A Cinefluorographic Study of Velopharyngeal Function in Normals During Various Activities

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Operation of the velopharyngeal mechanism to provide separation of the oral and nasal cavities presumably is involved in such varied activities as speech, swallowing, sucking, and blowing. Results of a number of investigations, however, suggest that velopharyngeal functioning may not be the same for all of these activities. For example, various investigators (*1–4, 8, 9*) have concluded that more extensive movements of the pharyngeal walls and more frequent occurrence of a definite Passavant's ridge are involved in swallowing than in speech production. Bloomer (*3*) concluded that the activity of blowing resembled speech in relation to velopharyngeal function. Warren and Hofmann (*12*), however, found consistently greater velar elevation on blowing than during phonation. Bloomer also reports that the closure mechanism while sucking liquid is like that observed for swallowing, although more recent data have been reported (*7*) which indicate that velopharyngeal closure may not be required for sucking liquids.

The differences which have been observed in velopharyngeal function for different activities appear to have important implications in the assessment and treatment of velopharyngeal incompetence in individuals with cleft palates. The observation reported by a number of investigators (*1, 2, 7*) that an individual may achieve closure on swallowing even though he exhibits grossly inadequate closure during speech suggests that a decision concerning closure adequacy may depend on the activity used in assessment. A similar conclusion might be drawn concerning the use of different activities as therapeutic exercises to develop velopharyngeal closure for speech.

The purpose of the present study was to investigate possible differences in how velopharyngeal closure is attained by normal subjects dur-

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ing different activities. Although some of these activities have been studied previously, the results often have been contradictory or inconclusive. It should be noted that no attempt was made in this study to describe the different activities except in relation to the closure mechanism. For example, pharyngeal wall movements not associated with velopharyngeal closure in such activities as swallowing were not analyzed.

Procedure

The subjects utilized in this study were 10 adults (six females and four males) who exhibited no deviant speech patterns and who had no known anatomic or physiologic abnormalities. Cinefluorographic films were taken at 24 frames per second while each subject performed various tasks which are described below:

Speech: Production of the following syllables in the carrier sentence, 'Say_____again.'

/sup/ /sæp/ /tup/ /tæp/ /lup/ /læp/

Swallowing

1. Swallowing liquid
2. Swallowing solid

Blowing on Oral Manometer

1. Without air bleed
   a. Maximum pressure
   b. Half maximum pressure
2. With air bleed
   a. Maximum pressure
   b. Half maximum pressure

Sucking on Oral Manometer

1. Without air bleed
   a. Maximum pressure
   b. Half maximum pressure
2. With air bleed
   a. Maximum pressure
   b. Half maximum pressure

Sucking Liquid: Barium liquid sucked through a straw

1. With immediate swallow
2. With delayed swallow

Puffing Cheeks

Gagging: Subject was gagged by placing a tongue blade against the posterior pharyngeal wall.

The speech samples were constructed so as to include various types of consonant and vowel sounds, although no nasal consonants were used. Blowing and sucking tasks on the oral manometer were performed both with and without an air bleed in the system and the subjects were instructed to produce two levels of positive or negative pressure: the maxi-

mum they could produce and one-half that maximum, measured in ounces per square inch. When sucking liquid through a straw, the subjects were first asked to suck and swallow normally and then to suck and delay the swallow. The order of the experimental conditions was randomized for each subject separately, although blowing and sucking at maximum pressure had to be accomplished before the half-maximum conditions could be defined. In addition, sucking liquid and the swallowing activities were always performed last so that the barium solution used would not interfere with observations of structures during the other conditions.

The cinefluorographic films were analyzed by frame-by-frame tracings and measurements. During the speech samples, frames associated with the consonant and vowel in the test syllable were traced. For swallowing and gagging, frames associated with closure of the velopharyngeal port were analyzed. During the manometer tasks and puffing, three frames were analyzed from the middle of the activity. For the condition of sucking liquid, frames showing the liquid coming up the straw were traced.

To evaluate velar activity, a measure of velar height, shown in Figure 1, was made from each tracing. This measure was made in millimeters between the most superior point on the velum and a reference line established between the anterior nasal spine and the juncture of the pterygomaxillary fissure and the superior surface of the hard palate. No measurements were made to assess differences in pharyngeal participation in velopharyngeal closure due to the difficulty in describing by specific measures the complex contours assumed by the pharyngeal wall. Instead, superimposed tracings from the films of the same subject in different conditions were examined.

Results and Discussion. The findings of this investigation will be discussed first in terms of the type of closure mechanism observed. In general, two grossly different mechanisms were noted: a) contact between the velum and posterior pharyngeal wall and b) contact between the tongue and the inferior surface of the hard and soft palates. The number of subjects exhibiting these two mechanisms during the various experimental tasks are presented in Table 1. It can be noted that during

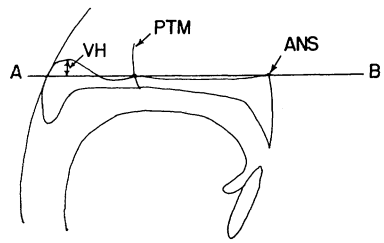


FIGURE 1. Line drawing of a cinefluorographic frame showing the measure of velar height (VH) made in this study.

TABLE 1. Number of subjects who utilized velopharyngeal closure or tongue-palate valving during the various experimental tasks. Two subjects did not exhibit gag reflex during the experimental procedure.

Experimental Task	*No. of Subjects Exhibiting*	
	Veloph. Closure	*Tongue-Palate Contact*
Speech	10	0
Swallowing (liquid and solid)	10	0
Blowing on Manometer (all conditions)	10	0
Sucking on Manometer		
1. Without air bleed		
a. Maximum pressure	3	7
b. Half maximum pressure	2	8
2. With air bleed (both pressures)	8	2
Sucking Liquid	0	10
Puffing Cheeks	3	7
Gagging	8	0

speech, swallowing, gagging, and all blowing tasks each subject exhibited velopharyngeal closure. The activity of sucking, however, appeared to involve a different mechanism in many subjects. When required to build up negative pressure on the oral manometer, without an air bleed, lingual-palatal contact only was observed for seven subjects when producing maximum pressure and for eight subjects when producing half the maximum pressure. The introduction of an air leak in the system had a definite effect on the mechanism used. All but two of the subjects who exhibited tongue-palate valving in the without-bleed conditions shifted to velopharyngeal closure when the leak was introduced. When sucking liquids, none of the subjects achieved velopharyngeal closure during the time at which the liquid was being drawn into the oral cavity; only a tongue-palate valving was utilized. This was true whether swallowing of the liquid was immediate or delayed. For puffing the cheeks, seven of the subjects exhibited tongue-palate valving, while three utilized velopharyngeal closure.

The use of lingual-palatal valving for puffing the cheeks is consistent with the observations of Bloomer (*3*) that velopharyngeal closure is not required to perform this activity. The findings for sucking tasks, however, are not in agreement with those of Bloomer, who observed velopharyngeal closure during sucking. This inconsistency may have resulted from the fact that Bloomer, observing the mechanism from above through a carcinoma opening, could not separate the sucking activity from the swallow which followed it. Velopharyngeal closure is achieved when the liquid is swallowed even though it is not observed during liquid intake. Such an explanation would account for Bloomer's conclusion that closure during sucking resembles that observed for swallowing. From the

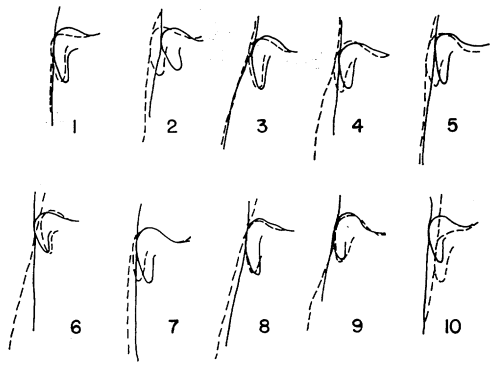


FIGURE 2. Superimposed tracings for 10 normal subjects showing the positions of the posterior pharyngeal wall and velum when velopharyngeal closure was achieved during speech (solid lines) and during swallowing (dotted lines).

present study, however, it appears that the normal mechanism utilized in sucking liquids is tongue-palate valving and not velopharyngeal closure.

Because few, if any, subjects achieved closure during some activities, further analyses of differences in velopharyngeal function were restricted to those conditions during which closure was achieved by most subjects; that is, speech, swallowing, blowing, gagging, and sucking on the manometer with an air bleed.

SWALLOWING. Figure 2 shows superimposed tracings of the velar and pharyngeal wall positions when closure is achieved during swallowing and during speech. Only findings for the task of swallowing liquid will be discussed since the results for swallowing solids are quite similar. Although the average velar elevation for the subject group was somewhat less on swallowing than on speech, the difference was not statistically significant. The inter-subject variability in velar elevation between the two tasks can be seen in Figure 2. Two of the subjects (№1 and №10) exhibit a difference in velar position between speech and swallowing; the velum is much lower on swallowing and makes contact at a more inferior point on the posterior pharyngeal wall. In addition, subject №10 shows a great amount of anterior movement of the posterior wall over a fairly great vertical extent. Except for that subject, there appear to be no large differences between pharyngeal wall activity on the two tasks; however, it can be noted that the wall often is at a more posterior position for swallowing than for speech. This is most noticeable for Subjects №2, №4, №5, and №7 in Figure 2. It is possible that this observation may not reflect actual posterior movement of the wall but may be due to slight changes in the relative positions of the anterior cranial structures and the pharynx. For example, a slight upward tipping of the chin during swallowing, which might occur even though a head positioner was utilized, or a movement of the body could account for this observation.

It is interesting to note that no distinct Passavant's bar was observed, although it has been described (*9–11*) as being typical of swallowing. It appears possible that these investigators may not have distinguished between the pharyngeal activity involved in closure of the nasopharynx and that occurring in later stages of swallowing. Roberts (*9*) describes a 'stripping' action of the pharynx later in the swallowing sequence in which a bulge is formed which moves down the pharyngeal tube. This phenomenon also was observed in this study. The present results, however, do not support the contention that closure of the velopharyngeal port during swallowing in most normal subjects involves more anterior movement of the posterior pharyngeal wall than that observed during speech production. In addition, comparison of cinefluorographic frames during speech with those at rest corroborate the conclusion of Hagerty and others (*5*) that movements of the posterior pharyngeal wall during normal speech are minimal.

The fact that very few differences in velopharyngeal function were observed between swallowing and speech is somewhat surprising in view of previous observations (*1, 2, 7*) that these two activities are grossly different in cleft palate subjects. Subject ℵ10, who exhibited a much different mechanism for swallowing than for speech, also exhibited opening of the nasopharyngeal port during many of the consonant and vowel sounds studied. This observation suggests the hypothesis that this subject may not have completely normal structures or structural relationships. Furthermore, if this is true, the suggestion is that velopharyngeal function during swallowing is different from that during speech only for individuals with abnormal mechanisms. As a partial check on this hypothesis, cinefluorographic films on five individuals with repaired cleft palates who were known to exhibit gross velopharyngeal inadequacy during speech were analyzed. Superimposed tracings of structural positions on swallowing and phonation are shown for these

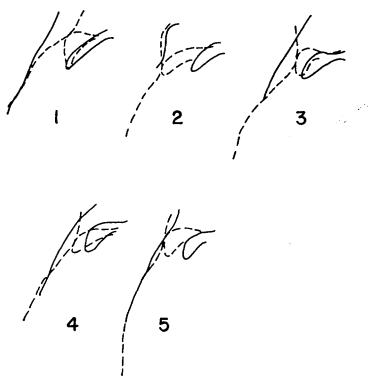


FIGURE 3. Superimposed tracings for five subjects with velopharyngeal incompetence showing the positions of the posterior pharyngeal wall and velum during speech (solid lines) and during swallowing (dotted lines).

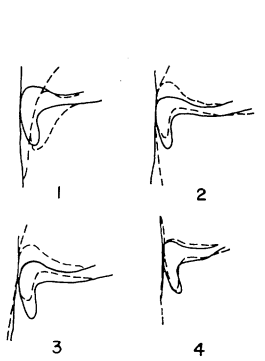
subjects in Figure 3. It can be noted that closure is achieved during swallowing by all of these subjects even though they exhibit wide openings of the port during speech. This is accomplished by increased velar movement and by marked anterior movement of the posterior pharyngeal wall. However, for Subject #5 the primary difference between speech and swallowing is velar position; the posterior wall positions are not appreciably different. The development of a pad on the posterior wall during swallowing is likely to represent a compensatory activity developed to achieve velopharyngeal closure. The question might be posed, however, regarding why such a mechanism is not used during speech and, further, why velar movement is greater during swallowing. Further observations revealed that for all five of the cleft subjects the tongue was in contact with the undersurface of the velum throughout the entire time that closure of the port occurred during swallowing. This was not the case for any of the normal subjects. In the cleft subjects the velum is 'swept' upward against the wall by the posterior portion of the tongue. Obviously such compensatory tongue activities cannot be used effectively during speech to close the velopharyngeal port, since the tongue must be utilized for sound articulation. As a result, the inadequate velum does not come close to the pharyngeal wall. In addition, it is likely that the lack of appreciable movement of the posterior wall during speech is due to the fact that such movement probably would achieve little in bringing about closure. This observation tends to support the frequent impression that Passavant's pad appears during speech primarily in individuals in whom there is some chance to achieve closure by such movement.

Blowing and Sucking. There also appear to be certain differences between velopharyngeal function for blowing and sucking than that observed during speech. Comparison of blowing and speech indicated that velar elevation is approximately two to three millimeters greater, on the average, for all of the blowing tasks. These differences were statistically significant ($p < .05$). However, elevation during sucking with an air bleed is not significantly different from that during phonation. The greater elevation observed for blowing is in agreement with the findings of Warren and Hofmann (*12*). Two hypotheses might be posed to explain this difference. First, greater effort may be expended during blowing which results in greater velar elevation. The alternate hypothesis is that the greater air pressures developed in the oral cavity during blowing force the velum higher. The velum is somewhat lower when a subject is required to produce only half the maximum pressure he can attain, although the differences in elevation are not statistically significant. However, this observation could reflect the use of less muscular effort during this task as well as decreased intraoral pressure. The fact that sucking did not create as much velar elevation as blowing may indicate that the effect of intraoral pressure offers the best explanation for these findings, although the efforts utilized in blowing and sucking

also may not be identical. Investigation of these two hypotheses will require further research.

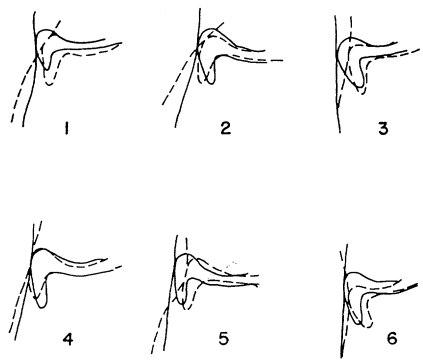
Superimposed tracings comparing blowing and speech are shown for four subjects in Figure 4. In relation to pharyngeal wall movement on all of the blowing tasks and on sucking with air bleed, the subjects can be grouped into three categories. Subject #1 showed more anterior movement of the wall for all of these tasks than for speech. This movement occurred over a great vertical distance. Four of the subjects showed forward positioning of the wall which occurred only above the site of velar contact. This is demonstrated by the tracings for Subject #2 in Figure 4. This observation may likely be related to the increased velar movement on blowing. Possibly the velum contacts the wall with more force than during speech causing the wall to 'buckle' forward above the site of contact. Findings for the remaining five subjects are demonstrated by the last tracing in Figure 4; there were no appreciable differences between pharyngeal wall activity during speech, blowing, or sucking.

GAGGING. When the gag reflex was elicited, velopharyngeal closure occurred in eight of the 10 subjects. In the other two subjects it appeared that the gag was not truly elicited. Although analysis of the velar elevation measures showed no significant difference between speech and gagging, Figure 5 indicates that there was a great deal of individual variation in velar movement. For example, the velum is much lower during gag than during speech for the last subject shown. The most consistent finding concerned differences in posterior pharyngeal wall position. Although one of the subjects (Subject #4 in Figure 5) exhibited little



BLOWING

FIGURE 4.



GAGGING

FIGURE 5.

FIGURE 4. Superimposed tracings for four normal subjects showing the positions of the posterior pharyngeal wall and velum during speech (solid lines) and during blowing tasks (dotted lines).

FIGURE 5. Superimposed tracings for six normal subjects showing the positions of the posterior pharyngeal wall and velum during speech (solid lines) and during gagging (dotted lines).

difference in wall position between speech and gag, the wall was at a more anterior position for gagging for the remainder of the subjects. For the first three subjects shown, the superior portion of the pharyngeal wall is simply sloped forward during gag. As mentioned previously in the discussion of swallowing, this change in wall position may be related to slight changes in head position. For the last two subjects, however, the occurrence of a definite pad on the posterior wall is suggested.

General Discussion

As in any cinefluorographic investigation the findings of this study are limited by the fact that observations were made in only two dimensions. Despite this limitation, however, the results are relatively consistent and indicate that closure of the velopharyngeal port does not involve the same mechanism for all of the activities studied. Such differences appear to have certain implications for selection of activities to be used in the assessment and treatment of velopharyngeal incompetence.

In evaluations of velopharyngeal adequacy, it is obvious that the ability to suck liquid through a straw or to puff the cheeks does not reflect the ability to achieve velopharyngeal closure, since these tasks can be accomplished with only tongue-palate valving. In fact, such valving appears to be the normal mechanism utilized in sucking liquid. Although velopharyngeal closure was observed during all blowing tasks in this study, previous investigation (*7*) indicates that individuals with inadequate mechanisms can perform such tasks under certain conditions by utilizing lingual-palatal contact. Further, even on tasks in which velopharyngeal closure may be achieved, such as swallowing, blowing, and gagging, observations concerning velar and pharyngeal movements may not accurately reflect the situation during speech production. All of these activities appear to involve somewhat more pharyngeal wall activity and, in the case of blowing, more velar elevation than occurs in speech production.

The differences observed between various tasks also appear to cast considerable doubt on the validity of using sucking, puffing, and blowing activities to develop velopharyngeal closure for speech. In the first place, such tasks may not require the individual to utilize velopharyngeal closure; tongue-palate valving may be used. Even if the velopharyngeal mechanism functions during some of these tasks, this function appears to be somewhat different from that observed during speech. Such tasks may be helpful in 'strengthening' presumably weak musculature in this mechanism; however, as pointed out by Kantner (*6*), the development of closure on these tasks may not generalize to speech production, which involves a somewhat different mechanism.

The results of this study also indicate that individuals with inadequate velopharyngeal closure may develop compensatory mechanisms which allow them to perform some of the nonspeech activities adequately. It

appears, however, that such mechanisms as tongue-palate contact and the use of the tongue to push the velum upward cannot be utilized effectively during speech production. These findings suggest the need for further research which is designed to compare different activities in individuals with inadequate velopharyngeal mechanisms. Such research may reveal even more differences between various activities. At this point, however, there apparently is no validity in assuming that velopharyngeal function in normal subjects is the same regardless of the task performed. Moreover, the assumption that the closure mechanisms of normal subjects on various tasks are the same as those utilized by individuals with velopharyngeal inadequacy is probably invalid.

Summary

This study was designed to compare velopharyngeal functioning in 10 normal subjects during the following activities: speech production, swallowing, blowing and sucking on an oral manometer, sucking liquid, puffing the cheeks, and gagging. In addition, swallowing and speech production were compared for five individuals with cleft palate who exhibited velopharyngeal incompetence. Cinefluorographic films were taken at 24 frames per second during the performance of these tasks and were analyzed by tracing and measurement of selected frames.

The results of this study can be summarized as follows: a) Puffing the cheeks and sucking can be performed without velopharyngeal closure by utilization of lingual-palatal valving. This latter mechanism was utilized by all normal subjects when sucking liquid through a straw. b) Although few differences were noted between swallowing and speech for the normal subjects, all individuals studied with inadequate velopharyngeal closure during speech obtained closure during swallowing. This was accomplished by compensatory movements of the pharyngeal wall and tongue. c) Blowing tasks result in greater velar elevation for normal subjects than that observed during speech production. d) Pharyngeal wall activity during gagging appears to be somewhat more extensive than that noted during phonation.

The findings of this investigation are discussed in terms of their implications for the assessment and treatment of velopharyngeal inadequacy in individuals with cleft palates. The dissimilarities of activities that make use of the nonspeech tasks for evaluating and exercising the velopharyngeal mechanism of questionable validity are pointed out. In addition, it is emphasized that mechanisms utilized by individuals with incompetent structures may be quite different from those observed in normal subjects. The type and extent of compensatory activities in individuals with cleft palates is suggested as a topic for further research.

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