A Tomographic Technique of Assessing Lateral Pharyngeal Wall Displacement

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Recently it has been emphasized that velopharyngeal closure for speech involves a sphincteric mechanism consisting of both velar and pharyngeal movements (*34*). Posterior-superior movement of the velum can be observed directly perorally or in the sagittal plane using standard lateral-view radiographic techniques. In contrast, visualization of pharyngeal movement is restricted since direct observation is limited to the area inferior to actual velopharyngeal contact. Moreover, radiographic observation of the lateral pharyngeal wall (LPW) component of velopharyngeal closure is complicated by the dense overlay of bony structures anterior and posterior to the pharynx.

The problem of assessing lateral pharyngeal wall displacement is especially intriguing. Various methods have been utilized in specifying the configuration and movement of LPW during speech and other activities. Several investigators have directly viewed and filmed movement through maxillofacial defects (*8, 9, 15, 36*). Peroral observation of LPW has involved methods such as caliper measurements (*1, 3*), oral panendoscopy (*37, 38*), and the use of an inverted laryngoscope (*40*). Movement of LPW also has been observed transnasally through a nasendoscope (*28, 29*) and a fiberscope (*21, 25, 30*). Movement of LPW during speech can be inferred using indirect methods of observation such as electromyography (*5, 6, 13*) and pulsed ultrasound (*26*). To determine cross-sectional measurements along the vocal tract, Ladefoged and his associates (*20*) used dental impression material to make casts of the pharyngeal and oral cavities while their subject was inverted and maintained a vocal tract position similar to that involved in producing the schwa vowel.

Several investigators have utilized radiographic techniques to assess mesial displacement of LPW. The majority of these techniques involve frontal projections using video- or cine-fluorography (*4, 14, 17, 18, 23, 31*). Campos-Giral and Cole (*10*) placed radiopaque balloons in the nasopharynx of cleft palate subjects and obtained frontal-plane radiographs during rest

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and sustained vowel production. LPW displacement also has been observed in base projection (*32*), submentovertical projection (*27*, *39*), and multiple projections of the same subject (*24*, *33*).

All of the methods cited have certain inherent disadvantages as well as advantages. For example, it is difficult to quantify LPW displacement using visualization methods involving scopes. With regard to radiographic techniques, the primary disadvantage of using base and submentovertical projections is the difficulty in specifying the exact inferior-superior level of mesial LPW movement. Using any radiographic technique in which the primary x-ray beam is parallel to the sagittal plane, it is difficult to visualize LPW displacement unless the pharyngeal walls are adequately coated with contrast material (*19*). Contrast material such as oily dionosil is usually introduced transnasally and is necessary because of the bony structures overlying the pharynx.

It is possible to eliminate or at least diminish the visual masking effect of structures overlying the pharynx by blurring them using a tomographic technique. Although transverse tomography (*7*) and frontal tomography (*12*, *16*, *35*) of the pharynx previously have been reported, little use has been made of this technique perhaps because of the apparent difficulty in specifying the exact plane or level within the pharynx to be "focused." The purpose of this paper is to review basic tomographic principles and to present a new tomographic technique of measuring mesial displacement of the pharyngeal walls.

Tomographic principles

Since basic tomographic principles have been described in detail elsewhere (for example, *2*, *11*), only a brief review will be given here. There are three essential elements in any tomographic system: 1) an x-ray source, 2) the object to be x-rayed, and 3) the recording system which is usually film. If any two of these three elements move synchronously relative to the third element, a tomographic effect can be produced. Figure 1 is a schematic drawing of one type of tomographic system. In the example shown, the x-ray source and film move along proportional arcs in opposite directions from position A to position B. Only one plane (the focal plane) will remain in focus on the film. Structures above and below this plane will be blurred on the film. The level of the plane to be focused within an object can be varied by moving either the fulcrum or the tabletop while the other remains stationary. An advantage of using a movable tabletop system (fixed-fulcrum or Grossman principle; see reference *22*) is that the object magnification is constant regardless of the level of the plane since the tube/fulcrum and fulcrum/film ratios always remain the same. This is the system which has been used in the present report.

The thickness of the focal plane or tomographic section (in this case the "plane" obviously is not infinitely thin) is inversely related to the tomo-

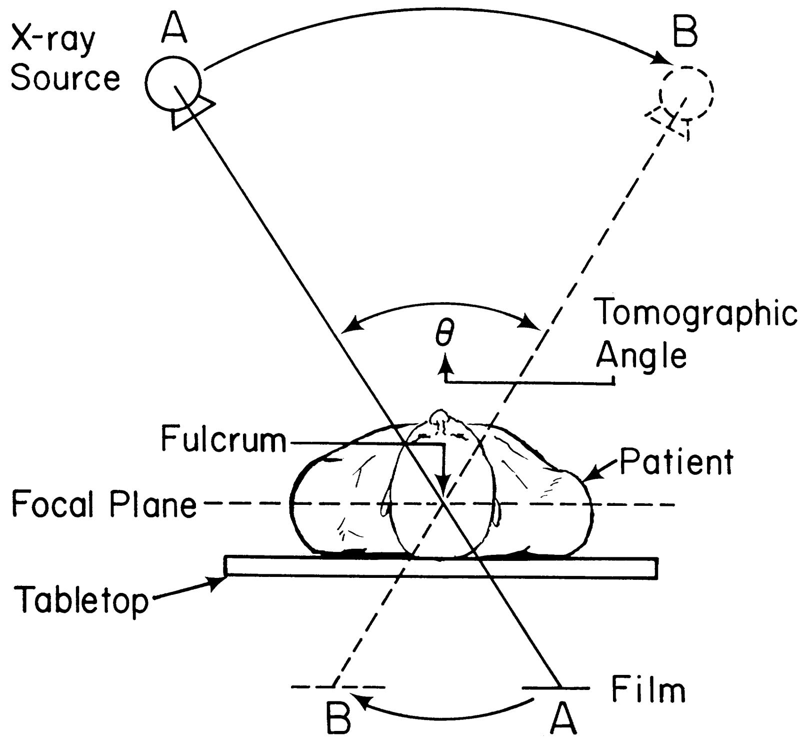

FIGURE 1. An example of a tomographic system.

graphic angle shown in Figure 1. Therefore, to decrease the thickness of a section, the amplitude of tube-film travel would be increased.

Several forms of tube-film motion are available for tomography. Figure 2 shows four common types of tomographic motions. Each of these four drawings represents the path of tube motion as seen from the ceiling looking down at the tube (film motion corresponds to tube motion). Although the nonlinear tube-film motions produce more complete blurring of structures outside the focal plane than the simpler linear motion, exposure time is considerably shorter for the latter. For example, using the Philips Polytome, the exposure times are the following: 1) hypocycloidal, 6 sec., 2) circular and elliptical, 3 sec., and 3) linear, variable from 0.15 sec. to 0.9 sec. depending on the amplitude of tube travel. The shorter exposure time associated with the linear motion has been found to be an advantage in this study since it is easier to sustain speech sounds for the shorter time periods. Moreover. subject radiation dose is less for the shorter exposure times. An exposure time of 0.3 sec. is utilized in this study which results

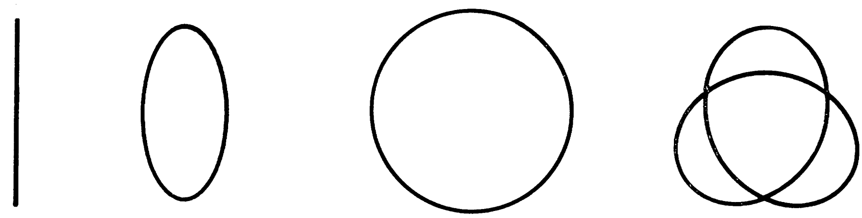

FIGURE 2. Tube-film motions used in tomography: a) linear, b) elliptical, c) circular, and d) hypocycloidal.

in a dosage of approximately 0.25 roentgen in the primary beam. In utilizing the linear tube-film motion, it is important to note that the optimal tomographic image will be produced if the tube-film motion is perpendicular to the edge of interest rather than oblique or parallel to it. The absorption edge may be a bone-soft tissue or soft tissue-air interface as the lateral pharyngeal walls are to the respiratory airway.

In the following section, frontal tomography of the pharynx will be described. Although the method involves a specific type of tomograph machine, other tomograph machines may be used. However, the following modifications may be necessary: 1) if the unit is an adjustable-fulcrum system, magnification of structures within different focal planes will vary and must therefore be calibrated, and 2) if the tube-film path cannot be adjusted to be perpendicular to the long axis of the tabletop (and thus to the pharynx) an additional table abutting the existing table would be needed.

Frontal tomography of the pharynx

Prior to tomographic filming, a serrated metal marker is taped to the subject's skin near the angle of the mandible so that the metal marker and the pharynx lie within the same frontal section. Final positioning of the marker can be achieved using lateral-view fluoroscopy which need not be in the same room as the tomograph. Points on the metal marker are used subsequently in determining the anterior-posterior plane of the frontal tomogram. A marker also may be introduced into the nasopharynx to provide an inferior-superior reference point within the pharynx which can be seen both in frontal-view tomographs and lateral-view radiographs. For this purpose, a small piece of metal is enclosed at the tip of a polyethylene tube. The tube is guided through the nasal cavity fluoroscopically such that the metal marker is positioned within the nasopharynx midway be-

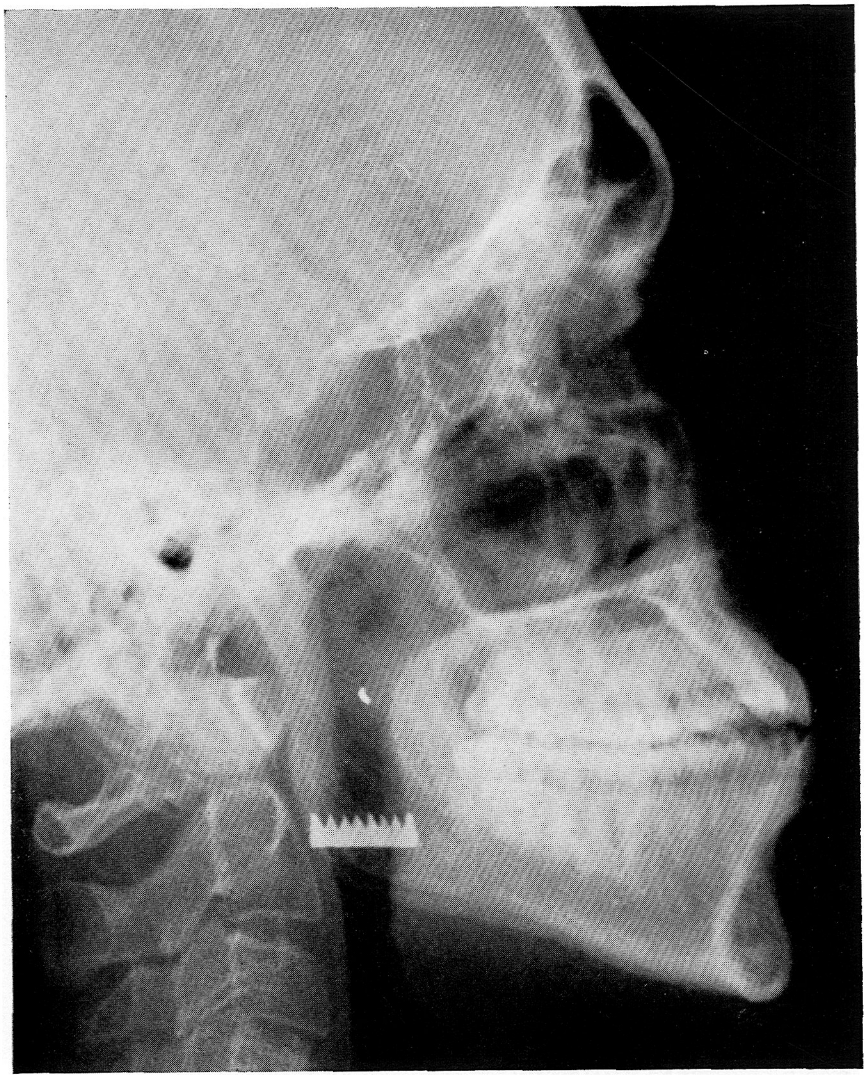

FIGURE 3. Lateral-view radiograph of a normal adult male showing the positions of the external serrated marker near the angle of the mandible and the internal nasopharyngeal marker between the posterior pharyngeal wall and the nasal surface of the soft palate.

tween the posterior pharyngeal wall and the posterior surface of the soft palate at rest. Figure 3 shows the positions of the external serrated marker near the angle of the mandible and the internal small metal marker in the middle of the nasopharynx. The latter marker can be seen above the level of the serrated marker between the posterior pharyngeal wall and the nasal surface of the soft palate.

The radiographic equipment consists of a tomograph (Polytome U) manufactured by Philips Medical Systems, Inc. and a General Electric portable x-ray machine. The portable unit, which is used to obtain standard lateral-view radiographs, is positioned so that the tube-film distance (143 cm) and the tube-to-midsagittal plane distance (110 cm) are the same as the tomographic tube-film distance and tube-focal plane distance respectively. Thus, structures filmed in the midsagittal plane and frontal plane have the same enlargement.

The subject is placed on the tomograph table in the supine position. Padding is placed under the neck so that the pharyngeal lumen is parallel to the tabletop. The head is stabilized using a cephalostat which is vacuum-mounted to the tabletop. The central beam of the portable unit is set to pass through the serrated marker and the central beam (perpendicular to the tabletop) of the tomograph is set to pass between the subject's occluded lips in the midline.

The initial radiograph is a lateral-view x-ray taken while the subject sustains the vowel /ɑ/. Using this x-ray film, two different methods have been utilized in determining the desired focal plane (frontal section) of the pharynx relative to the tabletop. One method consists of noting on the film the particular point of the serrated marker that lies midway between the posterior surface of the tongue and the posterior pharyngeal wall and setting the focal plane according to this externally observable point. The other method is to measure the distance between the bottom edge of the film (corresponding to the tabletop) and the mid portion of the pharynx using an x-ray image of a radiopaque ruler. Just prior to subject positioning, the radiopaque ruler is placed in the same plane as the eventual midsagittal plane of the subject and is filmed using the portable unit. Enlargement of the radiopaque ruler is thereby identical to that of structures lying within the subject's midsagittal plane.

The specific tomographic technique consists of a linear tube travel which is perpendicular to the long axis of the pharynx. The tomographic angle is 20° resulting in an exposure duration of 0.3 sec. and a section thickness of 3.4 mm which adequately blurs the bony structures anterior and posterior to the pharynx. Radiographic settings are 200 mA and 100 kV for most tomograms. Added filtration consists of 1 mm copper and 1 mm aluminum. An area of relative overexposure on the tomogram results when the subject's mouth is open during phonation. To eliminate this, a narrow compensating filter is taped across the face of the Polytome tube.

Frontal tomograms are obtained simultaneously with lateral-view radiographs. Inferior-superior levels of the pharynx as viewed on the tomogram can be assessed in relation to other velopharyngeal structures in the midsagittal plane by superimposition of the nasopharyngeal metal marker which appears on both the lateral-view and frontal-view radiographs. This is possible since the two radiographs are obtained simultaneously and the enlargement factor is the same for both. The pharyngeal configuration can thereby be measured in all three dimensions.

Mesial displacement of LPW during phonation is determined in the following manner. The outline of LPW during rest breathing as viewed on the tomogram is traced. Portions of the sphenoidal sinus also are traced on the same paper. These tracings are repeated for the tomograms obtained during sustained speech sound production. Mesial displacement at any inferior-superior level including the velopharyngeal area can be assessed by superimposing the tracings using the sphenoidal structures as a common

FIGURE 4a

FIGURE 4. Frontal tomograms of a normal adult male obtained during: a) rest breathing and b) sustained production of the vowel /ɑ/. The small elliptical object in the center of each tomogram is the image of the nasopharyngeal marker.

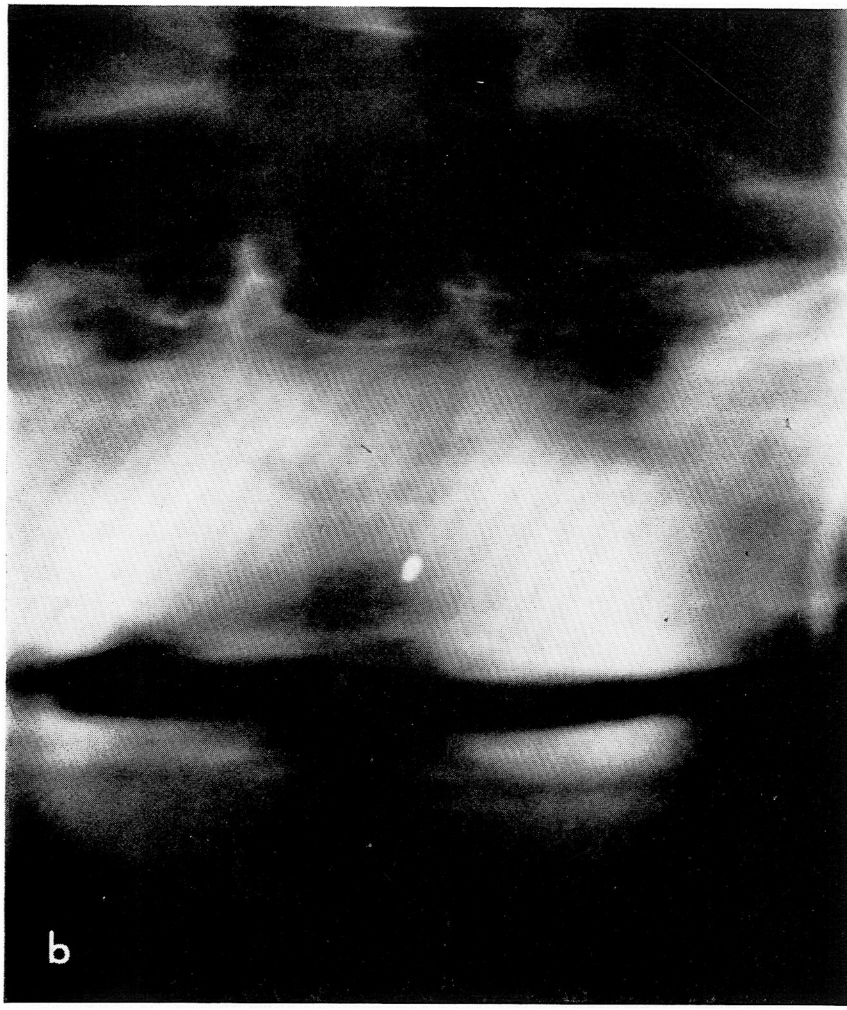

FIGURE 4b

reference. Differences in LPW configuration also can be related to such factors as tongue positioning since the tomograms and the lateral radiographs are obtained simultaneously.

Figure 4 shows frontal tomograms obtained during rest breathing and during sustained production of the vowel /ɑ/ for a normal adult male subject (the same subject as that shown in Figure 3). The outline of LPW can easily be visualized and compared between tomograms. A study currently is being designed to investigate the effects of different sustained speech sounds on LPW configuration in relation to velum and tongue positioning and to compare these data across subjects.

Summary

Various methods of specifying lateral pharyngeal wall configuration during speech and other activities are reviewed. Basic tomographic principles also are reviewed and a new tomographic technique of measuring mesial displacement of the pharyngeal walls is presented. An important advantage of the technique described in this report is that it enables one to measure the degree and level of mesial displacement of the lateral pharyngeal walls in relation to the soft palate, tongue, and other structures observable on lateral-view radiographs.

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