SUMMARY

Pulsed ultrasound was used to assess lateral pharyngeal wall (LPW) movement at the level of the velopharyngeal port in three adult males and two adult females. All subjects were normal talkers, and data were collected while each produced all combinations of the vowels /a/ and /i/ and consonants /p, t, k, s, m, n/ in a VCVCV context. On a qualitative basis, it appears that ultrasound technology has potential application for the measurement of LPW movement. However, a number of problems must be resolved before ultrasonic techniques surpass current methods of studying velopharyngeal function and/or incompetence.

Ultrasonic Measurement of Lateral Pharyngeal Wall Movement at the Velopharyngeal Port

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Introduction

Videofluoroscopic pictures of lateral, frontal, and base projections of velopharyngeal dynamics have shown that persons can achieve competent closure of the velopharyngeal (V-P) port through a variety of sphincteric patterns (Skolnick, 1973). However, two basic properties of competent closure are good velar elevation and elongation and significant medial movement of the nasopharyngeal walls. Persons with incompetent velopharyngeal port closure may exhibit only one or neither of these two properties but rarely both.

Hence, the lateral pharyngeal walls (LPW) must act in synchrony with the velum and, to a lesser extent, the posterior pharyngeal wall to open or close the velopharyngeal port during normal speech production. Incomplete closure of the port during the production of non-nasal consonants and vowels may produce an acoustic coupling of the nasal cavities to the vocal tract with resultant hypernasality and nasal emission of air.

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Two non-invasive diagnostic techniques designed to measure LPW motion during speech production are the previously mentioned uses of radiography and pulsed ultrasound. Kelsey, et al., (1972) have reported that diagnostic ratings of LPW motion can be made reliably with both radiographic and ultrasonic techniques. They suggest further that these measurements have predictive value with regard to the relative success of physical procedures designed to aid velopharyngeal closure.

The use of ultrasound would appear to have a number of distinct advantages when compared to conventional barium radiography techniques. First, ultrasound presents no discomfort to the patient and may thus be more applicable to young children. Secondly, at low energy levels, the energy of ultrasound is believed to be dissipated entirely as heat. Therefore, the hazards of irradiation are eliminated. Thirdly, the cost of ultrasound is far less than x-radiography. Fourthly, the equipment is reasonably portable.

In general, ultrasonic waves (1–10 MHZ) transmit well through most biological tissue and have recently been found to have a variety of applications for imaging structures within the body (King, 1974). When ultrasonic pulses are radiated into the body, acoustic echoes occur at boundaries between non-homogenous material. Ultrasonic waves will not transmit appreciably through air. Therefore, volumes of air in the body will strongly reflect ultrasound energy. These properties of ultrasound would suggest a high probability of observing the air-to-muscle interface of the pharyngeal walls during speech. In view of the diagnostic and prognostic potential of ultrasound, it is appropriate to continue to explore the uses and limitations of the technique.

The purpose of this paper is to present the findings of an investigation which was designed to examine one ultrasonic measurement technique based on recent descriptions of velopharyngeal dynamics by Skolnick (1970) and Shprintzen, Lencione, McCall and Skolnick (1974). Many of the studies that have employed ultrasonic detection of LPW motion (Kelsey, et al., 1972; Minifie, et al., 1970; Kelsey, et al., 1969) have measured the muscular activity at a level below the angle of the mandible. We feel, as do Dickson, et al., (1974), that the LPW motion being measured in this manner does not necessarily reflect the dynamic interaction between movements of the velum and upper lateral pharyngeal walls as shown in the x-ray studies by Skolnick (1970), Shprintzen, et al., (1974), and others. Indeed, Zagzebski (1975) has recently confirmed our suspicions by utilizing a two-transducer approach and showing different LPW motion at levels below the angle of the mandible as compared to that obtained with a transducer placed behind the ramus.

Method

Three adult males and two adult females served as subjects. All had normal speech articulation and no remarkable deviation in oral anatomy. The ultrasonic pulse was applied to each subject with a hand-held piezoelectric crystal.¹ This crystal converts electrical signals to acoustic signals during transmission

¹Alpha Series Transducer, 13 mm dia., Aerotech Labs, Lewistown, Pa.
and converts acoustic echo signals to electrical signals during reception. The frequency of the acoustic pulses was 1 KHZ and the sine wave frequency during the pulse was 2.25 MHZ with an average power of less than or equal to 10 mW delivered to the crystal.

The crystal was driven and received by an Ekoline 20 Diagnostic Ultrasoundoscope. The signals from the Ultrasonoscope drive a CRT viewing system called an M-scan. The M-scan is obtained by driving the horizontal plates of the CRT with a slow (5 sec) linear sweep and the vertical plates with a fast (200 μsec) linear sweep and putting the electrical echo signal on the Z-axis modulator. The phosphor storage time of the CRT allowed viewing of the time-motion event of about 5 sec duration. A camera system provided continuous photographic read-out of the data, and a voice signal from a contact microphone was simultaneously presented for reference viewing on the CRT and photographs. The ultrasound crystal was placed snugly against each subject's neck at a position slightly above (5 mm–10 mm) the angle of the mandible and behind the ramus. Previous videofluoroscopic views insured that the ultrasonic beam at this level would be directed toward the most active portion of the upper lateral pharyngeal wall during speech. An acoustic gel was applied between the crystal and the skin of the neck to increase acoustic coupling.

During data collection, each subject was instructed to produce all combinations of the vowels /a/ and /i/, and consonants /p, t, k, s, m, n/ in a VCVCV context (akaka), three times each at a conversational level. In addition, data were collected for one subject while he was intentionally nasalizing the non-nasal VCVCV combinations.

Results and Discussion

The data presented here represent an assessment of one ultrasound technique applied to the measurement of LPW movement in the region of the V-P port. It is apparent from Figures 1–5 that a good deal of qualitative evidence exists to suggest that we are indeed observing this movement. First, very good correlation may be observed between the voice signal, the movement of the trace believed to be the LPW, and known dynamics of the LPW at the level of the V-P port (Skolnick, 1970 and 1973). Secondly, in Figure 1, the trace presumably representing the LPW is clearly seen for both nasal and non-nasal speech tasks. A deflection of the trace suggestive of an anticipatory movement of the LPW always occurs prior to an acoustic event. Furthermore, a medial deflection of the trace is observed in synchrony with the acoustic events representing the non-nasal consonant and vowel combination /atata/, while virtually no deflection is observed in conjunction with the acoustic events representing nasal consonant production. Similar findings were obtained for the other VCVCV combinations, including both high and low vowel productions.

Figure 2 shows the ultrasonic traces obtained when a male subject produced the word (apapa) normally and when he intentionally nasalized the production.

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2 Manufactured by Smith-Kline Instruments, Palo Alto, Calif.
3 Aquasonic 100, Parker Laboratories, Inc., Irvington, N.J.
FIGURE 1. Acoustic signal and ultrasonic trace obtained for an adult male producing /atata/ and /anana/. Horizontal markers represent 1 cm displacements; time lines represent 100 msec. Medial displacements are indicated by a downward deflection of the trace.

FIGURE 2. Acoustic signal and ultrasonic trace obtained for an adult male producing /apapa/ normally, and when he intentionally nasalizes the production.

The lack of deflection of the trace during the nasalized condition clearly suggests that the LPW is being accurately detected and monitored in the vicinity of the V-P port. Again, similar normal and nasalized productions for /atata/ and /akaka/ by the same object resulted in virtually identical findings.

Despite the evidence presented above, we experienced several major difficulties which would suggest that the use of ultrasonic detection of LPW motion in its present form has questionable diagnostic and prognostic applicability.

The following problems were encountered in our data collection.

1. The search for good LPW reflection took from several minutes to one hour. Occasionally, no useful signal was obtained even after a one-hour attempt.
Our procedure was to place the crystal firmly against the neck and conduct a manual angular search to obtain a good reflection from the LPW. The criterion for good reflection was observance of the signal at the estimated depth while the subject repeated the previously mentioned speech stimuli. We found that a good deal of finesse was required to place the transducer at the appropriate angle with optimal pressure against the external neck. The sensitivity of crystal placement was such that many times the LPW would be detected only to be lost again during the data collection. From two of the five subjects, the trace could be obtained rather easily and reproducibly. Another subject was easily detectable from the right wall but was very difficult to detect from the left wall. In the remaining two subjects, it was difficult to obtain data from either wall. Attempts to utilize swallowing movements to locate the LPW were equally equivocal.

2. The tracings also showed multi-layer returns which moved synchronously with the voice signal. Figure 1 shows a two-layered return in the vicinity of the expected air/wall interface while Figure 3 shows a four-layered return in a different subject. These multi-layered returns made it difficult to locate unequivocally the actual air/wall interface. Ultrasonic principles would suggest the lower trace as the air/wall interface since the last visible pulse should be the reflection of the pulse from the pharyngeal airway. However, in Figure 1, the upper trace dimensional changes (1 cm) correlate with anatomic distances measured on the same subject using frontal view video-fluorographs (1 cm). The lower trace of Figure 1 moves 5 mm during V-P port closure. Since the
frontal view video-fluorograph showed total closure along a vertical path that encompassed the ultrasound pathway, we do not feel that this lower trace accurately reflects partial closure of the oro-pharynx. We were, therefore, unable to determine which trace represented the true air/wall interface. Possible explanations for the occurrence of the multi-layered returns may relate to the gain settings on the receiver and/or acoustic reverberations produced by the sound beam vibrating between the half-soft tissue interface and the transducer on the skin. Nevertheless, the traces represented in Figures 1 and 3 are among the best obtained throughout the course of the present study and were achieved with painstaking adjustment of the gain settings for each subject.

3. An individual trace on the M-scan has a line thickness which varied from 1 to 4 mm. Since the LPW movements are of the order of 8 to 10 mm, this variable thickness of the line trace could introduce serious error in the displacement measurement. We are aware that the line thickness is partially a product
Acoustic signal and ultrasonic trace obtained for an adult male producing /atata/.

of the brightness control on the display apparatus. However, as in the case of the multi-layered returns, the brightness control had to be compromised on many occasions to obtain even a minimally acceptable signal.

4. Figures 4, 5, and the non-nasal portion of Figure 1 represent the acoustic signal and ultrasonic traces of two males (Figures 1 and 5) and one female (Figure 4) obtained under identical experimental conditions. It is apparent that a good deal of inter-subject variability exists in magnitude and pattern of LPW motion. This finding is supported by recent x-ray evidence reported by Skolnick, et al. (1973), and others. Without a sizeable body of normative data on both normal and pathological speakers, this variability represents a potential source of error in interpreting the contribution of both LPW’s to V-P closure in a given individual when using ultrasound. In contrast, frontal x-ray views provide simultaneous images of both LPW’s necessary in pre-surgical planning.

5. The most critical flaw is the potential inability to detect a true lack of LPW motion in a pathological subject. That is, since all subjects in this study were normal speakers with presumably good LPW motion, we continued to search for the air/wall interface until it was detected. In the case of an individual with little or no movement of the LPW, it could conceivably be difficult to know at which point a true lack of movement existed as opposed to the possibility that
the LPW simply had not been detected. This problem increases in significance if recommendations regarding surgery are involved.

In conjunction with the last point, we noted a discrepancy between the findings of Kelsey, et al., (1972), Kelsey, et al., (1969), and the present investigation. That is, Kelsey, et al., (1969) used a transducer placement ... approximately 4 cm below the velum ...” and found that “…the pharyngeal wall moves medially during low vowels such as /a/ and laterally (our italics) during consonant production in all cases.” However, in 1972, Kelsey, et al., using a transducer placement and a speech task similar to that reported in their previous study, claimed to be measuring LPW motion related to velopharyngeal closure and went on to pool the results of “… ratings of LPW motion by both cineradiographic and ultrasonic techniques…” for the purpose of evaluating cleft palate speakers pre- and post-operatively.

In contrast, it is clear from Figures 1-5 that, during non-nasal productions, the LPW never moved laterally with respect to the relaxed pharyngeal wall position. These findings were similar for all speakers, although exact measurements were difficult to obtain for the reasons expressed earlier. Again, even in a nasal context (Figures 1 and 2), the LPW never moves more laterally than the relaxed pharyngeal wall position.

The difference between the results of the present investigation and those reported by Kelsey, et al. (1972) is, of course, due to the placement of the transducer. We believe that our traces reflect the LPW motion at the level of the velum (our findings are very similar to what would be expected from frontal x-ray data) whereas Kelsey, et al. viewed the pharynx at a much lower level. Unfortunately, these authors report no specific data that might be used for comparison purposes. Thus, the question of how cleft palate subjects were rated remains unresolved.

Conclusions

On a qualitative basis, it would appear that ultrasonic techniques possess the potential for clinical use in the assessment of LPW motion. However, a number of problems must be solved before ultrasound surpasses current methods such as cine- and video-fluoroscopy in the diagnosis and management of velopharyngeal incompetence. At present, the major advantages of ultrasound do not seem to outweigh the inherent disadvantages. Problems must be resolved in the search for and the location of the LPW by the ultrasound crystal by those concerned with interpretation of multi-layered returns. This would allow data collection for all subjects including those for whom there is no LPW movement. To match the information content now available in current fluoroscopic techniques, the ultrasound method should present a simultaneous real-time display of both right and left walls during speech. Skolnick, et al., (1975) have recently partially resolved this problem with a 20-transducer array which provides a more accurate representation of the vertical dimension of one LPW. Nevertheless, it appears that additional research and development will be necessary before ultrasound is an acceptable clinical tool. Finally, a large
body of normative data should be collected to insure confidence in interpretation before implementing ultrasound methods in pre-surgical planning.

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