Evaluation of US Image Echodensities During Contraction of the Lingual Musculature

Jeri L. Miller and **Kenneth L. Watkin**, Department of Communication Sciences and Disorders,
Biomedical Engineering, McGill University
Montréal, Quebec

I. INTRODUCTION

B–mode ultrasound imaging has been used clinically to visualize the temporal and spatial movements of the tongue surface during speech production. Although these parameters provide important diagnostic information, the quantification of the acoustic signal during B–mode imaging of the tongue musculature has not been investigated. Hicks, Shawker, Jones, Linzer and Gerber (1984) analyzed the echo intensities of the pixel distribution within B–mode scans of muscle regions of the limb. They suggested that observed differences in pixel distributions were related to the degree of muscle contraction representing a physiological alteration in the muscle to fat–fibrous tissue ratio per cross–sectional area [1]. Any physiological or pathological condition which altered the composition of tissue would therefore be observed in the distribution of pixel intensities of a specific region of interest [2].

Given that the structural arrangement of the lingual musculature functionally alters during differing movements and postures, similar changes during the contraction of the intrinsic and extrinsic lingual muscle groups should be demonstrated by an alteration in the echo amplitudes of the acoustic signal. In addition, because the muscular composition of the tongue is not uniform throughout its length, individual muscle groups should be identifiable as differing echo amplitudes based on the extent of regional muscular contractions. Further, off–line image–processing of tissue echo intensities should detect significant differences in the acoustic properties of the ultrasound signal independent of transducer type and frequency.

Thus, the purpose of this study was to examine the physical properties of lingual musculature using off–line image processing of tissue echo intensities. We present preliminary data of a noninvasive method to describe and quantify the relationship between in vivo sonographic recordings of echo intensities and lingual muscle contractile state.

II. METHODS

One normal English speaker (female; age 35 years) was used. All testing was conducted using an ALOKA 2000 Ultrasound Unit. Two transducers were used with a resonant frequency of 5.0 MHz (convex) and 7.5 MHz (linear). The use of the same ultrasound unit was done to control for variability in system controls (e.g., dynamic range, pre– processing). Settings were maintained for each trial. Transducer characteristics included axial resolution of .4 mm (7.5 MHz) and .6 mm (5.0 MHz), respectively. Lateral resolution for both transducers was less the 1 mm or better. All images were collected in real–time at 10 frames per second using the video–acquisition board on a SGI Indigo R3000. To obtain relatively approximate replications of lingual force during tasks, a portable force measurement system containing a Force Sensing Resistor (FSR) was used [3,4]. The sensor was placed along the mid–line of the tongue blade. The subject pressed against the FSR until a force level as indicated by a liquid crystal display was achieved. Two force levels were approximated: 1) light press (700 grams force), and 2) hard press (2000 grams force).

III. PROCEDURES

The transducer was hand–held by the experimenter and placed submentally with the beam directed perpendicular to the tongue in mid– sagittal plane. The angle of the transducer was manipulated to achieve complete views of the lingual musculature from the anterior shadow of the mandible to the posterior shadow of the hyoid bone. Three trials per each hard press or light press task were made. A 30 second rest between trials was introduced to avoid fatigue effect. For each task, the subject isometrically contracted the tongue against the FSR/palate at the target level for 5 seconds.

All images were converted to an array of digitized picture elements (pixels) with an 8–bit resolution range. The converted images were then analyzed off–line on an IBM RISC workstation using image processing software. Ten consecutive frames were selected from one randomly designated trial for each task. Each frame was then analyzed to obtain moment statistics of gray level histograms of the complete image.

A grid overlay was generated for each image. Three *x*–axis coordinates were determined for all images to represent 'A–lines' of the anterior, mid, and posterior regions of the tongue. Within the designated A–line regions, the superior and inferior boundaries of the intrinsic, genioglossus, geniohyoid, and mylohyoid musculature were identified and corresponding *xy* coordinates of these muscle regions determined for each frame using a mouse–controlled cross–hair cursor displayed on the screen (Figure 1.0). For some tasks, the genioglossus did not extend to the posterior A–line region. Further, if the connective tissue fascia separating the geniohyoid and mylohyoid muscles at the tongue base were indistinguishable, the A–line measurement was completed for the geniohyoid only.

The pixel intensity distribution for each A–line region was then determined for each frame. The A–line intensity profiles represented an interpolated intensity scale from 0 to 1 (zero: white; 1: black). Mean and standard deviation values were automatically calculated and recorded for each region of interest.

The means of each A–line region for all ten images were pooled. Descriptive statistics were determined and included an analysis of kurtosis to determine pixel distribution in terms of peakedness of a curve, and skewness representing the symmetry of the pixel distribution. Significant differences between means were determined through ANOVA and nonparametric statistical analyses. Multiple pairwise comparisons were conducted for significant effects.

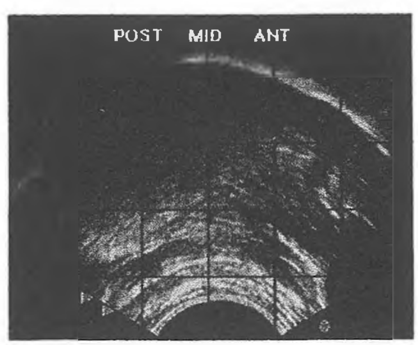

Figure 1.0. Example of gridded B–mode image containing A–line grid overlay.

IV. RESULTS

Results indicated the magnitude of echo intensities significantly differed as a function of contraction state. Significant differences in backscattered amplitudes were found between hard and light press tasks ($p < 0.0001$) for both transducer types, although the echo intensities were lower for the 5.0 MHz transducer (Tables 1.0–2.0). The data indicate the lowest echo intensities were found in the hard press task where the greatest levels of contraction were required. Higher echo intensities were found for light press tasks suggesting less contraction and a reconfiguration of the lingual musculature.

Within A–line regions significant differences ($p < 0.0001$) were found for all group means except the mid A–line region during the hard press task (5.0 MHz transducer). When the A–line regions from this image were reviewed, it was noted that the posture of the tongue was markedly different from that obtained with the 7.5 MHz transducer. Thus, postural differences may be one reason for this result. The data suggest that the extent of muscular contraction across regions of the tongue differ as measured by echo intensities.

Individual muscle groups within each A–line region were significant ($p < 0.05$) across tasks for the 7.5 MHz transducer. Results in individual muscles groups varied with the 5.0 MHz transducer. Overall, the results suggest that the contractile functions of individual muscle groups within A–line regions can be identified and may act functionally as semi–independent regions during different postural configurations.

In order to substantiate the findings of this subject, B–mode images were collected and analyzed for an additional subject. Results (Table 3.0) indicated that the same pattern of lower echo intensities for hard contraction vs. light contraction was maintained in this subject. The lowest echo intensities was found more posteriorly along the A–line regions. The lowest values representing the greatest contraction were found within the posterior geniohyoid and mylohyoid for both tasks. As in Subject 1, the mean pixel intensity values were greater than those obtained with the 5.0 MHz transducer.

IV. DISCUSSION

The data from this preliminary study support the hypothesis that echo intensities of the pixel distribution within B–mode scans of muscle regions differ as a function of degree of muscle contraction. The data from this investigation suggest that quantitative measures of echo intensities may provide useful information related to models of lingual muscle structure and function during speech and non–speech tasks. Tongue movements are recognized to result from the combination of extrinsic and intrinsic muscles in synergistic, antagonist, or protagonistic roles. In particular, the mylohyoid acts as the primary elevator of the floor of the mouth whereas the genioglossus serves to elevate the tongue [5]. The data from this study suggest that during maximum hard press isometric tasks, the base tongue musculature acts as the primary elevator of the tongue body with contractions within the genioglossus contributing to elevation more anteriorly. Higher variability occurs in light press postures where greater structural flexibility in achieving the task can occur.

Although distinct tongue muscle coordination is required for speech production, the role of the specific tongue muscles has not been completely investigated [5]. The observed differences in A–line echo intensity values suggest a means to visibly identify and quantify the unique muscular architecture of the tongue during a range of functional tasks. The data further suggest A–line analysis of regional echo intensities may provide a quantitative method to detect and measure changes to lingual tissue as a result of pathological conditions common in motor speech disorders or oral cancers, as well as the extent of muscular recovery as a result of myofunctional rehabilitation methods.

Table 1.0
Subject 1: Mean Pixel Echo Intensity of A–Line Muscle Regions: 7.5 MHz Transducer

SEGMENT	MEAN	INT	GG	G H	MH
HARD PRESS	.2295				
ANT	.3703	.4704	.3790	.2826	.1992
MID	.3889	.5224	.3501	.3012	.2125
POST	.4455	.4895	——	.4495	.3018
LIGHT PRESS	.2479				
ANT	.3673	.4385	.3275	.2920	.3834
MID	.4120	.5008	.3837	.2587	.2976
POST	.4515	.4740	.3336	.2670	——

Note. INT: intrinsic; GG: genioglossus; GH: geniohyoid; MH: mylohyoid. Dashed lines '—' indicate muscle region not within A–line region.

Table 2.0
Subject 1: Mean Pixel Echo Intensity of A–Line Muscle Regions: 5.0 MHz Transducer

SEGMENT	MEAN	INT	GG	GH	MH
HARD PRESS	.1673				
ANT	.2435	.2838	.1873	.1903	.4426
MID	.2809	.2863	.2670	.2815	.2838
POST	.2838	.3308	.2580	.2675	.2206
LIGHT PRESS		.1737			
ANT	.3134	.2994	.3179	.3558	.3118
MID	.3098	.3093	.3433	.3146	.2761
POST	.2765	.2892	——	.2450	.2308

Table 3.0
Subject 2: Mean Pixel Echo Intensity of A–Line Muscle Regions: 7.5 MHz Transducer

SEGMENT	MEAN	INT	GG	GH	MH
HARD PRESS	.3552				
ANT	.4666	.4805	.4440	.4814	.5968
MID	.4384	.4489	.4130	.4720	.4585
POST	.3723	.3906	——	.3570	.3243
LIGHT PRESS		.3710			
ANT	.4904	.4418	.4965	.5342	.5425
MID	.4711	.4837	.4794	.4965	.4691
P OST	.3921	.4003	——	.3615	.3648

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