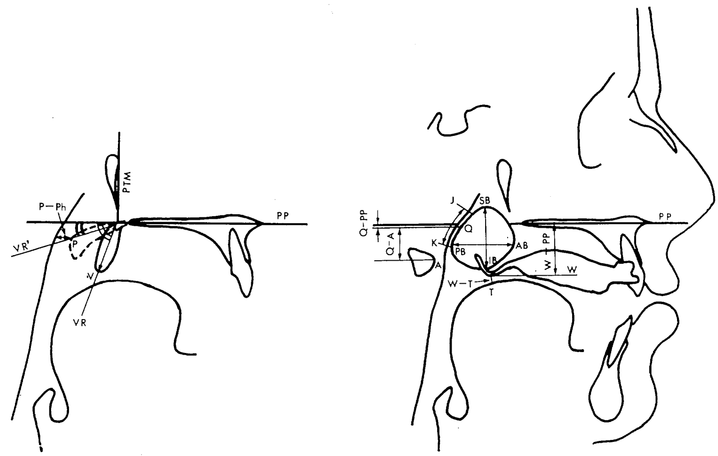

FIGURE 3. Cephalometric tracings illustrating reference points, lines, and angles used for measurements of the palatopharyngeal region (left); and the pharyngeal section of the prosthesis (right).

V, inferior tip of the soft palate at rest;

P, point of velar tissue in closest approximation to pharyngeal wall during function;

PTM, point of intersection between between perpendicular from anterior margin of pterygomaxillary fissure and palatal plane.

Reference lines:

PP, palatal plane—anterior nasal spine to posterior margin of hard palate;

VR′, velar reference rest—intersection of perpendicular from pterygomaxillary fissure and palatal plane to inferior tip of soft palate at rest;

VR[1], velar reference function-intersection of perpendicular from pterygomaxillary fissure and palatal plane to posterior most point of the soft palate during function.

Angles:

PP-VR, palatal plane—velar reference rest;

PP-VR′, palatal plane—velar reference function.

A, anterior most point of the tubercle of the atlas;

T, dorsum of tongue at point of closest approximation to carrier of bulb;

W, inferior most point of carrier for bulb;

J, superior most point of contact or uniform constriction between bulb and pharyngeal wall;

K, inferior most point of contact or uniform constriction between bulb and pharyngeal wall;

Q, midpoint of vertical extent of contact or uniform constriction between bulb and pharyngeal wall;

AB, anterior most point of bulb;

PB, posterior most point of bulb;

SB, superior most point of bulb;

IB, inferior most point of bulb.

tion of the mandible relative to the palatal plane, and in some cases, post-operative deficiency in lip length.

Coincident with the lower mandibular position, the hyoid bone was found in a significantly lower position when the prosthesis was in place. Since vertical and horizontal measures failed to indicate a significant change in tongue position, the lower hyoid position possibly may be explained by the lower position of the mandible. Measurements relating head position to the cervical vertebra showed that no change in head posture was associated with prosthetic placement. The significant physiological modifications in centric position which were found to occur as a function of prosthetic placement are summarized graphically in Figure 4.

TABLE 1. Comparative cephalometric analysis of centric position for 23 cleft palate subjects with and without prosthesis. The asterisk indicates significance at the 5 % level.

Measurement	*Condition*	*Mean*	*SD*	*SE*	*t*
Lip					
Lip aperture (LL)	with pros.	3.56 mm	5.50	1.37	2.36*
	without	2.00 mm	4.26	1.06	
Antero-posterior position of upper lip relative to lower lip. Minus measures indicating retrusive postures of upper lip relative to lower lip (U-L)	with pros.	−0.80 mm	4.71	1.22	2.41*
	without	−2.13 mm	5.53	1.43	
Antero-posterior position of upper lip relative to lower facial plane E (U-E)	with pros.	−8.21 mm	3.40	.91	2.38*
	without	−9.92 mm	5.58	1.55	
Antero-posterior position of lower lip relative to lower facial plane E (L-E)	with pros.	−2.71 mm	3.77	1.08	1.21
	without	−2.69 mm	3.64	1.01	
Angular position of upper lip relative palatal plane (USN-PP)	with pros.	99.53°	12.28	3.17	.62
	without	89.40°	11.61	3.00	
Tongue-Vertical Measures					
Dorsum of tongue to palatal plane (Hi-PP)	with pros.	20.11 mm	5.84	1.95	1.01
	without	18.38 mm	6.86	1.90	
Tongue tip to lower incisor. Minus measure indicating tongue tip below incisal edge (T-I)	with pros.	−2.14 mm	2.54	.96	.24
	without	−2.40 mm	3.92	1.24	
Tongue-Horizontal Measures					
Tongue tip, anteroposterior to lower incisor (APT)	with pros.	4.57 mm	2.57	.97	.90
	without	5.80 mm	4.49	1.42	
Tongue-pharynx on oral reference line (D_1-Ph)	with pros.	18.50 mm	6.68	1.67	.00
	without	18.50 mm	8.23	2.57	
Tongue-pharynx shortest dimension (D_2-Ph)	with pros.	11.81 mm	6.20	1.55	1.34
	without	10.44 mm	5.93	1.48	
Hyoid					
Hyoid-palatal plane (H-PP)	with pros.	70.38 mm	9.40	2.35	2.40*
	without	67.69 mm	10.10	2.55	
Hyoid to perpendicular from genial tubercle (H-G)	with pros.	38.06 mm	6.84	1.71	.06
	without	38.13 mm	7.52	1.88	
Mandible					
Palatal plane to lower border of mandible (PP-M)	with pros.	74.06 mm	9.12	2.28	3.05*
	without	72.94 mm	9.56	2.39	
Angle NSP	with pros.	68.50°	4.49	1.12	.59
	without	68.63°	4.51	1.13	
Angle SNP	with pros.	77.69°	2.63	.66	.65
	without	77.56°	2.50	.63	
Angle SN-Mandibular plane	with pros.	40.19°	6.36	1.59	1.15
	without	39.81°	6.17	1.54	
Pharynx					
Angle NSZ, tangent along posterior border of second cervical vertebra	with pros.	104.88°	7.65	1.90	.39
	without	104.38°	8.93	2.23	

FIGURE 4. Cephalometric tracing of subject in centric position. Means for various measures were used to define solid and superimposed dotted lines illustrating observed changes in lip, mandible, and hyoid positions associated with prosthetic placement.

Rest Position. A comparative cephalometric analysis also was undertaken to study resting postures with and without prosthesis. Again, results showed that the most prominent modification in physiologic position associated with the prosthetic insertion was related to upper lip posture. Increment in amount of upper lip protrusion was the only significant change observed.

Resting positions of the mandible and hyoid remained essentially the same with and without the prosthesis. In general, physiological relationships in rest position were not altered as a result of prosthetic placement, although certain tendencies for shifts in tongue positions were noted. The dorsum tended to drop relative to the palatal plane, the tongue tip tended to drop and retrude relative to the lower incisor, and the posterior aspect of the tongue tended to front relative to the posterior pharyngeal wall. Although these shifts in resting postures of the tongue are supported by measurements, none of the changes described were found to be statistically significant.

Physiological Relationships During Function. Measures of physiological relationships during sustained vowel phonation are reported in Tables 2 and 3. During sustained production of the vowel /u/, a functional state of lip protrusion exists. Data defining labial relationships during function show that no significant modifications in lip postures were associated with prosthetic insertion. This finding is in contrast to results obtained from the analysis of lip positions in relative relaxed states of centric and rest positions. Also in contrast to the results of centric and rest analyses, significant modifications in tongue position during vowel production were indicated. The tongue was significantly

TABLE 2. Comparative cephalometric analysis of relationships during sustained vowel /u/ phonation for 23 cleft palate subjects with and without prosthesis. The asterisk indicates significance at the 5% level.

Measurement	*Condition*	*Mean*	*SD*	*SE*	*t*
Lip					
Lip aperture (LL)	with pros.	2.74 mm	1.84	0.38	1.48
	without	2.22 mm	1.00	0.21	
Antero-posterior position of upper lip relative to lower lip. Plus measures indicating protrusive postures of upper lip relative to lower lip (U-L)	with pros.	+0.50 mm	4.35	.93	1.03
	without	+0.22 mm	4.63	.97	
Antero-posterior position of upper lip relative to lower facial plane E (U-E)	with pros.	−3.89 mm	3.23	0.74	1.75
	without	−4.90 mm	4.08	0.91	
Antero-posterior position of lower lip relative to lower facial plane E (L-E)	with pros.	+2.20 mm	3.04	0.68	1.84
	without	+1.45 mm	2.90	0.65	
Angular position of upper lip relative to palatal plane (USN-PP)	with pros.	103.05°	15.42	3.29	0.67
	without	103.86°	14.73	3.71	
Tongue-Vertical Measures					
Dorsum of tongue to palatal plane (Hi-PP)	with pros.	21.00 mm	6.69	1.46	1.30
	without	20.19 mm	7.43	1.55	
Tongue tip to lower incisor. Minus measure indicating tongue tip below incisal edge (T-I)	with pros.	−2.10 mm	6.89	1.50	2.67*
	without	−0.29 mm	6.77	1.48	
Tongue-Horizontal Measures					
Tongue tip, anteroposterior to lower incisor (APT)	with pros.	19.90 mm	9.00	1.96	1.44
	without	21.76 mm	8.62	1.88	
Tongue-pharynx on oral reference line (D_1-Ph)	with pros.	12.74 mm	5.50	1.14	1.74
	without	10.36 mm	5.13	1.09	
Tongue-pharynx shortest dimension (D_2-Ph)	with pros.	9.61 mm	5.25	1.09	1.67
	without	8.44 mm	5.57	1.16	
Hyoid					
Hyoid-palatal plane (H-PP)	with pros.	77.18 mm	9.57	2.04	0.10
	without	77.05 mm	10.17	2.22	
Hyoid to pharyngeal wall (H-Ph)	with pros.	35.45 mm	7.00	1.48	1.78
	without	36.65 mm	6.16	1.31	
Hyoid to perpendicular to genial tubercle (H-G)	with pros.	33.73 mm	6.86	1.46	3.30*
	without	31.81 mm	5.88	1.28	
Mandible					
Palatal plane to lower border of mandible (PP-M)	with pros.	79.83 mm	10.43	2.17	1.21
	without	80.52 mm	9.90	2.65	
Angle NSP	with pros.	72.17°	5.23	1.13	1.49
	without	72.78°	5.15	1.07	
Angle SNP	with pros.	75.13°	3.48	.07	2.68*
	without	74.30°	3.42	.71	
Angle SN-Mandibular plane	with pros.	43.48°	7.60	1.58	2.44*
	without	44.65°	7.02	1.46	
Pharynx					
Angle NSZ, tangent along posterior border of second cervical vertebra	with pros.	106.61°	7.41	1.55	1.17
	without	107.35°	7.35	1.54	

TABLE 3. Cephalometric analysis of the palatopharyngeal region of 23 cleft palate subjects with and without prosthesis.

Measurement	*Mean*	*SD*	*Range*
Without Prosthesis			
Velar length at rest (PTM-V)	27.19 mm	5.00	19.00 to 37.00 mm
Velar position at rest (PP-VR)	56.14°	8.91	−72 to −42°
Velar position during function. Plus and minus measures respectively indicating velar positions above and below palatal plane (LPP-VR′)	31.09°	26.77	−77° to +14°
Degree of velar movement (PP-VR)	25.52°	25.46	−10° to +71°
Palatopharyngeal aperture during function (P-Ph)	8.61 mm	4.17	3.00 to 16.00 mm
With Prosthesis:			
Nasopharyngeal aperture during function-posterior margin of bulb to pharyngeal wall (AP-Pros-Ph)	.22 mm	.52	0 to 2.00 mm
Vertical extent of contact of uniform construction between bulb and pharyngeal wall (J-K)	13.30 mm	5.45	1.00 to 24.00 mm
Bulb placement relative to palatal plane. Plus and minus measures respectively indicating midpoint (Q) above and below palatal plane (Q-PP)	−6.91 mm	7.10	−20.00 to +6.00 mm
Bulb placement relative to tubercle of Atlas. Plus and minus measures respectively indicating midpoint above and below tubercle (Q-A)	+3.70 mm	7.36	−8.00 to +22.00 mm
Antero-posterior dimension of bulb-anterior most and posterior most point of bulb (AB-PB)	23.35 mm	7.60	15.00 to 52.00 mm
Vertical dimension of bulb: superior most and inferior most point of bulb (SB-PB)	20.70 mm	6.25	11.00 to 35.00 mm
Dimension between inferior most point of carrier and palatal plane (W-PP)	21.76 mm	4.56	15.00 to 33.00 mm
Dimension between inferior most point of carrier and dorsum of tongue (W-T)	2.47 mm	33.8	0 to 10.00 mm

lower when prosthesis was placed, and a consistent tendency for the tongue to front relative to the pharyngeal wall was apparent.

Angular measurements of mandibular posture showed that during vowel phonation, significant increments in mandibular protrusion and elevation occurred when the prosthesis was in place. A larger dimension between the hyoid bone and genial tubercle of the mandible also was associated with prosthetic placement. With change in mandibular position, a co-existing larger dimension between the hyoid bone and genial

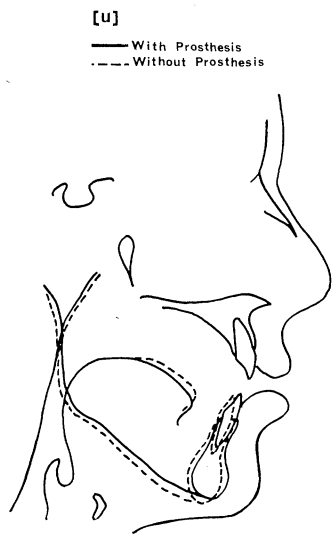

FIGURE 5. Cephalometric tracing of the subject during sustained phonation of /u/. Means for various measures were used to define solid and superimposed dotted lines illustrating observed changes in tongue and mandibular positions associated with prosthetic placement.

tubercle would be anticipated providing the hyoid bone itself remained fixed in position. Measurements showed that a constant vertical and horizontal position of the hyoid bone was maintained under both conditions (Table 2). Thus, the increase in dimension between the hyoid bone and genial tubercle associated with prosthetic placement is explained by the shift in mandibular position reported. The significant modifications in tongue and mandibular positions during vowel production which were associated with placement of the prosthesis are summarized graphically in Figure 5.

As anticipated, a marked reduction in nasopharyngeal apertures during vowel production occurred coincident with prosthetic placement. On the basis of averaged data (Table 3), nasopharyngeal apertures were reduced by prosthetic placement, from approximately $8\frac{1}{2}$ mm to less than a half a millimeter. This fact must be included to interpret the results of the complete cephalometric analysis.

PALATOPHARYNGEAL FEATURES. Many pertinent characteristics of the palatopharyngeal region defined by analysis of films secured without prosthesis are summarized in the upper portion of Table 3. These data provide an objective palatopharyngeal reference for consideration of the entire sample. Marked variation in velar and velopharyngeal characteristics is indicated by the large standard deviations and broad range of measurements reported. Measures of velar length ranged from 19 to 37 mm; palatopharyngeal apertures during function ranged from 3 to 16 mm. The angular position of the velum during function also varied from almost a right angle relative to the palatal plane to positions elevated above the level of the palatal plane. These differences relative to velar length, position, and mobility suggest that considerable variation in design and construction of prostheses would be required to fulfill individual obturation needs.

Despite striking differences in palatopharyngeal features, radiographic measures showed that satisfactory obturation generally was achieved. Measurements of the distance between the posterior margin of the pharyngeal bulb and the posterior pharyngeal wall during vowel production averaged .22 mm with little variation in measurements indicated. These findings based upon anteroposterior measures suggest a much greater degree of homogeneity for the obturated nasopharyngeal condition than is justified by other measurements. To illustrate, measurements of the vertical dimensions of the obturated nasopharyngeal port varied (SD 5.45 mm); placement of the pharyngeal bulb also varied from 20 mm below the palatal plane to 6 mm above. Measures of bulb size ranged from 15 to 52 mm in the anteroposterior aspect and from 11 to 35 mm in the vertical aspect.

As might be anticipated from co-existing differences in velar positions, the position of the carrier for the pharyngeal bulb varied a great deal. In some instances, the carrier projected well below the palatal plane and contact between the carrier and dorsum of the tongue was observed during function.

The results of the completed analysis of the obturated nasopharyngeal status may be generalized by stating that variability rather than consistency in measurements appeared to be characteristic. Rather remarkable consistency, however, was noted relative to the anteroposterior specification of the obturated nasopharyngeal apertures. Of itself, the latter finding, based upon radiographic evidence, encourages the assumption that routine success in obturation was obtained. This assumption was not supported by the results of oropharyngeal examinations which were made to evaluate pharyngeal contact with right and left margins of the bulb during vowel phonation. Examinations showed that in some speakers, pharyngeal bulbs were adequate in the anteroposterior aspect but inadequate in lateral aspects. In order to interpret whether or not the observed differences in palatopharyngeal features and prosthetic fitting were significant relative to the perceptual characteristics of speech produced, specific measurements of speech adequacy were required.

Intelligibility Measurement (Individual Variation). Intelligibility measures for each subject speaking with and without prosthesis are plotted in Figure 6. As shown, variable degrees of improvement in speech intelligibility were attained. One speaker improved over 40% to attain near normal intelligibility with prosthesis, whereas other speakers improved very little or not at all.

In addition to the difference in relative degree of improvement, differ-

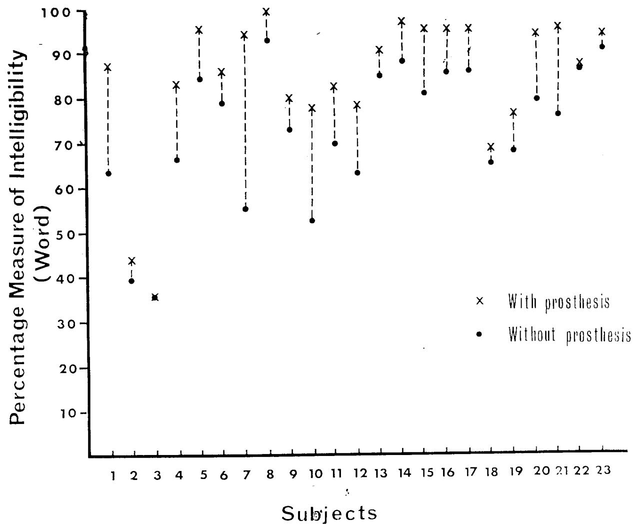

FIGURE 6. Individual intelligibility scores for speech produced with prosthesis and without prosthesis.

ent levels of speech intelligibility were attained with prosthetic insertion. Ten speakers with the benefit of obturation reached the 95% level for word intelligibility, which may be considered close to normal. Other speakers with prostheses were much less successful in achieving a reasonably adequate intelligibility index. Two subjects with obturation failed to attain a 50% level for word intelligibility.

Intelligibility levels for the obturated condition revealed marked speaker variability, although radiographic evidence indicated that very satisfactory obturation had been provided for all speakers. In combination, these results emphasize two important points: first, factors other than nasopharyngeal obturation are influential in determining total speech performance; secondly, evaluation of obturation adequacy should not be restricted to radiographic examination.

Intelligibility Measurement (Averaged Data). Although the relative degree of speech improvement showed prominent speaker variability, as a group, the subjects were found to achieve appreciable speech improvement when prostheses were placed. This point is illustrated by averaged data defining speech status without and with prosthesis (Figure 7). Averaged data for word intelligibility show that speakers without obturation produced intelligibly about three out of four words (73.25%). Speakers with obturation attained slightly more than a 10% improvement (84.67%). Thus, intelligibility level improved appreciably with obturation but, on the average, normal intelligibility was not achieved.

Visual comparison of averaged data shows that the pattern of intelligibility scores for words, consonants, vowels, and other phonetic groups for the obturated condition is similar to the general contour of the pattern

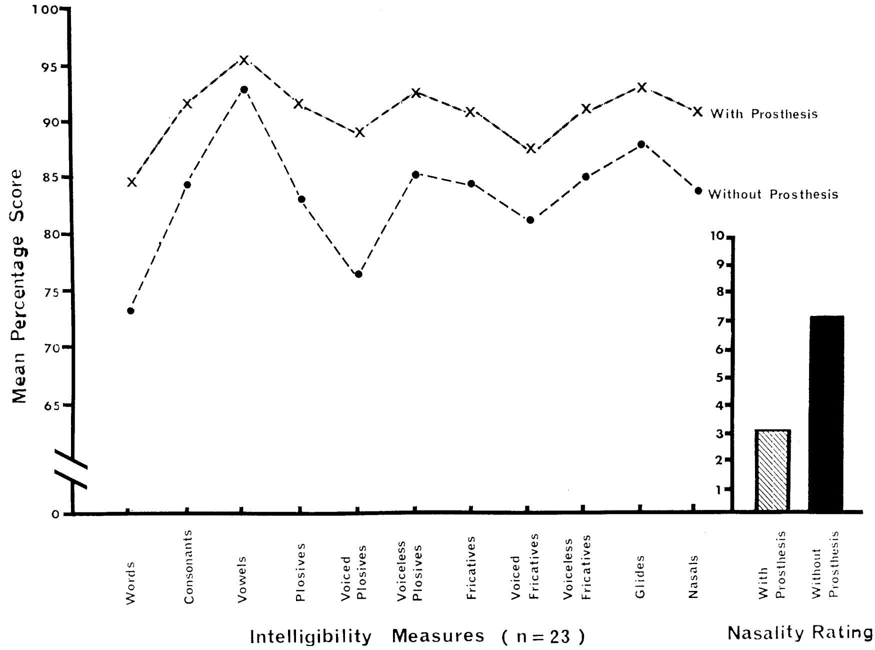

FIGURE 7. Graph of means for various measures of intelligibility and judgment ratings of nasality for 23 subjects speaking with and without prosthesis.

established for the unobturated condition. Under both conditions, intelligibility of voiced fricatives and voiced plosives tended to be lower than the intelligibility levels for other phonetic groups.

Statistical results of the comparative analysis of speech produced with and without prosthesis are reported in Table 4. On the basis of the t values recorded, intelligibility improvement was significant for all but one of the phonetic categories. Measures of voiced fricative intelligibility showed no significant improvement with obturation. Much greater variation in measurements of voiced fricative intelligibility also was apparent. In broad aspect, improvement in fricative intelligibility was attained as a function of nasopharyngeal obturation; however, the relative degree of improvement was less than that observed for other phonetic groups.

Subtle differences in degree of improvement for respective phonetic groups are illustrated in Figure 7. As shown, vowel intelligibility improved with obturation much less than consonant intelligibility. Plosives, as a group, tended to show a greater degree of improvement than was observed for other phonetic groups. Voiced plosive intelligibility was particularly improved as a function of nasopharyngeal obturation.[2]

[2] Glottal stops were used by some speakers to produce voiceless plosives. Thus, when the total sample is considered without regard to articulation skill, it is assumed that some speakers without obturation were successful in producing intelligible voiceless stops by using glottal substitutions. Glottal stops are produced by firm closure and abrupt release of the vocal folds. This articulatory method, successful for pro-

TABLE 4. Comparative analysis (paired observation) for 23 subjects of speech produced with and without prosthesis. The asterisk indicates significance at the 5% level.

Measure of intelligibility	*Condition*	*Mean*	*SD*	*t*
Word	with pros.	84.67%	16.07	6.11*
	without	73.25%	16.41	
Consonant	with pros.	91.87%	10.42	5.28*
	without	84.77%	11.02	
Vowel	with pros.	95.86%	6.57	3.27*
	without	93.07%	5.90	
Plosive	with pros.	91.63%	10.16	5.15*
	without	83.20%	12.69	
Voiced plosive	with pros.	89.03%	13.98	4.38*
	without	76.84%	21.24	
Voiceless plosive	with pros.	92.91%	10.23	3.27*
	without	85.68%	11.00	
Fricative	with pros.	91.18%	10.75	3.67*
	without	84.81%	12.56	
Voiced fricative	with proc.	87.67%	24.06	1.82
	without	81.91%	20.27	
Voiceless fricative	with pros.	91.40%	10.81	2.59*
	without	85.32%	12.40	
Glide	with pros.	93.27%	12.53	3.81*
	without	88.23%	11.70	
Nasal consonant	with pros.	91.06%	11.83	3.86*
	without	84.19%	12.37	
Nasality rating	with pros.	3.13	2.01	8.51*
	without	7.13	1.66	

NASALITY RATINGS. Paired observations of nasality ratings for speech produced with and without prosthesis showed that a significant reduction in nasalization was associated with obturation (Table 4). In accordance with scale values, the average rating was reduced from a low level of hypernasality to slight nasality. Averaging the data for the entire sample, therefore, permits the generalization that nasality was reduced significantly by prosthetic placement, although speaker variability relative to degree of nasal resonance for the obturated condition was found to be marked.

On the basis of combined cephalometric and speech data, grouped for the entire sample, it can be stated generally that satisfactory obturation was provided and significant improvement in speech intelligibility and

ducing voiceless stops, would not appear to be equally successful in producing voiced stops which require vocal fold vibration for sound generation. Synchronous function of the vocal folds as pressure valve and generator of tone is difficult to conceptualize from a physiological viewpoint. Thus, on a theoretical basis, a greater improvement in voiced as opposed to voiceless stop intelligibility might be anticipated when nasopharyngeal obturation is provided. With obturation, the demand for pressure modification at the glottal level is not superimposed upon the speech-producing system and intelligible voiced plosives can be produced.

quality was attained. Some modification relative to the degree of speech improvement attained is indicated, however, when two additional findings are reported. First, marked variability in speech results was evident, and secondly, *normal* speech intelligibility and quality was not achieved consistently as a consequence of the prosthetic fitting. To understand the basis for variable speech results obtained, additional information related to articulation skill and obturation adequacy was required.

COMPARATIVE SPEECH ANALYSIS OF SUCCESSFUL AND UNSUCCESSFUL SPEAKERS. Measures of word intelligibility obtained for the obturated condition were used as a practical means of differentiating successful (Group A) and unsuccessful (Group B) speakers so that the two groups of speakers could be established for comparative study. Group A included 10 subjects who achieved an average intelligibility score of 95% when speaking with prosthesis. Group B consisted of six speakers who achieved an average intelligibility score of 64% when speaking with prosthesis. Speakers whose intelligibility scores did not demonstrate clearly defined speech success or failure were excluded from analysis. By deleting the middle group, consisting of seven speakers, a sharper differentiation between the two levels of speech intelligibility was attained for comparative analysis.

Averaged speech data for Group A and B are graphed in Figures 8 and 9, respectively. Comparison of data for the two groups shows that there was much less variation in intelligibility percentages for respective phonetic categories in Group A, the successful speakers. A relatively flat pattern of intelligibility percentages for both obturated and unobturated conditions is apparent suggesting that speakers in Group A were about equally successful in producing all sound groups. In Group B, an irregular pattern of intelligibility percentages was characteristic for both conditions.

Other differences between Groups A and B are apparent. Comparatively little improvement in vowel intelligibility was associated with obturation in Group A, whereas marked improvement was noted in Group B. Nasal consonant intelligibility was greatly *improved* by obturation in Group A. In contrast, nasal consonant intelligibility was *reduced*, not improved, by obturation in Group B.

A reasonable interpretation for the latter finding may be suggested when nasality ratings are considered conjunctively. Nasality was eliminated completely by obturation in Group A. Only slight reduction in nasality resulted from obturation in Group B. Thus, a gross difference in degree of nasalization for the obturated condition coexisted with the marked difference in nasal consonant intelligibility. Significant improvement in nasal consonant intelligibility was associated with elimination of nasality (Table 6). No improvement in nasal consonant intelligibility was observed when excessive nasalization persisted for the obturated condition. Compositely, these findings support the concept that a positive

TABLE 5. Comparative cephalometric analysis of two groups of prosthetically fitted cleft palate subjects: Group A, 10 subjects who attained normal quality and intelligibility with prosthesis; Group B, six subjects who failed to appreciably improve speech quality and intelligibility with prosthesis. The asterisk indicates significance at the 5% level.

Measurement	*Group A*			*Group B*			*t*
	Mean	*SD*	*SE*	*Mean*	*SD*	*SE*	
Without Prosthesis							
Velar length at rest	24.40 mm	5.74	1.82	30.50 mm	5.32	2.17	2.11*
Angular position of velum during function	−13.56°	19.90	6.63	−47.33°	14.61	5.96	3.39*
Degree of velar movement	45.29°	23.06	8.70	9.67°	9.23	3.77	3.53*
With Prosthesis							
Antero-posterior position of upper lip relative to lower lip	+2.70 mm	3.89	1.23	−2.00 mm	4.18	1.87	2.19*
Vertical position of tongue tip relative to lower incisor	−5.89 mm	6.61	0.73	+1.17 mm	9.11	3.72	1.53
Dorsum of tongue relative to palatal plane	18.44 mm	4.53	1.51	25.40 mm	8.62	3.87	2.01
Dorsum of tongue relative to pharyngeal wall	12.40 mm	5.76	1.82	16.50 mm	3.83	1.56	1.54
Vertical position of the hyoid relative to palatal plane	73.30 mm	7.82	2.47	84.17 mm	8.11	3.31	2.66*
Horizontal position of the hyoid relative to pharyngeal wall	35.40 mm	7.62	2.41	39.83 mm	5.74	2.34	1.22
Bulb placement relative to palatal plane	−6.40 mm	7.93	2.51	−10.50 mm	7.26	2.96	1.03
Inferior most point of carrier relative to palatal plane	20.78 mm	3.46	1.15	23.60 mm	6.07	2.72	1.12

relationship exists between loss of nasal consonant intelligibility and nasalization (*10*).

Oropharyngeal Examinations and Articulation. The difference between Groups A and B relative to nasal resonance was explained by the results of oropharyngeal examinations. All speakers in Group A were found to have adequate obturation, which was defined as complete contact of the bulb by pharyngeal musculature or pharyngeal constriction which was within 2 mm of bulb contact on just one margin. In contrast, four of the six speakers in Group B had inadequate nasopharyngeal obturation. During vowel production, apertures not less than 5 mm in diameter were visible between right and/or left margins of the bulb and the lateral pharyngeal walls. This latter observation is compatible with the greater degree of nasality noted for the obturated condition in Group B.

Ratings of articulation for obturated and unobturated conditions also revealed differences between speakers in Group A and B. In addition to scaled ratings of articulation, judgments were made to identify glottal

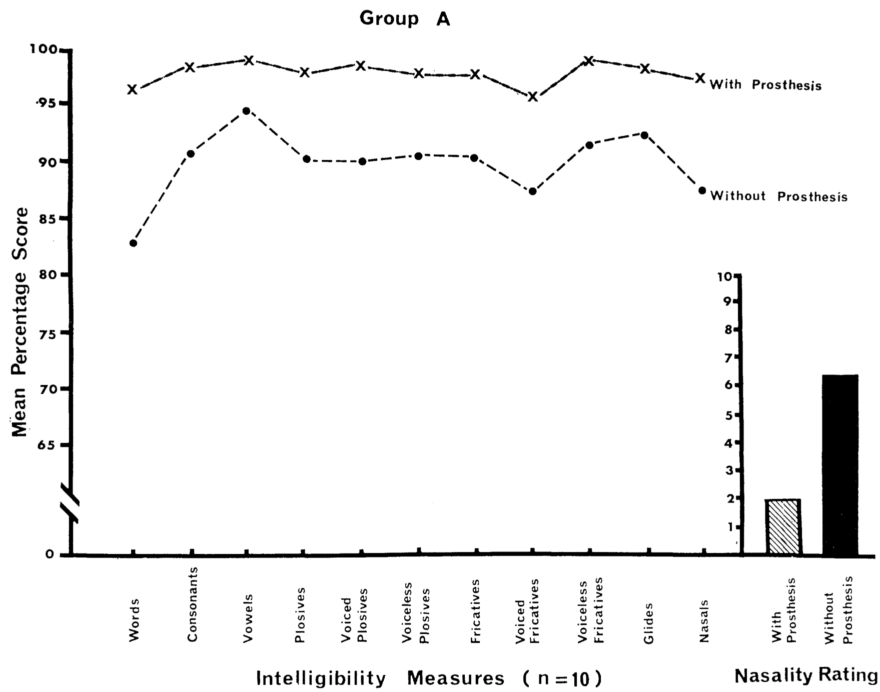

FIGURE 8. Graph of means for various measures of intelligibility and judgment ratings of nasality for a select group of cleft palate subjects speaking with and without prosthesis. All 10 subjects had normal articulation.

stops and nasal emission as absent, inconsistent, or consistent. Data for the unobturated condition in Group A showed articulatory distortions resulting from excessive nasalization, nasal emission of air, and reduced (audible) oral pressure. However, glottal stops, pharyngeal fricatives, other substitutions, distortions, and omissions of sounds generally were not observed. Articulation for the obturated condition was found to be essentially normal in Group A.

Articulatory ratings and observations in Group B revealed a high incidence of glottal stops for both obturated and unobturated conditions. Other articulatory errors were apparent for both conditions. With obturation, articulatory distortions were reduced, primarily as a result of some reduction in nasalization and nasal emission. Fundamentally, Group B speakers had defective articulation which was not altered appreciably by prosthetic placement, per se.

Group differences in articulatory skill may be partially explained by differences in speech training. All speakers in Group A had many years of speech training before prosthetic fitting with some additional training after the prosthesis was obtained. Speakers in Group B had comparatively little, if any, speech training before prosthetic fitting and then afterwards ‘only a few speech lessons’.

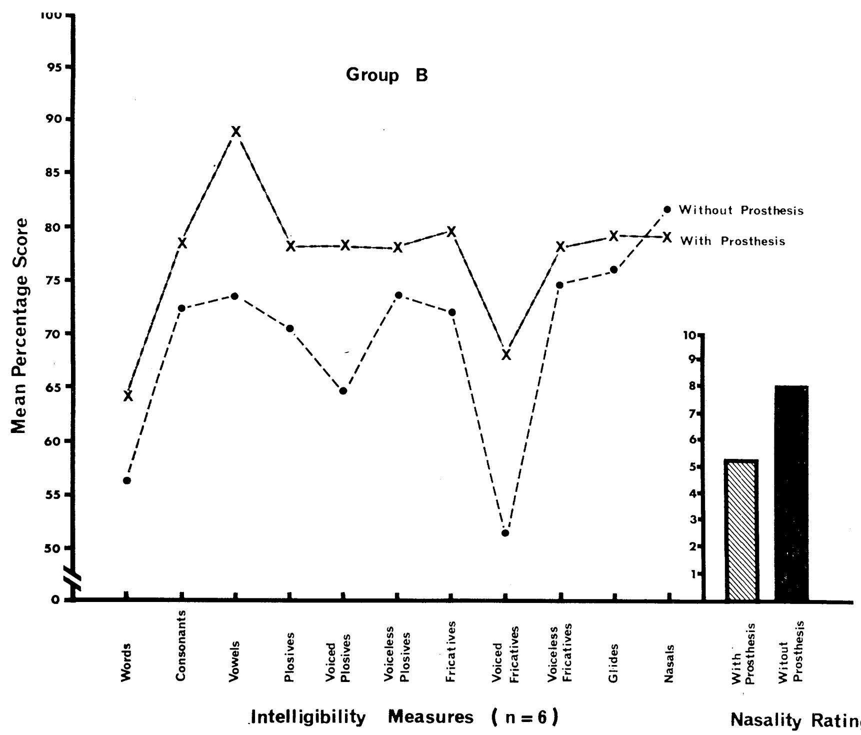

FIGURE 9. Graph of means for various measures of intelligibility and judgment ratings of nasality for 6 cleft palate subjects speaking with and without prosthesis.

To summarize, the superiority of Group A speakers is explained by more adequate obturation and greater articulatory skill which probably was developed as a combined consequence of more speech training and more adequate obturation.

Comparative Cephalometric Analysis. In an effort to understand why obturation should be more adequate in one group of speakers than in another, a comparative cephalometric analysis was undertaken. Statistical results of this analysis identify the physiological features associated with successful and unsuccessful prosthetic fittings (Table 5).

The most prominent differentiations were related to palatopharyngeal features. The angular position of the velum during function was significantly lower in the unsuccessful speech group. Specifically, velar position during function averaged 47.33° below the level of the palatal plane in Group B as opposed to 13.56° in Group A. In addition to the lower angular position, the degree of velar movement was significantly less (9.67°) in Group B than in Group A (45.29°).

Measures of velar length also differed significantly with the poor speakers in Group B having the longer as well as the less mobile soft palates. Measures of palatopharyngeal relationships during function

TABLE 6. Comparative analysis (paired observation) of speech produced with and without prosthesis (N = 10 cleft palate speakers with normal articulation, Group A). The asterisk indicates significance at the 5% level.

Measure of intelligibility	*Condition*	*Mean*	*SD*	*t*
Word	with pros.	96.27%	1.41	4.23*
	without	82.93%	10.74	
Consonant	with pros.	98.44%	0.65	5.28*
	without	91.08%	7.30	
Vowel	with pros.	99.20%	0.82	3.27*
	without	94.94%	4.69	
Plosive	with pros.	98.18%	1.69	2.88*
	without	90.31%	8.49	
Voiced plosive	with pros.	98.89%	3.51	2.37*
	without	90.18%	11.32	
Voiceless plosive	with pros.	97.86%	2.23	2.69*
	without	91.04%	11.39	
Fricative	with pros.	97.84%	1.81	1.91
	without	90.77%	10.78	
Voiced fricative	with pros.	95.91%	4.74	2.35*
	without	87.58%	11.25	
Voiceless fricative	with pros.	99.29%	1.63	1.74
	without	92.02%	8.22	
Glide	with pros.	98.35%	0.17	3.41*
	without	92.92%	6.18	
Nasal consonant	with pros.	97.65%	3.34	4.07*
	without	87.93%	8.72	
Nasality rating	with pros.	2.00	1.33	5.23*
	without	6.50	1.96	

indicated that the greater velar length characteristic in Group B was of no advantage in effecting closure because of the restricted mobility. For the unobturated condition, the average palatopharyngeal aperture during vowel phonation was slightly larger in Group B (9.67 mm) than in Group A (7.60 mm).

Both groups had complete obturation as revealed by cephalometric study, although pharyngeal bulb locations differed with a somewhat lower placement relative to the palatal plane observed in the unsuccessful speakers of Group B. The carrier for the pharyngeal section also tended to be lower in Group B.

In addition to palatopharyngeal features, other measures of the obturated condition differentiated speakers in Group A and B. In Group A, the dorsum of the tongue was more closely related to the palatal plane and the hyoid bone was in a significantly higher position. An abnormally low tongue posture was observed in Group B and may be explained as a necessary adjustment imposed by the associated low angular position of the velum and carrier for the pharyngeal bulb of the prosthesis. Correlative to the low tongue posture in Group B, a lower hyoid position would be anticipated.

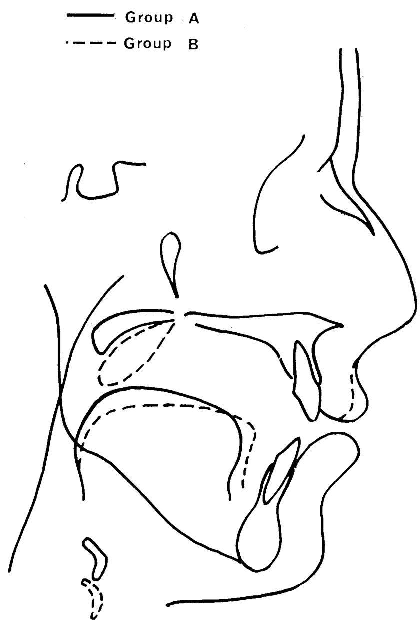

FIGURE 10. Cephalometric tracing to illustrate the significant differences in physiological relationships which were found to differentiate success and unsuccessful speech results after prosthetic fitting.

Measurements of the anteroposterior relationship of the upper lip also revealed a significant difference with Group A speakers showing the more protruded or normal upper lip posture. On the basis of combined lip and tongue measurements, it may be postulated that the better speakers in Group A possessed a more favorable oral environment for articulate speech as well as more favorable palatopharyngeal features for successful prosthetic fitting. Figure 10 graphically presents the significant differentiations between Groups A and B which were revealed by statistical analysis.

Effect of Nasalization Upon Speech Intelligibility. By all criteria employed, the 10 subjects in Group A were found to have normal speech. Articulation, intelligibility, and quality of speech were normal when the prosthesis was in situ. Combined cephalometric and oropharyngeal examinations provided further evidence that nasopharyngeal obturation was completely adequate. On the basis of these findings, an extensive comparative analysis of speech characteristics for obturated and unobturated conditions was justified for the purpose of studying the effect of nasalization upon speech intelligibility.

Results of the comparative analysis of intelligibility for obturated and unobturated conditions in Group A are presented in Table 6. Word intelligibility was found to average 82.93% for the unobturated condition and 96.27% for the obturated condition. When the prosthesis was out, approximately one out of every five words could not be identified accurately by listeners. Speech produced with the open nasopharynx was not *just* nasal and slightly distorted in an articulatory sense. Despite normal articulatory skill, communication efficiency, as measured by intelligibility testing, was appreciably and significantly reduced by the nasopharyngeal apertures and attendant nasalization.

As indicated by the *t* values reported, intelligibility for almost all phonetic categories was significantly improved by prosthetic placement in Group A. Only subtle differences in intelligibility levels for respective phonetic categories were revealed. With obturation, intelligibility improvement was significant at the 1% level for nasal consonant, glide, and vowel categories. Improvement with obturation was significant at the 5% level for voiceless and voiced plosives and for the voiced fricative category. Statistically, the overall category for fricative intelligibility showed no significant improvement as a function of nasopharyngeal obturation in this group of speakers with 'normal' articulation.

To further evaluate the relationships between intelligibility loss for respective phonetic groups and nasality rating, correlation coefficients were calculated. The results show that positive relationships exist between most intelligibility measures and nasality ratings. The correlation between percentage loss of nasal consonant intelligibility and nasality rating (.67) was found to be somewhat higher than the correlations obtained for other phonetic groups. Correlations between percentage loss of glide intelligibility and nasality (.61) and between plosive intelligibility and nasality (.58) were both significant but no significant relationship between loss of fricative intelligibility and nasality was indicated (.30). Increased loss of fricative intelligibility as a function of greater nasalization was not indicated by the correlation coefficient obtained.

Discussion

Some interpretative comments are encouraged by the speech data derived from subjects with normal articulation. On the basis of judgment ratings, the open nasopharynx resulted in increased nasalization and nasal emission. Further, it may be *assumed* that there was an associated reduction in intraoral air pressure. Compositely, increased nasal air flow, nasal resonance, and decreased oral pressure are physical modifications resulting from palatopharyngeal deficiency. Continued research endeavor is required to specify pressure-flow dynamics in oral and nasal cavities so that the valving function of the normal palatopharyngeal complex can be understood more adequately. Thereafter, statements pertaining to *reduced* oral pressure and *excessive* nasal air flow can be made with confidence. The significance of such deviations can then be studied and interpreted relative to the acoustical and perceptual character of speech output.

Within the limitations of this study, it is concluded that the modifications in pressure-flow dynamics resulting from removal of nasopharyngeal obturation were of considerable magnitude and perceptual significance. Reduced intelligibility was associated with the open nasopharynx in speakers with normal articulation. Thus, modifications in pressure-flow dynamics appreciably altered spectral output and phonemic identity was destroyed in some instances. Some speech sounds, possibly depending upon their respective physical requisites for a distinctive spectral pattern, were not merely distorted by nasalization and reduced oral pressure. Rather, phonemic distinctiveness was lost when the nasopharynx was open.

In particular, nasal consonant intelligibility was reduced by the open nasopharynx and increased nasalization. In this regard, some further interpretative comments may be ventured. Spectral features of nasal resonance are known to constitute auditory cues for identification of nasal consonants (*2, 3, 6*). The requisite nasal resonance for nasal consonant identification is present during nasalized speech production; however, nasal resonance also is present during production of other phonemic groups. The figure background relationship for the auditory distinctiveness of nasal consonants, therefore, may be reduced in sharpness. In other words, an appropriate degree of oral-nasal resonance differentiation cannot be produced when the nasopharynx is open. When the overall background of speech becomes nasal, the noticeable auditory difference between background and nasal consonant foreground tends to be obscured. As perceptual distinctiveness of nasal consonants is reduced by the disturbance in resonance balance, auditory confusion between nasal and homophonous voiced plosive consonants may develop. The same type of phenomenon might also be anticipated when hyponasalized speech quality exists; in which case again auditory confusion between denasalized nasal consonants and voiced plosives may result.

A second factor related to temporal modification of air pressure may contribute to perceptual confusion between nasal and plosive consonants when there is palatopharyngeal incompetence and nasalization of speech. The burst or plosive character of stop consonants is created by the abrupt release of air pressure which has been imploded behind a tightly closed articulatory valve. With the physiological release of the articulatory valve, a simultaneous pressure release occurs which generates a pulse of sufficient amplitude to yield an audible sound burst. The burst is recognized as a distinguishing cue for auditory identification of plosive consonants (*4*).

When palatopharyngeal deficiency is present, the oral pressure posterior to the constriction is reduced (Figure 11). As a result, the auditory burst, if it appears at all, is considerably reduced in amplitude (Figure 12). Stop consonants without burst character and with nasal resonance superimposed therefore come to have spectral features approaching the pattern of nasal consonants, which normally has nasal resonances with no burst associated.

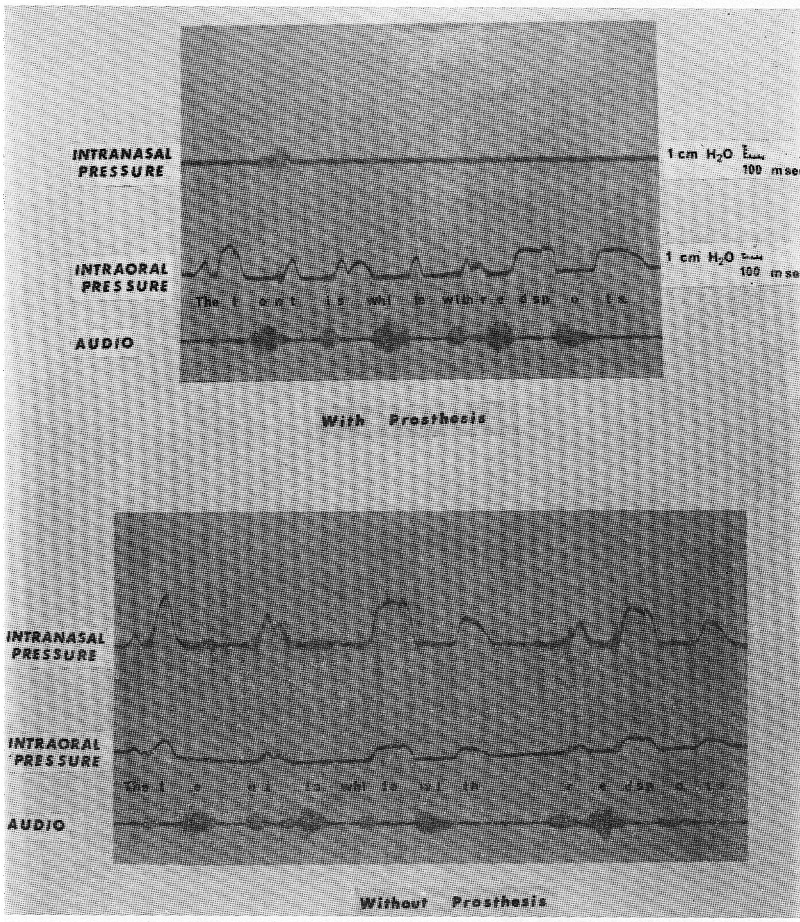

FIGURE 11. Simultaneous recordings of intraoral and intranasal air pressure for the same subject speaking with prosthesis (above) and without prosthesis (below). The intraoral pressure sensing device was a small silicon strain guage transducer which was pasted with denture adhesive to roof of the mouth. Intranasal pressure was sampled by inserting a catheter in the nostril.

Although discussion has been limited to plosive and nasal consonant categories, intelligibility loss associated with nasalization was not restricted to these two phonetic categories. Glide intelligibility also was reduced significantly by the open nasopharynx. It seems more reasonable to attribute decreased glide intelligibility to resonance distortion rather than to modification in oral pressure, per se.

These interpretations of present findings appear realistic; however, they must be regarded as hypotheses, and possibly as theoretical references for continued study, until much more information has been obtained. The paucity of research data defining physical parameters of consonant production becomes glaring when discussion is focused upon

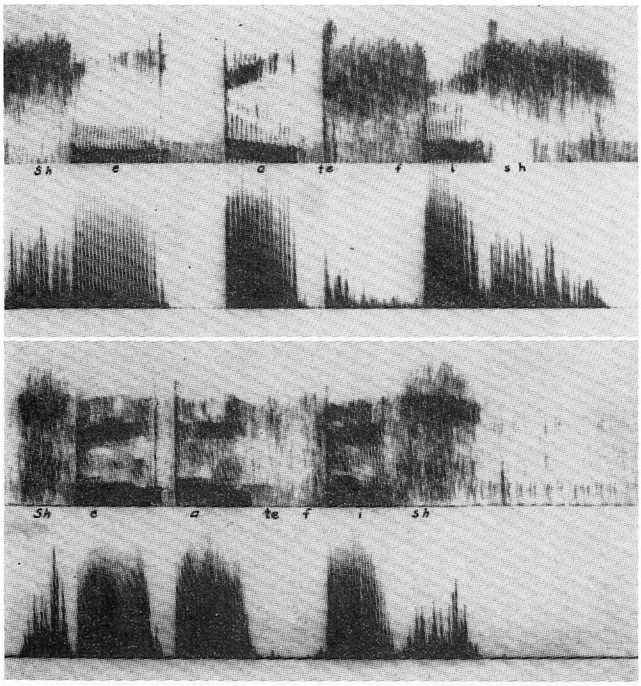

FIGURE 12. Spectrograms of the same subject speaking with prosthesis (above) and without prosthesis (below). Horizontal and vertical directions represent time and frequency (0–3500 cps), respectively. The lower spectrogram is differentiated from the upper by: reduced amplitude of the burst for the /t/, an excessively broad distribution of energy for the /sh/, and by diffuse spectral components which may be attributed to sound or noise emitted from the nostrils when the prosthesis was removed.

the effect that palatopharyngeal incompetence has upon consonant production and perception.

Comparative cephalometric analyses of obturated and unobturated conditions for rest and centric positions showed that physiological relationships generally were not modified by prosthetic insertion, except in regard to upper lip positions. During sustained vowel production, physiological relationships were altered significantly by prosthetic insertion.

The adjustments associated with obturation included increased mandibular elevation and protrusion, forward shifting of the posterior aspect of the tongue, and depression of the tongue tip. The fronting of the dorsal aspect of the tongue may be considered as an adjustment to increase the pharyngeal space which otherwise would be reduced by the introduction of the pharyngeal bulb mass. Similarly, the dropping of the tongue tip and protrusion of the mandible may be considered adjustments to increase anterior space which otherwise would be reduced by the observed elevation of the mandible. Compositely, these adjustments associated with prosthetic placement may be interpreted as accommodations tending to equate dimensions of oral and pharyngeal resonance chambers for the two conditions in order to preserve phonetic character of the vowel /u/. Theoretically, a reasonably comparable resonance system for both obturated and unobturated conditions is required.

Cephalometric findings, limited to static analyses, provide evidence that relatively widespread physiological modifications do occur during speech production when prosthesis is placed. The changes observed were not restricted to the palatopharyngeal region. In broad aspect, the physiological modifications described are interpreted as evidence that the vocal tract functions physiologically and acoustically as a complexly integrated system.

Cephalometric data, per se, indicated that satisfactory obturation was achieved in all subjects. Intelligibility and nasality data for the entire sample, however, showed that there was marked speaker variability in speech improvement. Explanations for the variable speech results obtained with prosthesis were provided when data was regrouped on the basis of intelligibility indices and when oropharyngeal and articulation examinations were incorporated in analysis.

Successful speakers were found to be differentiated from unsuccessful speakers by superior articulatory skill and more adequate obturation as revealed by oropharyngeal examinations. Comparative cephalometric analysis also revealed significant differences relative to palatopharyngeal features and obturator fitting. Unsuccessful speakers were found to have significantly longer but less mobile soft palates. Associated with these palatal features, the carrier and obturating pharyngeal bulb generally were located at lower levels within the oral and oropharyngeal cavities.

The position of the carrier and pharyngeal bulb is generally dictated by palatopharyngeal features. To fulfill obturation requirements, sometimes the carrier must project downward to accommodate a long, immobile velar mass and then upward to position the bulb at a proper site for satisfactory obturation. Cephalometric data showed that complete obturation in the anteroposterior aspect was achieved in most of these instances. However, oropharyngeal examinations revealed that obturation generally was inadequate laterally under these conditions.

Defective speech associated with low carrier and bulb placement may be explained by several factors. For example, the inferior position of the carrier may restrict dorsal tongue activity and thus interfere with lingual coordination during speech. In some patients, mesial movement of the lateral pharyngeal wall during deglutition may be excessive. As a result, a pharyngeal bulb which satisfactorily obturates during speech may be too broad in lateral aspect to be tolerated during deglutition. When and if this situation occurs, the lateral dimensions of the pharyngeal bulb must be reduced to accommodate the more extensive pharyngeal movement occurring during deglutition (*1, 5, 7, 8*).

Regardless of explanation, present findings permit the conclusion that the comparatively long, immobile soft palate constitutes an unfavorable physiologic circumstance for successful prosthetic fitting and good speech performance. The most successful speech results attained with prosthesis were achieved by subjects who had very short soft palates.

In considering surgical and prosthetic procedures to correct palatopharyngeal incompetence, the results of this investigation suggest that the patient with a very short soft palate, mobile or immobile, is an excellent candidate for obtaining successful speech with prosthetic fitting. Long, immobile soft palates, regardless of the relative degree of activity in the pharyngeal musculature, were not found to predispose success via prosthesis. The speech needs for subjects with these latter palatopharyngeal features may best be fulfilled by a surgical procedure, such as pharyngeal flap, which simultaneously retroposes the velar mass and reduces the nasopharyngeal aperture.

Further studies are needed to determine the degree of diminution in palatopharyngeal aperture which may be anticipated as a consequence of surgical techniques designed to narrow the pharyngeal isthmus, implant the posterior pharyngeal wall, or create a pharyngeal flap. In preoperative and post-operative appraisals, the critical need is to appraise speech and the palatopharyngeal sphincter quantitatively and qualitatively.

Summary

This report summarizes the results of an extensive analysis of 23 cleft palate subjects who received prosthetic treatment for correction of palatopharyngeal incompetence. Pertinent information was derived from nasality and articulation ratings, intelligibility testing, cephalometric films, and oropharyngeal examinations.

By pairing observations of speech produced with an open and an obturated nasopharynx, two experimental conditions in the same subject were provided. Comparative analysis revealed that speech quality and intelligibility were significantly improved by obturation, although normal intelligibility and quality generally were not attained. Marked speaker variability also was evident.

Measures of intelligibility obtained for the obturated condition were used to differentiate successful and unsuccessful speakers. Speech produced by subjects with normal articulation was then analyzed to study the effect of the open nasopharynx and nasalization upon speech intelligibility. With one exception, intelligibility for all phonetic categories was significantly reduced by nasalization. Nasal consonant intelligibility was particularly lowered by nasality, suggesting that there is a positive relationship between nasality and loss of nasal consonant intelligibility. The dynamics of the breath stream and spectral output is considered and the need for continued research emphasized.

A comparative cephalometric analysis of successful and unsuccessful

speakers was undertaken to define respective palatopharyngeal features. Unsuccessful speakers were found to have significantly longer and less mobile soft palates. Associated with these palatal features, the carrier and obturating pharyngeal bulb were located at lower levels within the oral and oropharyngeal cavities. Under these conditions, obturation frequently was observed to be deficient in the lateral aspect. Extensive mesial movement of the lateral pharyngeal walls during deglutition is postulated as a possible explanation for this latter finding. In summary, obturation was found to be most adequate and speech most satisfactory in subjects who had very short soft palates.

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Acknowledgments. The authors wish to acknowledge Drs. Charles Elliott and Morton Rosen for assistance in supplying case material, and the cooperation of the Cleft Palate Center of the University of Illinois. Facilities for spectrographic study were made available by Dr. Gordon E. Peterson, Director of Communication Sciences Laboratory, University of Michigan. The assistance of Dr. Donald J. Allard, Davenport, Iowa, is also acknowledged.

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