M-Mode Color Doppler Ultrasonic Imaging of Vertical Tongue Movement During Articulatory Movement

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Summary: To observe and estimate the movement of the tongue, ultrasonic investigation is the most harmless real-time monitoring procedure for analyzing articulatory movements. Color Doppler ultrasonic imaging is special in that it can only sample a moving target, and it can indicate the velocity and direction of the target by color and brightness in real time. This study assessed and demonstrated the validity of M-mode color Doppler ultrasonic imaging to observe the movements of the tongue during syllable repetition tasks performed by normal subjects and dysarthric patients, those affected by amyotrophic lateral sclerosis, cerebellar ataxia, Parkinsonism, and polymyopathy. When the transducer was set below the jaw, upward movement was indicated by a blue signal and downward movement was indicated by a red one on the screen of the ultrasound machine. We also measured the velocity of the tongue by contrast scale classified by 15 degrees. Thus, we could observe vertical tongue movement by a color-coded pattern after quantitative analysis. The Doppler signal patterns of normal subjects were verified by simultaneous video x-ray fluorography recordings. The findings for dysarthric patients corresponded well with previously reported features analyzed by other methods. Therefore, color Doppler ultrasonic imaging of the tongue is a useful procedure to researchers for clinical speech and voice studies.

Key Words: Color Doppler ultrasonic imaging—Ultrasonic imaging—M-mode ultrasonic imaging—Tongue movement—Motor speech disorders.

INTRODUCTION

Various methods are applied to investigate and estimate the articulatory movements, including x-ray cineradiography,[1,2] video x-ray fluorography,[3] x-ray microbeam systems,[4,5] ultrasound imaging,[6–10] tagging snapshot magnetic resonance imaging,[11,12] electromyography,[13–16] and elecromagnetic midsagittal articulometer systems.[17,18] Among these methods, ultrasound imaging is the most harmless and convenient. B-mode ultrasound imaging can visualize the morphological features of tongue gestures and the tongue locations. On the other side, M-mode ultrasound imaging can detect vertical tongue movement and reveal sectional changes in a target

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along the ultrasonic beam and is more suitable for quantitative analysis. Hirose[5] and Hirose et al.[19] reported that the velocity of an articulatory organ depends on the range of its articulatory movement, as far as pertinent articulatory movement is concerned. He also noted that the velocity of articulatory movement is not affected unless the articulated sound is disturbed, and that for a dysarthric speaker, the velocity and regularity of articulatory movement are disturbed and inconsistent. From these points of view, if the direction and velocity of articulatory organs is real time with acoustic signals, the articulatory movement can be estimated in a more simplified manner. To accomplish this result, M-mode ultrasound imaging is more suitable than B-mode imaging.

Color Doppler ultrasonic imaging is special in that it can only sample a moving target, and it can determine its velocity and direction of movement by its color and brightness in real time.[20–23] A comb filter (moving target indication filter) can cancel the effects of wall motion to which the transducer is attached. Thus, only the Doppler signals pass through the filter. With regard to direction, a red color indicates movement toward the transducer, whereas a blue color denotes movement away from it. The color brightness is proportional to the velocity of the moving target. From the degree of the brightness, the velocity can be measured and the direction of movement of the target can be determined with a color-coded pattern.

When the M-mode color Doppler ultrasonic imaging transducer is set below the jaw (the submental region), it provides a color-coded image of the vertical motion of the tongue blade. For articulatory movement associated with the phonation of /ta/, to produce explosive consonant sound /t/, the tongue moves away from the transducer and toward the alveolar edge (upward tongue movement), and the Doppler signal appears blue. When following the vowel /a/, the tongue moves close toward the oral floor and the transducer (downward tongue movement), and the Doppler signal is red. The comb filter cancels out the jaw movement and some diffused ultrasonic reflection. Figure 1 shows a schematic representation of the Doppler signals for the production of /ta/. The M-mode line display, the locus line of the vertical position of the tongue blade, appears upside down relative to the original direction.[10]

The purpose of this study was to describe and assess the validity of M-mode color Doppler ultrasonic imaging in clinical speech and voice studies.

METHODS AND SUBJECTS

All research was approved and conducted according to the institutional ethical committee at the Nippon Medical School.

Apparatus

A color Doppler ultrasonic apparatus (Toshiba Medical Sonolayer Model SSA-270A; Toshiba, Tokyo, Japan) originally for echocardiology was incorporated in this study. It comprised a single transducer mechanical sector scanner, and the frequency of the ultrasonic beam was 2.5 MHz. The transducer was placed on the midsagittal line of the submental triangle of the subject, and the M-mode was selected. In certain cases, the B-mode screen was simultaneously superimposed with the M-mode to monitor the axis of the ultrasonic beam to keep it on the midsagittal line. On the left side of the screen, a color brightness scale classified into 15 degrees in proportion to the velocity of the target was displayed. The scale velocity size was 3.7 cm/s, which was the minimum scale of the apparatus. The direction and velocity of the tongue movement based on the color (blue = upward movement, red = downward movement) and brightness was displayed on the screen. A contact-microphone was set on the skin surface of the anterior part of the neck originally as a phonocardiogram to detect the voice signal, which was displayed as a green signal on the screen of the ultrasound machine. Thus, it was possible to visually discern the correlation between the tongue movement and the voice signal.

Subjects

Five healthy native Japanese speakers (all of whom used the same Tokyo dialect) were selected.

Speech samples

The repetitive production of a monosyllable is a simple task, but it readily reveals a characteristic pattern of abnormal movements for each type of