Velopharyngeal Movement Patterns in Patients Alternating Between Oral and Glottal Articulation: A Clinical and Cineradiographical Study

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ANNIKA M. ISBERG, D.D.S., ODONT. DR.

Eight patients who presented velopharyngeal incompetence and who spontaneously alternated between oral and glottal stop articulation were cineradiographically examined in lateral and frontal projections to compare their oral stops and glottal stop substitutions. A cineradiographic frame-by-frame analysis of the movements of the velum and the lateral and posterior pharyngeal walls was performed. During glottal stop substitutions and coarticulation involving glottal stops and oral lingual or bilabial stop gestures, all patients demonstrated either no velopharyngeal movement or impaired movement, mostly affecting the lateral pharyngeal walls. In contrast, during oral stops, moderate-to-good velopharyngeal movements were produced. Poor quality or absence of velopharyngeal movement associated with glottal stop substitutions may be misinterpreted as weakness or inability to perform motor activity. Presurgical cineradiographic or fluoroscopic analysis of a patient’s speech with regard to velopharyngeal movements should therefore be based on speech sequences free from glottal stop substitutions. A careful speech analysis should also precede presurgical cineradiography.

Glottal stops are, by definition, produced by vocal fold valving (Morley, 1966; Bzoch, 1979; Trost, 1981). Morris (1979) described the glottal stop as an interruption of the air stream at the level of the glottis, releasing a cough-like sound phonetically identified as [ʔ].

Bergendal and Fex (1977) described two different types in the Swedish language: (1) The “phonatory” glottal stop, used to initiate phonation and also called the “hard attack.” It was suggested that this should be regarded as a vocal phenomenon without linguistic significance.

(2) The “phonemic” glottal stop arises when there is inadequate intraoral air pressure for the production of plosive sounds such as /p, t, k/ and /b, d, g/. In such cases the stop is produced below an insufficient velopharyngeal closure, i.e., in the glottis. The authors suggested that this form of glottal stop should be regarded as “a distinctive feature in the realization of the phoneme.” In many languages glottal stops are used as phonemes and not as a substitution (Morley, 1966). In this study the glottal stop is a phoneme substituted for an oral stop. Glottal stops that form articulatory substitutions are most frequent in cleft palate speakers (Bzoch, 1965); in this case they are thought to compensate for poor velopharyngeal closure or function (Morris, 1968; Morris, 1979; Bzoch, 1979) by placing an obstruction, the vocal folds, in the way of the outgoing air stream to impede the air flow and develop the breath pressure used in producing the stop (McDonald and Koepp Baker, 1951).

A closely related compensatory behavior is
glottal coarticulation, i.e., a glottal pulse formed in combination with lip or tongue articulation (Morley, 1966; Bzoch, 1979). In this study, the term glottal coarticulation will only be used when articulation of the lips or tongue can be seen to occur in combination with the glottal stop.

There is a lack of information about the relationship between glottal articulation and velopharyngeal function. The purpose of this investigation was therefore to examine cineradiographically registered movements of the velum and the pharyngeal walls during production of oral stops, glottal stop substitutions, and coarticulation of glottal stops with lingual or bilabial stop gestures. In each case, the vowel following the stop was also studied. Velopharyngeal movements during oral and glottal stops were to be compared.

**METHODS**

**Patients**

From 80 patients consecutively evaluated, ten produced glottal stops who were selected for study. Two of these patients suffered from congenital neurological disturbances resulting in dysarthric speech and were excluded from this study. The remaining eight patients spontaneously produced both glottal stops and oral stops during connected speech. They were all receiving or had received speech therapy for glottal articulation. Two patients had submucous clefts, one of them surgically treated. Six patients had previously been surgically treated for unilateral complete clefts. One of them demonstrated residual cleft of the hard palate which was covered by an acrylic plate, while another had an uncovered residual cleft involving the alveolar process. Four patients, two adults and two children, had previously undergone velopharyngeal flap surgery. Sex, age distribution, and type of velopharyngeal disorder are presented in Table 1.

**Speech Material**

Short sentences (Table 2), were repeated by each patient. Every patient produced at least six of the sentences listed. The style and content of the sentences were suitable for 3- to 4-year-old children. They included phonemes varying in place of articulation, with emphasis on different stops in combination with high and low vowels, in words such as [pi:pa], [ku:ka], [puta:tis], [ti:sdag].

**Cineradiography**

The movements of the velum and the pharyngeal walls were cineradiographically registered during connected speech. The equipment consisted of an x-ray tube (Bi 150/30/50 R), image intensifier (Siemens Sirecon II), Vidicon camera,
Arriflex cine-camera running 35 mm film and a TV monitor. In the present study 77 or 72 kVp were used. The mAs value was automatically adjusted to achieve optimal attenuation. The cine-camera ran at 25 frames per second. Simultaneous fluoroscopic video recording was obtained. The skin dose, as measured by a calibrated ionization chamber, never exceeded 27 mGy. During cineradiography the head of the patient was immobilized in a cephalostat with earplugs and head and neck supports.

A TV camera simultaneously recorded facial movements to document co-movements and grimaces and also recorded reduced lip movements associated with deviant articulatory patterns (Fig. 1).

The synchronized recordings from the microphone (Sony ECM-50PS electret condenser), the Vidicon camera (the x-ray picture of the velopharyngeal movements) and the TV camera (the view of the facial movements) were transferred to a mixing board and registered on a video tape. The same speech samples were used during cineradiographic recordings in both the lateral and frontal projections. To improve visualization of the soft tissues of the velum and nasopharynx, barium sulphate contrast medium (E Z HD, E-Z-EM Company, Westbury, N.Y.) was applied via the nasal cavity.

Speech Analysis

A perceptual speech analysis of the sound from the videotapes was performed by three experienced speech pathologists independently of one another. The degree of hypernasality and prevalence of glottal articulation, including glottal coarticulation, were evaluated according to a five-point scale (Henningsson and Karling, in press) (Table 3).

The listeners were to mark every glottal stop or glottally coarticulated stop in the speech sample of each patient. When disagreement existed concerning presence of glottal coarticulation, these sounds were excluded from further analysis. Moreover, the presence of glottal stops and glottal coarticulation was double-checked by an investigator from the videorecordings of the facial exterior, by simultaneous analysis of speech sound and lip articulation. The same procedure was used for analysis of lip and tongue coarticulation movements using the cinefluoroscopic

### Table 3 Scales for Rating the Degree of Hypernasality and the Prevalence of Glottal Articulation*

<table>
<thead>
<tr>
<th>Degree of Hypernasality</th>
<th>Description</th>
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<tbody>
<tr>
<td>0</td>
<td>Normal resonance</td>
</tr>
<tr>
<td>1</td>
<td>Somewhat distorted but acceptable resonance</td>
</tr>
<tr>
<td>2</td>
<td>Deviant resonance in need of treatment</td>
</tr>
<tr>
<td>3</td>
<td>Severely deviant resonance in urgent need of treatment</td>
</tr>
<tr>
<td>4</td>
<td>Unintelligible speech due to severe hypernasality</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prevalence of Glottal Articulation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No glottal articulation</td>
</tr>
<tr>
<td>1</td>
<td>Correct position of articulation with some glottal coarticulation</td>
</tr>
<tr>
<td>2</td>
<td>Occasional glottal substitutions and considerable glottal coarticulation</td>
</tr>
<tr>
<td>3</td>
<td>Glottal substitutions in some word positions</td>
</tr>
<tr>
<td>4</td>
<td>Glottal substitutions of most stops</td>
</tr>
</tbody>
</table>

* Henningsson and Karling: In press
recording. Finally, the listeners were asked to mark the most hypernasal words in the speech material of each patient.

**Radiographic Analysis**

All sequences of glottal articulation or glottal coarticulation plus the following vowel were identified on the videotape and cinefilm and selected for detailed analysis. All oral stops with following high or low vowels were selected for comparison.

Accuracy in identifying the specific cine frames corresponding to selected stops was checked. Identification of 499 separate cine frames was repeated three times at intervals of several weeks. Agreement in identifying a frame was found to be 99 percent. When the same frame was identified following at least five such selections, this frame was used for analysis.

A frame-by-frame analysis of the selected cineradiographic sequences was made using a Tagarno 35.3® projector allowing the cinefilm to be run both forwards and backwards at varying speeds. The contours of the velum and pharyngeal walls in the different frames were traced. The movements of the velum and the lateral pharyngeal walls were rated according to a five-point scale (Table 4). The labels "good, moderate, insufficient, poor," and "no activity" were used in the description of the velopharyngeal movements. Tracings of oral stops were superimposed on tracings of glottal stops, along with the following vowels, for comparison. Oral and glottally coarticulated stops plus vowels were likewise compared. The presence of Passavant’s ridge was also noted.

**RESULTS**

**Speech**

The degree of hypernasality and the prevalence of glottal articulation including glottal coarticulation are shown in Table 5. The degree of hypernasality varied between 2 and 3 and the prevalence of glottal articulation between 2 and 4. Six patients (numbers 1, 2, 3, 5, 6, and 8) demonstrated occasional use of glottal coarticulation. The words selected as being the most hypernasal turned out to be words with solely glottal stops and vowels.

**Velopharyngeal Movements**

Ratings of velar and lateral pharyngeal wall movements during oral and glottal stops are reported in Table 6. During glottal articulation, velopharyngeal movements were impaired, especially the movements of the lateral pharyngeal walls (Table 6, Fig. 2).

The movement of the velum in seven patients (numbers 2 to 8) demonstrated good or good/moderate activity during oral articulation, but the movement decreased to insufficient activity during glottal articulation. In one patient (number 1), the velar movement was limited and insufficient during oral articulation because of a low-based and stiff velopharyngeal flap. However, less velar movement was observed during glottal than oral stops. The lateral pharyngeal wall movements in all patients demonstrated good or good/moderate activity when oral stops were produced but insufficient, poor, or no activity during glottal stops.

Movement of the posterior pharyngeal wall was observed during nonglottal articulation in three patients (numbers 2, 5, 6) and was then associated with the formation of a Passavant’s ridge. In only two of these patients (numbers 2

<table>
<thead>
<tr>
<th>TABLE 4 Movement Ratings of the Velum and the Lateral Pharyngeal Walls</th>
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<tbody>
<tr>
<td>Rating</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Good activity</td>
</tr>
<tr>
<td>Moderate activity</td>
</tr>
<tr>
<td>Insufficient activity</td>
</tr>
<tr>
<td>Poor activity</td>
</tr>
<tr>
<td>No activity</td>
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</table>

<table>
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<tr>
<th>TABLE 5 Clinicians’ Rating of Two Speech Parameters</th>
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</thead>
<tbody>
<tr>
<td>Patient Number</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
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<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
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<tr>
<td>8</td>
</tr>
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</table>
TABLE 6 Degree of Velar and Lateral Pharyngeal Wall Movements During Oral and Glottal Articulation

<table>
<thead>
<tr>
<th>Patient Number</th>
<th>Prevalence of Glottal Articulation</th>
<th>Oral Articulation</th>
<th>Glottal Articulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Velum</td>
<td>Lateral Pharyngeal Walls</td>
</tr>
<tr>
<td>1</td>
<td>4 Insufficient</td>
<td>Good</td>
<td>Poor No activity</td>
</tr>
<tr>
<td>2</td>
<td>3 Good</td>
<td>Good/moderate</td>
<td>Insufficient No activity</td>
</tr>
<tr>
<td>3</td>
<td>2 Good</td>
<td>Good</td>
<td>Insufficient</td>
</tr>
<tr>
<td>4</td>
<td>2 Good</td>
<td>Good</td>
<td>Poor Poor</td>
</tr>
<tr>
<td>5</td>
<td>3 Good/moderate</td>
<td>Good</td>
<td>Insufficient Poor</td>
</tr>
<tr>
<td>6</td>
<td>3 Good</td>
<td>Good</td>
<td>Insufficient Poor</td>
</tr>
<tr>
<td>7</td>
<td>4 Good</td>
<td>Good</td>
<td>Insufficient Poor</td>
</tr>
<tr>
<td>8</td>
<td>3 Good</td>
<td>Good/moderate</td>
<td>Insufficient</td>
</tr>
</tbody>
</table>

and 6), did the ridge contribute to narrowing of the velopharyngeal port. In two cases (numbers 5 and 6), the ridge was less prominent during glottal articulation, and it did not always occur in conjunction with velar elevation. In one case (number 2) the ridge was absent.

When glottal coarticulation was observed, as it was in subjects 1, 2, 3, 5, 6, and 8, the velopharyngeal movements were almost as impaired as during glottal stops. Velopharyngeal closure was obtained during production of oral stops in five patients (numbers 2, 3, 4, 7, and 8). The velopharyngeal movements for oral stops in all patients appeared alike regardless of whether the following vowel was high or low. Another consistent finding in all patients was the lack of velopharyngeal closure for all vowels following oral stops, but velar elevation and lateral pharyngeal wall movements were more pronounced for high vowels than for low vowels. During glottal stops, velopharyngeal closure was never obtained, and the velopharyngeal movements showed similar impairment in all patients. Except for /a/, vowels following glottal stops were associated with the same degree of impairment of the velopharyngeal movements as was seen during the production of glottal stops. However, /a/ following a glottal stop was an exception, since associated velopharyngeal movements were unaffected by the glottal surrounding, and good velopharyngeal movements were observed; however, there was not closure.

No compensatory movements of the lips or the tongue were seen during oral articulation. During glottal stops no lip movements were seen at all. The only tongue activity registered was slight movement of the posterior portion of the tongue, and they were part of the movements associated with a forthcoming vowel.

**DISCUSSION**

In clinical assessment, glottal stop substitutions are postulated to be associated with velopharyngeal incompetence (Morley, 1966; Bzoch, 1979; Morris, 1979; McWilliams et al., 1984). The present investigation demonstrated cineradiographically that velopharyngeal incompetence is greater during glottal stops than during oral stops. This was found to be related to the perceptually determined findings of a higher degree of hypernasality in words with glottal stops than with oral stops.

Several authors have claimed that glottal stops in patients with cleft palate are a compensatory mechanism (McDonald and Koepp Baker, 1951; Bzoch, 1979; Morris, 1979; Trost, 1981; Smith and Weinberg, 1983). This study supports the view that the glottal stop is a compensatory mechanism, since the velopharyngeal movements which contribute to velopharyngeal closure during oral speech are grossly impaired during glottal articulation. This impairment was most pronounced in the lateral pharyngeal walls. A further support for the idea of regarding the glottal stop as a compensatory mechanism was our finding that all expected articulatory movements connected with an oral stop, i.e., the movements of the tongue, the lips, and the velopharyngeal structures, were absent or severely impaired when articulation was glottal. However, as soon as an oral stop was produced, expected tongue and lip movements were present in combination with increased velopharyngeal movement, and in five patients even closure.

When a stop is compensatorily produced at the
FIGURE 2  Tracings of velopharyngeal movements from cineradiographic frames in lateral and frontal views for oral and glottal stops. Shadowed areas indicate pharyngeal flap position. Superimposition of tracings for oral (continuous line) and glottal articulation (dashed line) shows impairment of velopharyngeal movements for glottal articulation.
glottis, the velopharyngeal movements obviously
serve no articulatory purpose and thus appear
grossly impaired.

During glottal coarticulation, velopharyngeal
movements were shown in this investigation to
be almost as impaired as during glottal articula-
tion. This indicates the importance of identifi-
ing glottal coarticulation. Unfortunately, glottal
coarticulation appears to be difficult to ascertain.
In a pilot study, 50 percent of a listener group
consisting of 24 listeners with experience in
analyzing cleft palate speech failed to observe
any glottal coarticulation, although all observ-
ers were able to identify glottal articulation. This
indicates a risk of misinterpreting impaired
velopharyngeal activity in patients with
unidentified, but consistent, glottal coarticulation
as the best velopharyngeal activity these patients
are capable of performing. In fact, such patients
are likely to have a potential for improved ac-
tivity if glottal coarticulation could be eliminated.

The absence or poor quality of velopharyngeal
movements during glottal articulation was found
to be associated with a reduction of Passavant’s
ridge. The functional significance of the ridge
during oral articulation has been discussed by a
number of authors. Some have questioned its
function in reducing velopharyngeal incompete-
tence during speech (Calnan, 1957; Massengill
it contributes to velopharyngeal closure during speech (Beery et al, 1983; Glaser et al, 1979).
Glaser et al, (1979) studied ridge movement in
relation to articulation using multiview video
fluoroscopy and reported a highly consistent
movement during correctly articulated pho-
nemes, but absence of ridge movement during
incorrect production such as /s/ with a severe
lateral distortion. In our study, a ridge was
present in three patients (numbers 2, 5, and 6)
but was seen to contribute to approximation of
velopharyngeal closure during oral articulation
in only two of them (numbers 2 and 6). During
glottal articulation, the decreased ridge in two
patients (numbers 5 and 6) did not necessarily
occur in conjunction with velar elevation and was
inconsistent with regard to movement pattern.
As the ridge in this study contributed to reduced
velopharyngeal incompetence during oral
production but not during glottal stops, it seems
reasonable to assume that the ridge serves no
articulatory purpose during glottal stop production.

The findings of more pronounced velar and
lateral pharyngeal wall movements for high
vowels than for low vowels in an oral stop con-
text is in agreement with the results of several
other authors (Moll, 1962; Moll and Shriner,
1967; Bzoch, 1968; Lubker, 1968; Fritzell,
1969; Niimi, 1979; Seaver and Kuehn, 1980).
An influence of the vowel on velar position dur-
ing the preceding stop production, e.g., when
velar elevation during production of a syllable
including a stop followed by a vowel appears to
be essentially similar to that of the sustained
vowel, was suggested for noncleft palatal speak-
ers (Lubker, 1968). Higher elevation in [pi:] than
in [pa] in the Swedish word [pi:pa] ought to be
expected. This did not seem to be valid for cleft
palate speakers, since no such influence of ve-
lar position in oral stops followed by a vowel
could be observed during oral speech in the pa-
tients in this investigation. The velopharyngeal
movements appeared alike regardless of the fol-
lowing vowel. When articulation in these patients
became glottal, the velopharyngeal movements
for stops and vowels were equally impaired with
the exception of /a /, which remained unaf-
ected by the glottal surrounding but demonstra-
ted no velopharyngeal closure. The fact that
velopharyngeal closure is not required for /a / in
an oral surrounding but is required for other
vowels, probably explains why velopharyngeal
movements for /a / in a glottal context are not
impaired.

The question of impairment or absence of
velopharyngeal movement during glottal articu-
lation ought to be considered in clinical assess-
ment before velopharyngeal flap surgery.
According to Shprintzen et al (1979), decisions
regarding the width and base of a velopharyn-
geal flap should be based on evaluation of
velopharyngeal movements with respect to type,
size, and location of the velopharyngeal in-
competence. If the cineradiographic analysis of
the patients in this study had been the only evalu-
ation instrument and had it not been associated
with a careful speech analysis, the study would
probably have given a misleading indication of
physiological weakness or even paralysis of
velopharyngeal musculature. Such an impression
of impaired velopharyngeal movements would
have been strengthened by the absence of in-
fluence on the velopharyngeal movements from
following vowels. However, this study has
shown that there is not a question of impaired muscular function, but rather the consequence of glottal articulation. Presurgical cineradiographic or fluoroscopic analysis of a patient’s ability regarding velopharyngeal movements should thus be based on speech sequences with oral articulation.

If the association among glottal articulation, glottal coarticulation, and impaired velopharyngeal movements is not taken into account, a patient with glottal articulation or glottal coarticulation might be recommended for a wider than necessary flap to compensate for the impaired lateral pharyngeal wall movements. In fact, a narrower flap would be sufficient for oral articulation or might not be needed after speech therapy eliminated the glottal stops.

In conclusion, this investigation indicates that radiographic analysis of velopharyngeal function should be based on oral speech samples, since glottal articulation and glottal coarticulation are consistently associated with impaired velopharyngeal movements, whereas oral articulation is not. If velopharyngeal incompetence is inferred from radiographic observations made during glottal stops, the findings could be erroneously interpreted as evidence of decreased velopharyngeal motor function or even paralysis.

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