The Use of Time-Motion Ultrasound For Measuring Lateral Pharyngeal Wall Displacements

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SUMMARY

A technique utilizing pulsed ultrasound and a time motion echo display promises to be useful for monitoring dynamic gestures of the lateral pharyngeal walls. The monitoring technique has been used to measure pharyngeal wall displacements at the level of the angle of the mandible during speech.
The present research was concerned with two aspects of the monitoring technique, which require improvement:

- **a)** We often find it difficult or impossible to obtain clear records of the LPW position from which the displacement of a single surface on the pharyngeal wall can be continuously followed during speech utterances.
- **b)** The resultant measurements are imprecise; under controlled experimental conditions, variations of 1.8 mm (1 standard deviation) have been noted for 5 mm displacements of the LPW. The uncertainty of clinical measurements has been estimated to be about 3 mm.

Specific experiments described in this thesis dealt with selection of transducers for monitoring lateral pharyngeal wall motion and with investigations in the effects of principal sources of variation on ultrasound LPW displacement measurements.

A) Transducer selection

Transducer studies were carried out to determine whether LPW echo signal loss problems and difficulties obtaining a clear time motion trace from the pharynx could be solved by employing an optimum transducer for this ultrasound application. Original transducers selected for monitoring LPW motion were typically 13 mm diameter, plane circular probes with a 2.0 MHz resonant frequency. Alternative transducers tried in this study ranged from custom in-house constructed, broad-beam sources with a 20 mm wide sensitivity profile at the LPW depth to narrow, sharply focused sources.

Using wide beam transducers, echo loss during speech samples still occurred, and careful manipulation was required to align the ultrasound beam so that continuous time motion records could be obtained. The detection of additional multiple echoes from the area of the pharynx made alignment of wide beam transducers more difficult than alignment of standard probes. Therefore, broad beam transducers were not considered suitable replacements for standard medical probes in this application.

Focused transducers also required careful placement in order to obtain continuous time motion records from the pharynx. They did offer some advantage, however, in obtaining clear records without multiple echoes. Our best experimental results have been obtained using 19 mm diameter probes with focal lengths of 6 -8 cm.

B) Sources of Variation

The effects of two types of variation on ultrasound measurements of LPW motion were investigated. The first areas studied were the effects of changing the placement and alignment of the ultrasonic transducer, resulting in different regions being monitored on the pharyngeal wall. Secondly, we investigated whether notable variations in LPW displacement measurements could be brought about by subject inconsistencies both in speech effort and in head angle settings. The findings are summarized below.

1. <u>AP transducer shifts</u>: With the ultrasonic transducer constrained to a horizontal plane at the level of the angle of the mandible pharyngeal wall displacement during low vowel utterances were monitored for six to eight AP alignments of the transducer. For each speaker employed average displacements for individual transducer settings ranged typically from 2.5 mm to 4.0 mm. The results demonstrated the extent with which variations could be introduced by varying the AP alignment of the probe; however, no systematic correlations were noted between the magnitude of the displacement and the AP monitoring position on the pharyngeal wall. This apparently was due to the limited resolution of the transducer beam and the accuracy with which the relative AP position of the beam axis was specified with the scanning device of Figure 5. 5.
2. <u>Monitoring level variations</u>: Pharyngeal wall displacements measured with the transducer placed posterior to the mandible were found to depend on the monitoring level of the ultrasonic transducer. For all speakers utilized in this study displacements during low vowel utterances increased by a factor of two or more as the monitoring level was raised from the level of the angle of the mandible to the level of the earlobe. One-centimeter elevations in the monitoring level resulted in measurement increases as large as 2.5 mm.
3. <u>Difference in LPW motion for "low" and "high" transducer placement</u>: In addition to variations in the magnitude of LPW displacements at different monitoring levels our data demonstrated that there is not a direct relationship between pharyngeal wall motion at the level of the angle of the mandible ("low") and displacements near the level of velopharyngeal closure ("high"). LPW motion was monitored at both levels during speech samples which contained high and low vowels and either nasal or non-nasal consonants. It was seen that the superior walls of the oropharynx moved medially during most speech samples, regardless of the direction of movement of the lower walls. For example, during high vowel phonations the superior walls were constricted whereas the lower walls were displaced in the outward direction for this same phone. Non-nasal consonants also resulted in large medial displacements at the high transducer placement. Low in the oropharynx displacements during consonant articulations depended on the phonetic environment, with medial displacements during consonants uttered in low vowel environments and small outward displacements in high vowel environments.

   The data indicate that at the two levels in the pharynx, the lateral walls are subjected to different mechanical forces and constraints. Constrictions of the pharyngeal walls near the level of the velum occur during phonem productions for which the velopharyngeal port is closed down. Thus, LPW constrictions at this level appear to be part of the normal valve action of the velopharyngeal port. The position assumed by the LPW low in the oropharynx can be most closely characterized in terms of the nature of the vowel sounds being uttered. LPW displacements at this level result in an expanded pharyngeal volume during high vowels and a reduced volume during low vowel productions.

4. Effects of head angle variations: Possible influences of subject posture were investigated by measuring LPW motion for different speaker head angles. In four out of six speakers there appeared to be no significant change in measured displacements for different head angle settings. However, for two speakers measured LPW displacements doubled after the head was either maximally extended or flexed from the normal, upright position. Variations in measured displacements may have been partially due to changes in the effective monitoring location of the ultrasonic beam as it was reflected from the pharyngeal wall. For example, 1 cm elevations in the monitoring level could result in a difference of 2 -3 mm in the extent of measured displacements.

5. Speaker effort changes: The effects of speaker effort changes were investigated by measuring LPW motion at the level of the angle of the mandible as a function of the sound pressure level (SPL) during isolated low vowel utterances. Ten subjects participated in this study. Each uttered the low vowel "a" beginning at a "normal" effort level and then repeating the speech sample at intensities above and below the normal output. The sound level range achieved by each speaker was between 10 and 15 dB. For three speakers LPW displacements increased with increasing SPL, for low intensity utterances. However, in only one of these three speakers displacements increased throughout his entire SPL range, resulting in a 43% increase in measured displacements for a 12 dB SPL change. For most speakers variations in displacement for speech samples spoken at a given sound level were greater than variations resulting from changes in intensity.

Possible correlation between LPW displacement and speaker pitch levels were also investigated. Speakers were instructed to vary their pitch while avoiding concomitant changes in the loudness of the speech signal. In one speaker LPW displacements increased from 1.8 mm for normal pitch phonations (~110hz) to 2.7 mm for a 60hz pitch elevation. However, in the remaining nine speakers no correlations were found between the extent of LPW displacement and pitch levels.

The results show that LPW displacement variations can be brought about by varying the vocal output, ie., by changing the loudness or pitch of the speech sample. However, for most speakers, consistent changes in LPW displacement following SFL variations and pitch elevations were not significant.

Speaker effort control for the studies in this thesis was achieved by allowing subjects to subjectively set their own vocal output at a "normal, conversational" level. The present studies suggest that more specific control over the vocal output, for example, a requirement that speech signals be held within a selected SPL range, would offer little advantage for improving the precision of LPW displacement measurements. The reasons for this are the large variations in measurements for a given vocal level and the absence of significant variations in LPW displacements for concomitant sound level variations.

6. Effects of phonemic stress: The extent of pharyngeal wall displacement during each vowel of the utterance "a ka ka" was found to vary somewhat, depending on whether stress was applied during production of that vowel. LPW displacements during stressed vowels were typically 1 mm greater than displacements during adjacent, unstressed vowels. For one of the four speakers utilized in this study displacements during a stressed vowel were up to twice as large as those for the same vowel but uttered without stress.

7. Variations for "normal effort" utterances: From the results of this thesis it appears that the most precise measurements of LPW motion would be obtained if the transducer and the speaker are stabilized, thus making certain that the same area on the pharyngeal wall is consistently monitored. We found that under controlled conditions such as this, there still is a certain degree of instability among measured displacements for normal effort utterances. Typical variations noted in Section 5.5 above were 0.7 mm standard deviations for measurements whose mean value was 5 mm. These variations are believed to originate mainly from speaker inconsistencies in actual LPW displacement during phonations produced with "normal effort".

8. Reproducibility of ultrasound measurements: Since measurements may vary significantly if the probe alignment changes, the problem of obtaining reproducible measurements of LPW motion is primarily one of consistently repositioning the transducer towards the same location on the pharyngeal wall. He found that repeatable transducer placement could be achieved by replacing the probe at the same level on the external neck wall for every monitoring session. The final alignment of the probe was then carried out by "searching" for an LPW echo with the transducer motion constrained to horizontal directions. Using this method of transducer alignment, the results of measurements obtained during 14 different monitoring sessions over a two-week period were in agreement to within 1 mm (each session's results were within 1 mm of the average of 14 different monitoring sessions).