Pre and Post-Operative Analysis of Velar and Pharyngeal Flap Mobility

JOANNE D. SUBTELNY, Ph.D.
NOBUO OYA, D.D.S., D. Med. Sc.
J. DANIEL SUBTELNY, D.D.S., M.S.
JOHN W. CURTIN, M.D.
ROBERT M. McCORMACK, M.D.
Rochester, New York

Although investigators agree that pharyngeal flap surgery is effective in correcting palatopharyngeal incompetence, opinions differ as to the mechanics of valving after surgery. Opinions also differ relative to: the effect of pharyngeal flap surgery upon the mobility of the velum (*3, 4, 8, 10*) and the importance of flap mobility as it pertains to post-operative speech status (*1, 4*).

The study reviewed here was undertaken to investigate relationships between: a) pre-operative velar movement and pharyngeal flap movement; b) activity in the lateral pharyngeal walls before and after surgery, and; c) pharyngeal flap movement and the success of the operative technique as defined by nasality ratings.

Sample. The sample included 60 subjects ranging from 6 to 43 years of age, with the majority (34) falling within the 6 to 12 year category. With the exception of four patients, superiorly based flaps were constructed to correct velopharyngeal incompetence. Of the 60 subjects studied, there were 14 with submucous cleft palate; 20 with posterior cleft palate; 18 with unilateral cleft lip and palate, and; 8 with bilateral cleft lip and palate. All subjects, with the exception of the submucous group and 8 subjects with posterior cleft palate, had had at least one surgical procedure for palate closure.

Procedures

Ratings of nasality and nasal emission were used to differentiate successful and unsuccessful speech results (*12*). To evaluate activity in the lateral pharyngeal walls, oropharyngeal examinations were made

Drs. Joanne D. and J. Daniel Subtelny are affiliated with Eastman Dental Center, Rochester, New York; Dr. Nobuo Oya, of Mie Prefectural University, Japan, is presently serving as Research Associate at Eastman Dental Center. Dr. John W. Curtin is Clinical Professor and Chairman, Department of Plastic and Reconstructive Surgery, University of Illinois Medical Center, Chicago, Illinois. Dr. Robert M. McCormack is Professor and Chairman, Division of Plastic Surgery, School of Medicine and Dentistry, University of Rochester.

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with degree of activity rated as 1—marked; 2—moderate; 3—slight, and; 4—none. When activity could not be observed with confidence, a rating of 5 was assigned. Modifications in lateral pharyngeal apertures during function were also rated on a five point scale in post-operative evaluations. Judgments of the factors responsible for aperture modification were also made. All oropharyngeal examinations were made by the same examiner before and eight months after surgery.

To appraise velar and flap mobility, cephalometric x-ray films secured during rest and during production of /u/ and /s/ were traced and measured. Procedures to analyze movement involved arc constructions as illustrated in Figures 1 and 2. In principle, the system was developed: a) to identify the same relative points for measurement of velar position at rest and in function and in post-operative conditions of rest and function, and; b) to gain linear and angular measures of velar position in each circumstance.

Velar position was measured at its midpoint or in the mid-third segment which is considered to be the most mobile portion of the functioning soft palate. Degree of movement was determined by subtracting the angular position at rest from the positions assumed during production of /u/ and /s/. Measures of velar and flap position and movement were then compared relative to the sound produced and relative to operative status. Pharyngeal measures illustrated in Figure 3 were included for correlated study of pre and post-operative conditions.

To supplement post-operative information gained from cephalometric study, cineradiographs filmed at 240 f.p.s. were analyzed for 30 patients or for half the subjects studied. In film analysis, two investigators studied palatopharyngeal activity and recorded observations according to the rating scale described by McWilliams and Bradley (*5*).

Results

Judgement Ratings. The percentage of patients with marked activity in the lateral pharyngeal walls decreased slightly after surgery, however, the incidence of slight or no activity increased markedly from 18% to 40%. Incidence of decrease or increase of activity after surgery was determined by individually comparing pre and post-operative ratings. A change in rating of one interval or more designated increase or decrease in activity. By this procedure, almost half the subjects (45%) had decreased pharyngeal mobility with only 16% showing increased activity after surgery. Although reduction in mesial movement may be partially attributed to the lower and more restricted area of visualization after surgery, the overall results warrant the generalization that pharyngeal muscle movement, as evaluated in examinations, tended to decrease more frequently than increase after surgery.

Examinations relative to aperture modification revealed non-nasal speakers had more movement in flap and pharyngeal walls than the

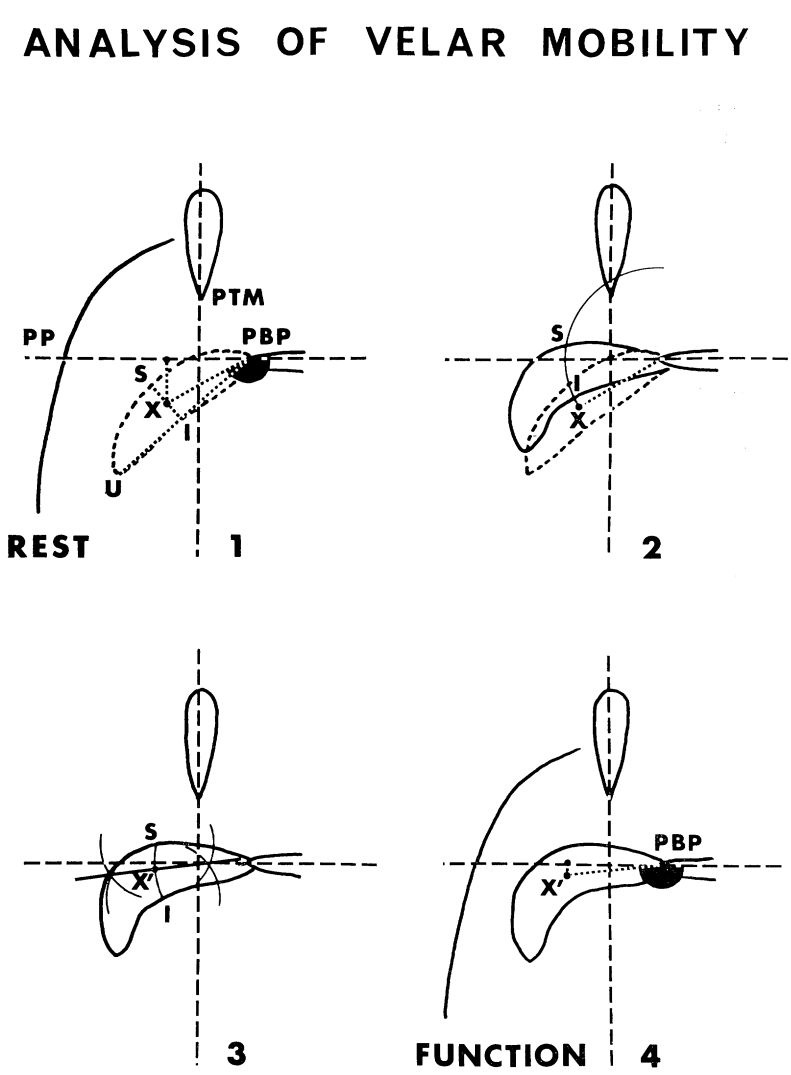

FIGURE 1. Pre-operative analysis of velar mobility showing reference lines: 1. (PP)—palatal plane, anterior to posterior border of the hard palate (PBP); (PTM)—perpendicular to PP bisecting pterygomaxillary fissure; (PBP-U)—PBP to inferior point of uvula (U); (SI)—perpendicular to midpoint of Line PBP-U, transecting superior (S) and inferior (I) surfaces of velum. Point X, midpoint of Line SI, and Line X-PBP are basic references used for other constructions and for linear and angular measures. 2. Superior and inferior surfaces of velum in function are determined by constructing an arc from PBP with X-PBP radius. 3. To determine X′, SI is mathematically bisected by constructing arcs from Point S and I with radius of SI and by connecting points of intersect. 4. X and X′ locate the same approximate velar point for measurement. Pre-operative linear and angular measures in rest and function included: X-PP, PP-PBP-X, X′-PP and PP-PBP-X′.

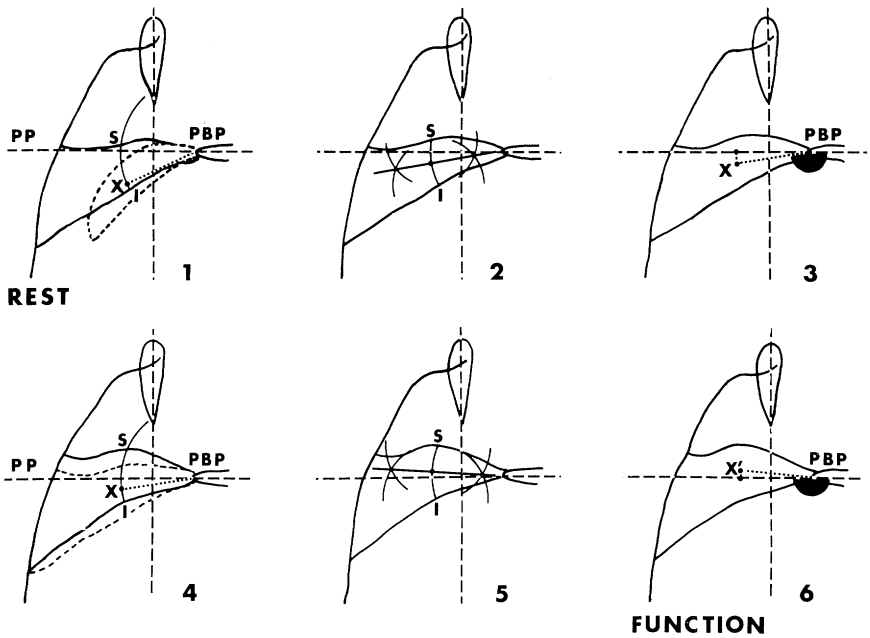

FIGURE 2. Post-operative analysis of flap mobility showing: 1. The velum before surgery (dotted) and flap at rest (solid). Superior and inferior surfaces of the flap at rest are determined by arc with X-PBP radius from Point PBP. 2. Point X is defined by arcs of SI radius from Points S and I. 3. X-PP and PP-PBP-X define flap rest position linearly and angularly. 4. The flap at rest (dotted) and in function (solid) is shown. Points S and I in function are defined by arc of X-PBP radius. 5. Point X′ is defined by arcs of SI radius from Points S and I. 6. X′-PP and PP-PBP-X′ define flap position linearly and angularly during function.

nasal speakers. Over half the non-nasal subjects showed marked reduction in apertures during function; none showed aperture enlargement. Mesial movement was identified as the primary factor responsible for valving in 60% of the non-nasal speakers. Flap mobility was identified as the primary factor in only 13%. In overview, mesial movement was found to be the most consistent single factor responsible for aperture modification during speech.

One-third of the patients who retained residual nasality showed no reduction and sometimes enlargement of apertures during function. Subjects who showed enlarging apertures tended to have tight anteriorly located posterior pillars before surgery. After surgery, levator activity seemed to be associated with a forward pull on the flap which resulted in a deepening or enlarging of the apertures. Elevation of the flap itself was not necessarily deficient. Good mobility was sometimes

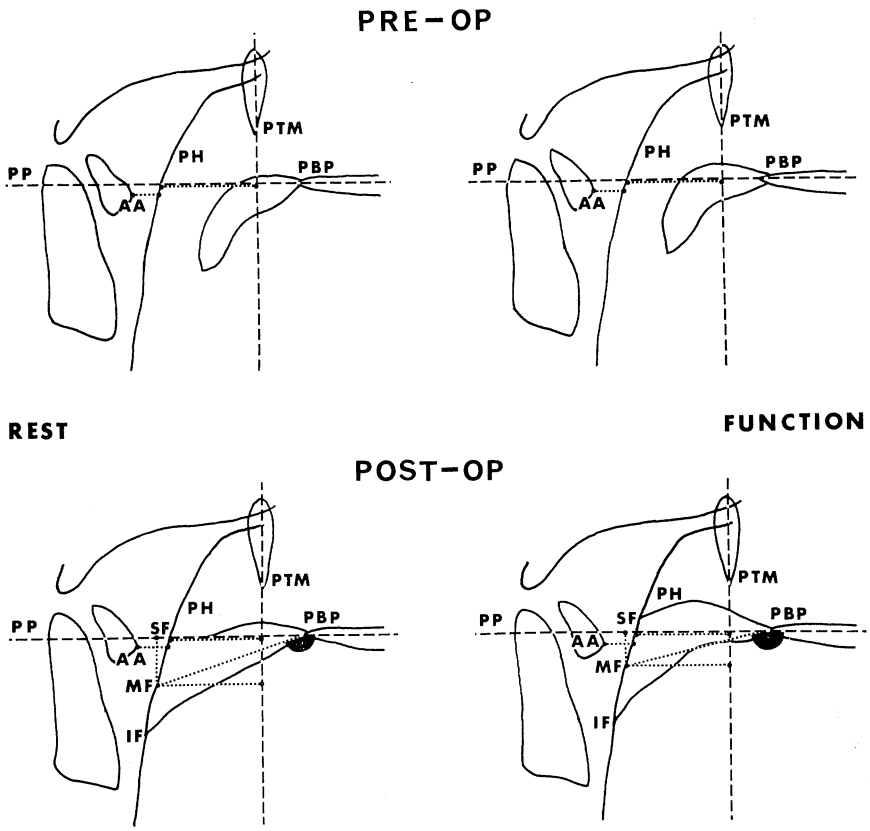

FIGURE 3. Pre-operative pharyngeal measurements of rest and function included: anterior superior point of the Atlas to posterior pharyngeal wall parallel to palatal plane (AA-PH); and PTM to posterior pharyngeal wall on palatal plane (PTM-PH). Post-operative measurements included: superior to inferior point of the flap attachment (SF-IF); midpoint of pharyngeal flap attachment to palatal plane (MF-PP) and to PTM (MF-PTM); and measures (AA-PH) and (PTM-PH) as described. The Line MF-PBP at rest and in function defined angular position of the flap attachment relative to the palatal plane (PP-PBP-MF).

evident in the flap as well as the lateral pharyngeal walls. In this group of unsuccessful speakers, a faulty relationship between the mobile flap and lateral walls seemed to account for the speech failure. These observations are described simply to emphasize that movement as well as proper relationships of structural components is important to the success of surgery, as it pertains to speech function.

Cephalometric Comparisons /u/ and /s/. Because velar and flap positions and movements were studied during production of two sounds, a two way comparison of data was needed. The first involved individual comparisons between measures for /u/ and/s/ to determine whether or not a functional difference in valving existed relative to the

sound produced in pre-operative and in post-operative conditions. The second involved individual comparisons between pre and post-operative measures for each respective sound.

Measures of velar and flap position and mobility during production of /u/ and /s/ are reported and compared in Table 1. Pre-operatively, velar position for /u/ and /s/ averaged 169° and 162° respectively, with more movement recorded during vowel (28°) rather than /s/ production (20°). The associated t values show the higher velar position and greater degree of movement for the vowel was significant at the .01 level. It appears, therefore, that the full potential for velar elevation was not consistently expressed during sibilant articulation. Comparisons of standard deviations for pre-operative mobility measures also show velar function varied to a greater extent during attempted articulations of /s/. Post-operatively, flap positions and mobility were identical for /u/ and /s/.

Since the majority of subjects with marked palatopharyngeal deficits showed less mobility during sibilant articulation before surgery, it is concluded that reliable radiographs defining potential for velopharyngeal closure frequently may not be obtained if stringent physiologic

TABLE 1. Comparative analysis of data defining velar and flap position and movement during production of /u/ and /s/.

measurement	*/u/*	*/s/*	*paired difference /u/ − /s/*	*t*
	n 60	n 52	n 52	
Pre-operative				
Velar Position (angular)				
Mean	168.98°	161.69°		
SD	16.01°	18.65°		
Velar Movement (angular)				
Mean	28.49°	19.93°	7.24°	3.252**
SD	15.16°	20.25°	16.05°	
Velar Movement (linear)				
Mean	5.69mm	4.16mm	1.38mm	3.096**
SD	3.10mm	4.18mm	3.22mm	
Post-operative				
Flap Position (angular)				
Mean	164.68°	165.30°		
SD	14.45°	15.74°		
Flap Movement (angular)				
Mean	21.87°	21.88°	−.64°	.429
SD	13.09°	13.68°	10.66°	
Flap Movement (linear)				
Mean	4.61mm	4.70mm	−.27mm	.747
SD	2.93mm	3.12mm	2.56mm	

requisites for sibilants cannot be met. In some instances, greater mobility during /s/ was observed, as recently noted by Pruzansky and Mason (*9*). The latter investigators have attributed this finding to the "stretch factor" in soft palate function. Regardless of explanation, the clinical implication of the pre-operative differences in velar mobility occurring as a function of the sound produced seems quite clear. To obtain reliable diagnostic information before surgery, several films should be obtained to appraise function.

Pre and Post-Operative Comparisons. Pre and post-operative measures of the velum in rest position (Table 2) showed no significant shift in position after surgery. The flap, however, tended to be in a slightly higher position in the oropharynx or in a more obtuse angular position relative to the palatal plane after surgery. Thus, the posterior attachment did not lower, but rather slightly raised velar-flap position at rest.

Comparisons of velar and flap movement for vowel phonation revealed reduction in movement post-operatively, which was significant

TABLE 2. Pre and post-operative comparisons of data defining velar or flap position and movement.

measurement	*n*	*pre-op*	*post-op*	*paired difference (pre-post)*	*t*
Angular Position (velum or flap)					
Rest					
Mean	60	140.70°	142.70°	−2.00°	1.866
SD		12.79°	12.80°	8.30°	
/u/					
Mean	60	168.98°	164.68°	4.07°	2.638*
SD		16.01°	14.45°	11.94°	
/s/					
Mean	52	161.69°	165.30°	−3.61°	1.635
SD		18.65°	15.74°	15.90°	
Angular Movement (rest → /u/)					
Mean	60	28.49°	21.87°	6.59°	
SD		15.15°	13.09°	14.00°	
(rest → /s/)					
Mean	52	19.93°	21.88°	−1.95°	0.811
SD		20.25°	13.68°	17.36°	
Linear Movement (rest → /u/)					
Mean	60	5.69mm	4.61mm	1.09mm	2.869**
SD		3.10mm	2.93mm	2.93mm	
(rest → /s/)					
Mean	52	4.16mm	4.70mm	−.54mm	1.012
SD		4.18mm	3.12mm	3.80mm	

at the .01 level. Linear measures showed essentially the same thing—movement was diminished after surgery.

Pre and post-operative comparisons of measures for /s/ showed no reduction in movement after surgery. This finding may be explained by the limited mobility for /s/ before surgery. Pre-operatively, the full potential for movement was not consistently expressed, probably because maximum effort resulted in distorted sibilants. After surgery, the flap effectively reduced nasal airflow and acceptable sibilants could be produced; hence, greater elevation and muscle activity was expressed.

The generalized effect of surgery upon velar mobility is perhaps most clearly revealed by comparative study of submucous cleft palate subjects with no past history of palate repair. Despite marked palatopharyngeal gaps comparable in size to those observed in other subjects, submucous speakers generally had better velar and pharyngeal mobility before surgery. For this group, velar mobility averaged 33° pre-operatively; flap mobility averaged 23°. Since this reduction in movement is greater than that observed in other cleft groups, additional support is provided for the conclusion that flap surgery generally reduced velar mobility.

Pharyngeal Analysis. Pharyngeal measures were secured to define the depth of the pharynx and to determine whether or not the elevation of pharyngeal tissue for flap construction reduced the anterior posterior dimension of the pharynx at the level of the palatal plane. For the same purpose, a second measurement of tissue overlaying the tubercle of the atlas was made at a slightly lower site, especially in younger patients with less mature skeletal growth.

Statistical comparisons of pre and post-operative measures by paired difference (Table 3) showed pharyngeal depth was shorter (.01 level) and tissue overlaying the atlas increased (.01 level) after surgery. It is concluded, therefore, that the operative technique had a favorable effect in reducing pharyngeal dimensions as defined by lateral film projection. The observed reduction may be attributed to healing down of raw pharyngeal tissues or to scarring in the region of the donor site. If such is the explanation, a slight forward traction of the pharyngeal wall or thickening of tissue in the region of the palatal plane and the anterior tubercle of the atlas may be anticipated. A slight reduction in the muscular width of the pharynx might also be postulated for the same reasons.

The midpoint of flap attachment averaged approximately 16 mm below the palatal plane at rest, 14 mm during /u/, and 11 mm during /s/ production. On the basis of these measures, the pharyngeal attachment moved or was pulled upward during function, with maximum movement identified with sibilant articulation.

The vertical extent of pharyngeal attachment at rest varied markedly from 6.5 to 36.5 mm (mean 20.71, sd 5.27). It may be postulated that the

TABLE 3. Summary of pre and post-operative measures of the pharynx during rest and during production of /u/ and /s/.

measurement	*pre-op*	*post-op*			*paired difference*	*t*
	(Rest) n 59	(Rest) n 59			(Pre-Post) n 59	
Pharyngeal Depth (PTM-Phar.)						
Mean	22.66mm	21.68mm			.99	3.194**
SD	5.20mm	4.60mm			2.38	
Tissue Overlay (Atlas)						
Mean	5.60mm	7.49mm			−1.89	7.846**
SD	2.73mm	2.63mm			1.85	
			(/u/) n 59	(/s/) n 49	(/u/ − /s/) n 49	
Flap Attachment						
Vertical (SF-IF)						
Mean		20.71mm				
SD		5.27mm				
Flap Position						
Angular (Midpt.-PBP)						
Mean		151.96°	155.66°	160.43°	−3.28	3.543**
SD		10.38°	11.17°	10.95°	6.47	
Vertical (Midpt.-PP)						
Mean		15.70mm	13.68mm	10.97mm	1.94	3.082**
SD		6.33mm	6.66mm	6.49mm	4.40	
Anterior (Midpt.-PTM)						
Mean		25.03mm	25.31mm	24.49mm		
SD		3.81mm	4.04mm	4.61mm		

extent of attachment is partially determined by scarring which in turn may depend upon many factors such as: differences in the management of the donor site, flap lining, and inevitable individual differences in tissue response to surgery. Regardless of explanation, pertinent questions are suggested by the observations reported. Does the flap move less efficiently in patients presenting radiographic evidence of massive scar areas? Is the large area of attachment a favorable factor in reducing nasal airflow and nasality? Is flap mobility significantly related to speech success? What factor or factors can be identified with flap mobility and speech success? Because answers to these and other questions appear pertinent to surgical technique, further study employing statistical correlations was undertaken.

Factors Related to Flap Mobility. Coefficients of correlation between

TABLE 4. Coefficients of correlation between pre and post-operative measures of velar and pharyngeal flap mobility and between other variables of interest as they relate to flap mobility and post-operative nasality rating.

variables	*n*	*r*
pre vs post-operative mobility (angular)		
/u/	60	+.512**
/s/	52	+.534**
pre vs post-operative mobility (linear)		
/u/	60	+.530**
/s/	52	+.485**
flap mobility /u/ vs site of flap attachment	59	NS
flap mobility /u/ vs extent of flap attachment	59	NS
nasality rating vs flap mobility /u/	58	NS
nasal emission rating vs flap mobility /s/	50	NS
nasality rating vs flap position /u/	58	NS
nasality rating vs site of flap attachment	57	NS
nasality rating vs extent of flap attachment	57	NS
nasality rating vs post-op pharyngeal depth	57	+.305*

pre and post-operative measures of mobility (r = .51 for /u/ and r = .53 for /s/) revealed positive relationships significant at the .01 level (Table 4). Since a number of factors other than velar mobility can influence mobility of the flap, very high correlations between pre and post-operative measures of movement probably could not be expected. The pertinent point is that patients with good velar mobility before surgery generally had good flap mobility after surgery. Thus, if good velar movement exists before surgery, the prognosis appears good for a mobile flap. This conclusion remains defensible despite previous data showing that the extent of movement generally was reduced after surgery. In summary, velar mobility before surgery definitely is a factor related to flap mobility.

Two other factors investigated as possibly related to flap mobility were site and vertical extent of flap attachment. The basic questions posed were as follows: Do lower pharyngeal attachments restrict the upward pull of levators resulting in proportionately less flap movement? Do broad vertical areas of attachment retract, but also bind flap elevation? The two correlations germane to these areas of inquiry (Table 4) provide statistical support for negative answers: Mobility of the flap was not significantly related to either the site or the extent of pharyngeal flap attachment.

Factors Related to Non-Nasal Speech. Since movement is considered essential to palatopharyngeal valving in normal speech, it may be assumed that speakers showing greater flap mobility would be less nasal than speakers with immobile or less mobile pharyngeal flaps. Likewise, speakers with mobile flaps theoretically would be more successful in curtailing nasal airflow during sibilant production, hence, they should

have less audible nasal emission during speech than speakers who cannot efficiently move the flap to close the nasopharyngeal port.

No support for either assumption was provided by correlated study. Nasality ratings and flap mobility were not significantly related. Nasal emission ratings and flap mobility were not related. In short, a meaningful relationship between specific and isolated measures of flap movement and speech quality could not be statistically established.

Four other factors were posed as potentially related to nasality. These included: a) flap position during function; b) site of flap attachment; c) extent of attachment, and; d) pharyngeal depth. Respective correlations (Table 4) showed the first three variables were unrelated to speech quality. Pharyngeal depth, however, was significantly related to post-operative speech quality with shorter dimensions identified with less nasality. In summary, with the exception of pharyngeal dimensions, the isolated factors investigated were not found to be statistically related to post-operative speech quality.

The results of correlated study are interpreted as follows: Adequate valving after pharyngeal flap surgery seems to require appropriate relationships established between the flap and pharyngeal structures which will facilitate satisfactory valving effected by: flap movement, mesial movement in the lateral pharyngeal walls, and/or combinations thereof. For this basic reason, isolated measures of flap movement represent an incomplete index of valving efficiency.

It is not the extent of movement of any single structural component, which ultimately determines valving efficiency. In some instances, marked flap movement is insufficient to functionally obturate large pharyngeal ports. In other instances, minimal flap movement is adequate because it is associated with synchronous movement occurring in contiguous structures or because minimal movement is enough to functionally obturate a small pharyngeal isthmus. Since total efficiency of pharyngeal obturation depends upon varying degrees of movement occurring in isolation or in conjunction with other contiguous structures, a high correlation between any single index of movement and speech would not be anticipated and was not realized.

Tracings for two speakers reproduced in Figure 4 illustrate the futility in attempting to relate the isolated factor of flap mobility to speech. Speakers A and B both have broad vertical pharyngeal attachments located below the level of the palatal plane. Speaker A is differentiated from B by: nasalized speech, a much greater extent of flap movement (32.5°), and a much larger anterior posterior dimension of the pharynx (26 mm). The nasalized speech is attributed to the exceptionally large and immobile pharyngeal environment rather than to the lack of flap mobility.

Although the flap moved much less (14°) in Speaker B, the limited movement was identified with satisfactory valving and good speech. In

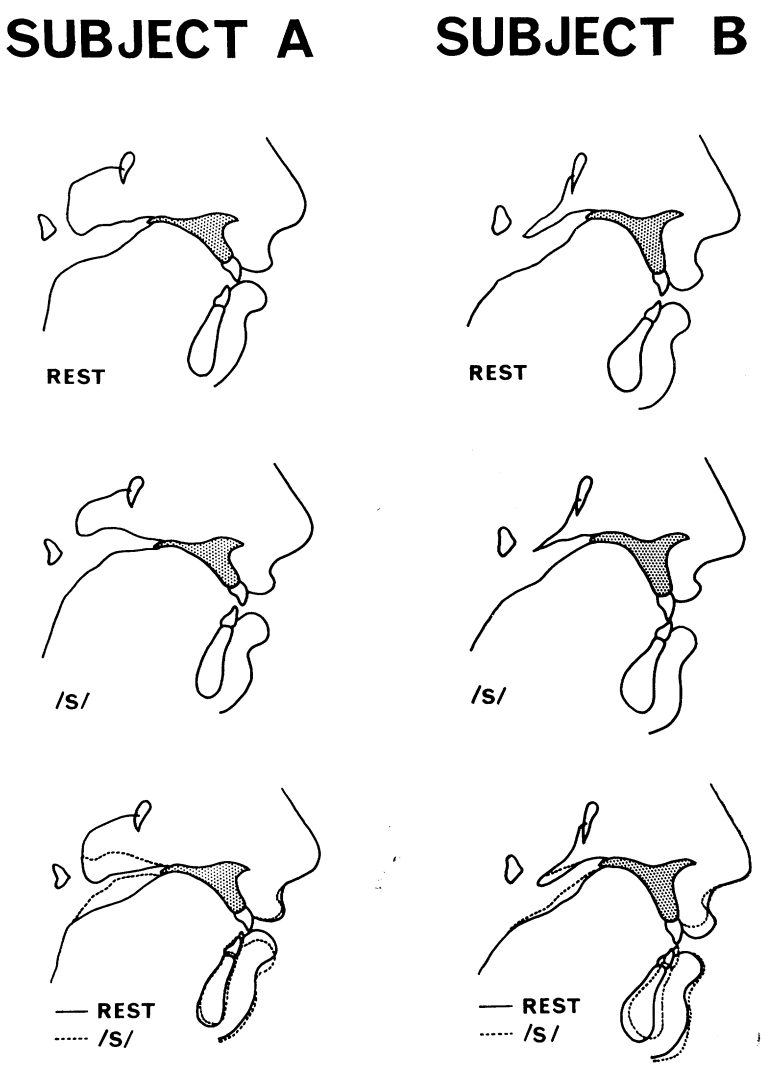

FIGURE 4. Cephalometric tracings of two male subjects. Subject A is differentiated from B by a larger pharynx, more mobile flap, and nasalized speech.

short, a lesser degree of flap movement appropriately modified a much shorter antero-posterior pharyngeal dimension (13 mm). Satisfactory speech is therefore attributed primarily to the favorable size and mobility of the pharyngeal environment.

Cineradiographic Analysis. In overview, cineradiographic observations have strengthened and expanded the concept that single isolated factors cannot definitely be related to post-operative speech status. For purposes of organization, cine observations are categorized by character and site of pharyngeal constriction.

Total or partial blending of flap and pharyngeal tissues at, slightly above, or slightly below the level of the palatal plane occurred in 53% of the subjects. Thus, a relatively normal type of velopharyngeal constriction, with good speech associated, was observed.

Partial or touch contact established at a site well below the palatal plane occurred in 17% of the subjects. In this group, the flaps did not appear loose enough for levator activity to lift the structure, or the levator activity was simply very deficient. Regardless of explanation, abnormal valving with the flap flattening against the posterior pharyngeal wall at a point closely related to the pharyngeal attachment was observed. When non-nasal speech was attained in this group, it appears that mesial movement in the lateral pharyngeal walls was sufficient to obturate and compensate for deficient flap movement. For some speakers within this group, mesial movement failed to adequately compensate and speech remained nasal.

Very little or no flap movement in the direction of closure occurred in an additional 17% of the subjects. The relatively immobile flaps sometimes appeared excessively thick and sometimes very thin. In either event, the flap structure itself had the appearance of a static bridge of tissue rather than a dynamic muscular unit as described by Broadbent and Swinyard (*2*).

Very large pharyngeal dimensions were identified in 13% of the subjects with half showing very good flap movement and half showing very little movement. On the basis of the latter observation, speech failure is attributed primarily to large pharyngeal dimensions rather than to limited flap movement.

Cine observations generally have indicated that there are different ways in which pharyngeal flaps contribute to adequate valving. In this regard, observations support the conclusions of Morris and Spriestersbach (*7*). Slightly over half the subjects displayed good flap movement approximating the characteristics of velopharyngeal valving observed in normal speakers. By and large, the most outstanding examples of speech failure were identified with slightly mobile or immobile flaps located within excessively large pharyngeal environments.

Discussion

Despite the effectiveness of pharyngeal flap surgery, the results of this study indicate the technique generally does reduce velar mobility as reported by Skoog (*10*). Mobility of the flap is, however, significantly related to the extent of velar movement observed before surgery. For this and other reasons, definitive pre-operative study to appraise the form and function of the velopharyngeal complex seems highly important to intelligent surgical planning and ultimate speech success. In this regard, pharyngeal dimensions as well as velar and lateral pharyngeal movement should be evaluated. Several cephalometric films, rather

than one, are recommended to obtain reliable information relative to velar function and pharyngeal dimensions. Judgements concerning the latter factor may be assisted by referring to cephalometric data defining pharyngeal dimension in normal subjects (*11*).

Since shorter pharyngeal dimensions were identified with less nasality, present findings appear to be compatible with previous research reports (*6, 10*) which have identified age as a factor related to speech success, i.e., younger patients with smaller pharyngeal dimensions may provide a more favorable relationship of structural parts which facilitates adequate valving after surgery. Further study is indicated to investigate the characteristics of pharyngeal environment and combined factors as they relate to speech and operative success.

Summary

Cephalometric films, oropharyngeal examinations, and speech recordings were secured for 60 subjects before and eight months after pharyngeal flap surgery to investigate relationships between: a) pre-operative velar movement and pharyngeal flap movement; b) activity in the lateral pharyngeal walls before and after surgery, and; c) pharyngeal flap movement and success of the operative technique as defined by nasality ratings.

Velar mobility before surgery was significantly related to mobility of the flap. Despite the effectiveness of pharyngeal flap surgery, results indicate the technique generally reduces velar mobility and the anterior posterior aspect of the pharynx. Shorter pharyngeal dimensions were identified with less nasality. The latter finding emphasizes the relative importance of pharyngeal environment and its influence upon post-operative speech status. Although isolated measures of flap mobility could not be established as statistically related to nasality, the overall results of study support the concept that mobility of the flap and/or adjacent structures is generally essential to satisfactory speech.

Joanne D. Subtelny, Ph.D.
Eastman Dental Center
800 Main Street East
Rochester, New York 14603

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