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Application of B+M-Mode Ultrasonography in Assessing Deglutitive Tongue Movements in Healthy Adults

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

ABCDEF 1 Changtian Li
ABCDEF 1 Junlai Li
BCDEF 2 Changsheng Zhang
BCDE 1 Xiaolin Cao
BCDE 1 Nan Li
BCD 1 Danfei Song
BCF 1 Tengfei Yu

1 Department of Ultrasound, Chinese PLA General Hospital, Beijing, P.R. China
2 Anesthesia and Operation Center, Chinese PLA General Hospital, Beijing, P.R. China

Corresponding Author: Junlai Li, e-mail: li_jl@yeah.net
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Background: The purpose of this study was to evaluate tongue movements during swallowing in healthy adults using the B+M-mode ultrasonography, and to determine a common feature in the M-mode traces for quantitative measurement and individual comparison of tongue movements.

Material/Methods: Ninety healthy subjects were divided into 3 groups according to age (20–39, 40–59, and 60–80 years). The tongue movements during 3 saliva swallows were examined using real-time B+M-mode ultrasonography. The M-mode traces of tongue movements were recorded and evaluated.

Results: Both intra-individual and inter-individual differences were detected in the M-mode traces during the 3 saliva swallows. Characteristic types were seen during the individual swallowing phases of M-mode traces: 2 activity types in phase I, 2 types in phase IIb, and 3 types in phase III. However, no variations were seen during phase IIa, in which all subjects displayed a continuous upsloping trace. The average range of swallow-related tongue radial displacement during phase IIa decreased gradually with age, while the average duration of tongue movement during phase IIa increased gradually with age. These 2 trends were not statistically significant across age groups. However, differences between sexes were found in both the range of tongue radial displacement and the duration of deglutitive lingual actions during phase IIa in all 3 age groups ($P<0.05$).

Conclusions: B+M-mode ultrasonography may offer a quick and safe alternative for the preliminary evaluation of deglutitive tongue movements.

MeSH Keywords: Age Groups • Gender Identity • Swallows • Tongue • Ultrasonography

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Background

Tongue movement is associated with various diseases, such as dysphagia. A good understanding of the details of tongue movement is critical for the diagnosis and treatment of such conditions. During swallowing, the tongue plays critical roles in oral bolus formation and oropharyngeal bolus transport. Many methods have been employed to track these movements, including videofluoroscopy [1–3], electromyography [4–6], electro-magnetic articulography [7], palatography [8], magnetic resonance imaging [9], scintigraphy [10], and tongue pressure measurements [11]. Among these methods, videofluoroscopy is considered the criterion standard for deglutition and dysphagia evaluation [12–15]. This method records the movement of radiopaque barium through the upper digestive tract in real time using conventional X-rays. However, because of the risks of radiation exposure, repeated fluoroscopic evaluations are often avoided.

Real-time ultrasound is a non-ionizing imaging modality and has been used to observe deglutitive movements since the late 1970s [16–20]. Qualitative differences have been observed between patients with dysphagia and normal subjects in B-mode images, and the capability of ultrasonography for detailed, repeatable, and dynamic soft tissue imaging makes it superior to videofluoroscopy for deglutitive tongue research [21]. Moreover, ultrasonography has higher sensitivity for assessing the dynamic factors that represent the early signs of dysphagia, such as reduced or disorganized tongue movement and fragmented swallowing [21].

Methodological innovations and technological advances have advanced ultrasonography from qualitative observations to quantitative assessments of the dynamic aspects of swallowing [22]. By imaging lingual contour changes, temporal and spatial measurements can be made during swallowing in different imaging planes [23,24]. To improve ultrasound imaging stability, Peng et al. [19] developed the cushion scanning technique, which replaced the traditional hand-held transducer-skin coupling method, to minimize probe movement and inadvertent submental compression. B+M-mode ultrasonography was also used to assess lingual propulsion during oral bolus transport. With this technique, M-mode traces represent the sequential movements of the tongue dorsum during swallowing, from which quantitative measurements could be made [25]. Although combined B+M mode ultrasonography has been widely used in assessing deglutitive tongue movements, no conclusive results have been obtained thus far [26–28]. For example, Galen et al. [28] reported that none of the subjects examined by real-time B+M-mode ultrasonography showed a clearly reproducible trace.

For deglutitive ultrasound to reach clinical utility, it is necessary to determine a common feature in the M-mode traces as a reference, particularly to enable accurate inter-subject comparisons. For example, in deglutitive videofluoroscopy, a common measurement for image-based displacement is the subject-specific distance from the anterior-inferior corner of one cervical vertebra to that of another [29].

Peng et al. [19] divided the swallowing process into 5 phases (phases I, IIa, IIb, IIIa, and IIIb) based on specific inflection points identified on the M-mode traces, which is used to determine and interpret variations within each swallowing phase of the trace sequence. It also has been shown that tongue movements during swallowing have age-related changes [30]. In this study, we used B+M mode ultrasonography to observe the tongue movements during swallowing in normal adults of different age groups. We recorded the swallow-related activity types of each phase to determine a common feature as measurement reference in the M-mode traces and to establish reference measurements for data normalization.

Material and Methods

Patients

Ninety healthy participants (45 females, 45 males) were included this study. The exclusion criteria were: (1) congenital malformation of oral cavity, (2) history of oral or orthodontic surgery, and (3) disease processes that may cause deglutition disorders, such as dysphagia. The participants were divided into 3 age groups – 20–39 years, 40–59 years, and 60–80 years – with 15 males and 15 females in each age group. Descriptive characteristics of the subjects are shown in Table 1. This observational study was approved by the Ethics Committee of Chinese PLA General Hospital, and written informed consent was obtained from all subjects.

Ultrasonography procedure

A Philips IU22 (Philips Medical Systems, Bothell, WA) ultrasound machine equipped with a C5-2 convex transducer was used. The transducer was placed submentally in the midsagittal plane, centered between the anterior border of the hyoid bone and the posterior border of the mandibular symphysis, with the central sound wave running perpendicular to the Frankfort horizontal plane. Subjects were examined in the upright position with the head and transducer fixed by a special device to avoid relative movements between them (Figure 1). The M-mode scanning section was set at the mid-portion of the tongue at a distance of 3–4 cm from the symphysis. With the subject's head kept in neutral position, the subject was asked to perform a saliva swallow 30 s after drinking 3–5 mL of mineral water. Three saliva swallows were recorded for each participant. The latex bag filled with water, the "cushion technique," as described by Peng et al. [31], was not used.

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Table 1. Study population demographics (N=90).

Age group	Gender	Median age in years (range in years)	Mean weight in kg (SD)	Mean height in cm (SD)
20–39 years	15 m; 15 f	29.3 (20.4–39.2)	69 (7.8)	175 (9.2)
40–59 years	15 m; 15 f	50.6 (40.2–59.1)	66 (9.6)	179 (6.6)
50–80 years	15 m; 15 f	70.4 (60.1–80.5)	71 (11.2)	173 (9.0)

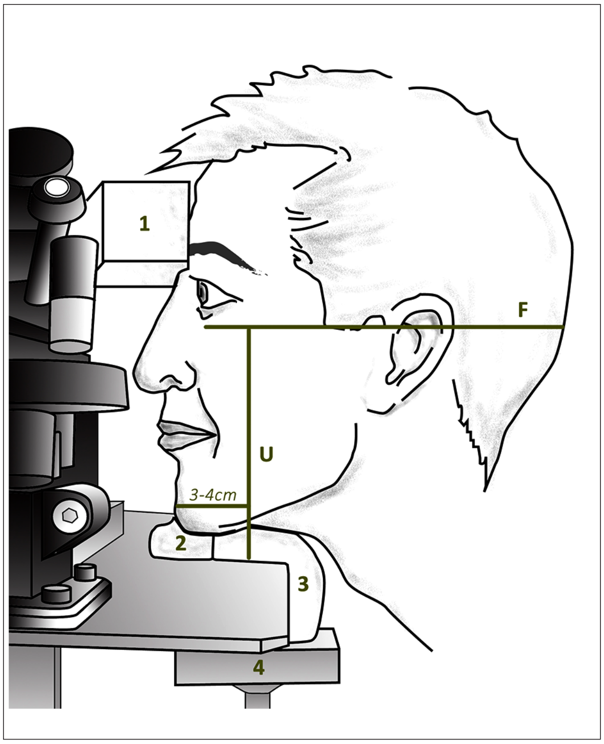

Figure 1. Position of the subjects for ultrasonography: (1) forehead rest; (2) silicone support for the symphysis; (3) ultrasound transducer; (4) transducer holder; (F) Frankfort horizontal plane; (U) central ultrasound beam.

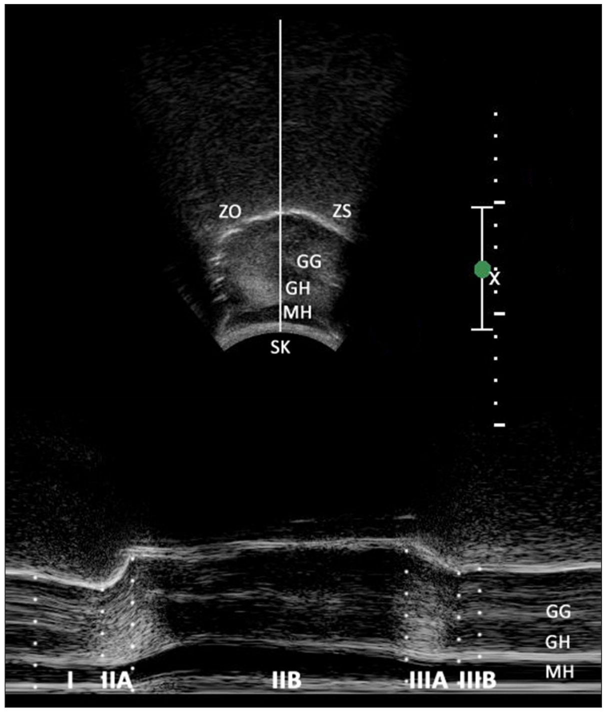

Figure 2. B+M-mode ultrasound image. Top: Labeled B-mode image of the tongue. (ZO) the dorsal tongue surface; (ZS) tip of the tongue; (GG) genioglossus muscle; (GH) geniohyoid muscle; (MH) mylohyoid muscle; (SK) ultrasound transducer. Bottom: M-mode image with phase labeling.

Statistical analysis

Data are presented as mean ± standard deviation. SPSS version 13.0 (SPSS Inc.; Chicago, IL) was used for statistical analysis. An analysis of variance (ANOVA) test was used for the comparison of variables in the M-mode images among the 3 age groups. *P* values <0.05 were considered statistically significant.

Results

B+M-mode images of tongue movements

In the M-mode images, the tongue was characterized by a hyperechoic line that synchronized with the movements of tongue during swallowing (Figure 2). Both intra-individual and inter-individual differences during the 3 saliva swallows of each subject were examined. Although the amplitude and duration of the M-mode traces differed, characteristic types could be identified during the following individual swallowing phases:

(1) Phase I

Type 1. Prior to swallow initiation, the tongue tip contacted the maxillary teeth or the incisive papilla, and the posterior portion of the tongue was raised cranially. During swallow initiation, the central part of the tongue moved with a caudal concavity that appeared as a downward slope in the M-mode tracing.

Type 2. Only the posterior part of the tongue moved in this type. Both the anterior and mid-portions of the tongue remained in

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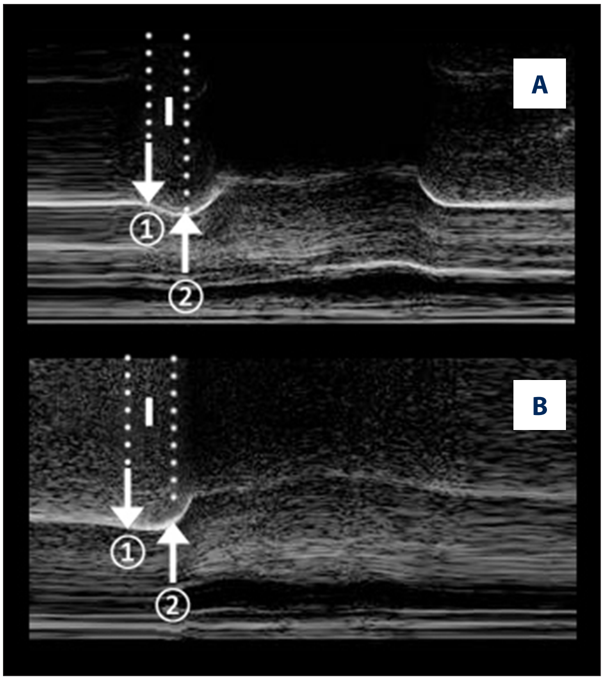

Figure 3. M-mode ultrasound tracings with phase I, indicated by arrows, demonstrate characteristic type 1 (**A**) and type 2 (**B**) phase I movements.

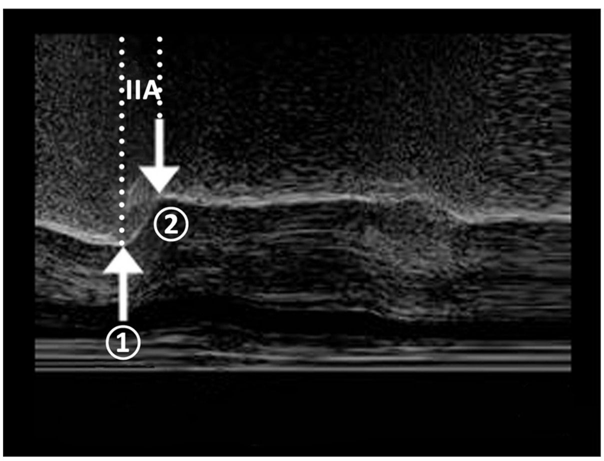

Figure 4. M-mode ultrasound tracing demonstrates phase IIa, indicated by arrows.

contact with the hard palate. The M-mode images demonstrated an easily identifiable hyperechoic horizontal line formed by the contraction of the tongue muscles (Figure 3).

(2) Phase II a

The mid-portion of the tongue moved upwards to contact the palate in this phase. An upward slope in M-mode traces was found in every subject, and no variations were detected (Figure 4).

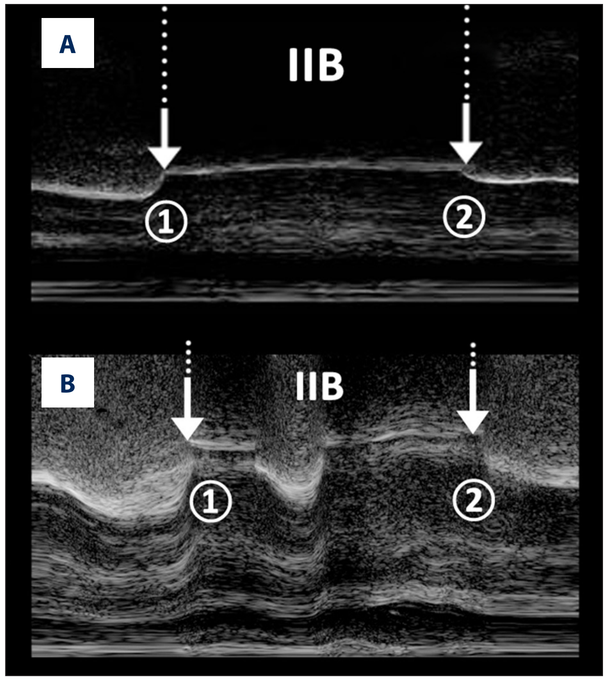

Figure 5. M-mode ultrasound tracings with phase IIb, indicated by arrows, demonstrate characteristic type 1 (**A**) and type 2 (**B**) phase IIb movements.

(3) Phase II b

Type 1. The mid-portion of the tongue remained in contact with the palate, which was represented by a horizontal trace in M-mode images.

Type 2. Compressive peristaltic waves of the tongue surface producing an inverted "V" trace (a downward slope followed by an upward slope) in the M-mode images. (Figure 5)

(4) Phase III

Type 1. The mid-portion of the tongue moved downwards then upwards to return to the state of rest at the end of the oral swallowing process. In the M-mode images, a downward slope was recorded in phase IIIa and was always followed by an upward trace in phase IIIb, which appeared as a "U" or "V."

Type 2. The mid-portion of the tongue returned to the rest state. In the M-mode images, phase IIIa revealed a downward trace that was then followed by a horizontal line during phase IIIb.

Type 3. The tongue dorsum remained on the palate after swallowing. In the M-mode images, both phases IIIa and IIIb demonstrated a single horizontal trace (Figure 6).

Table 2 shows the ratio of each phase subtype during different swallowing phases. In phase I, the frequency of type 1

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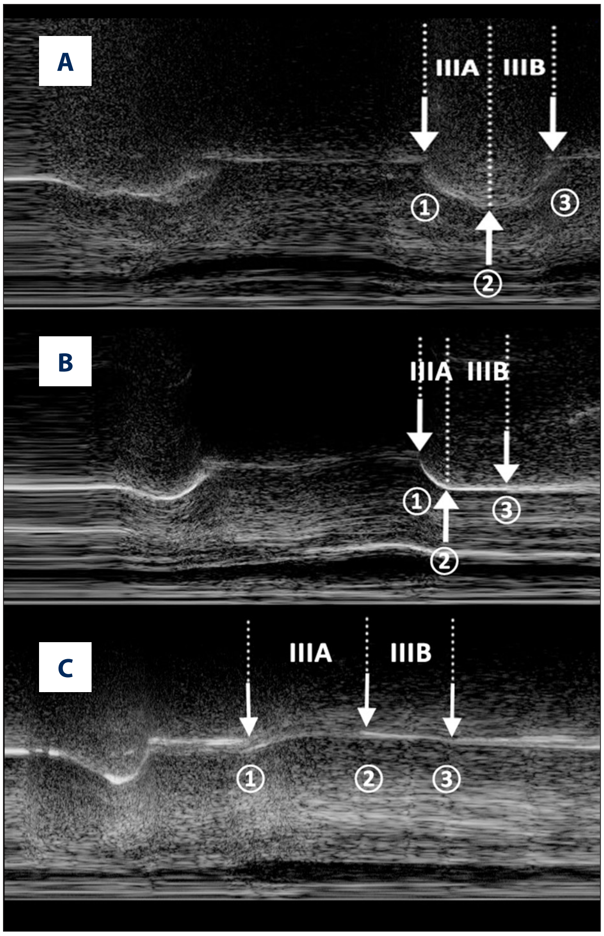

Figure 6. M-mode ultrasound tracings, with phase IIIa occurring between arrows 1–2 and phase IIIb occurring between arrows 2–3, demonstrate characteristic type 1 (**A**), type 2 (**B**), and type 3 (**C**) phase IIIa and IIIb movements.

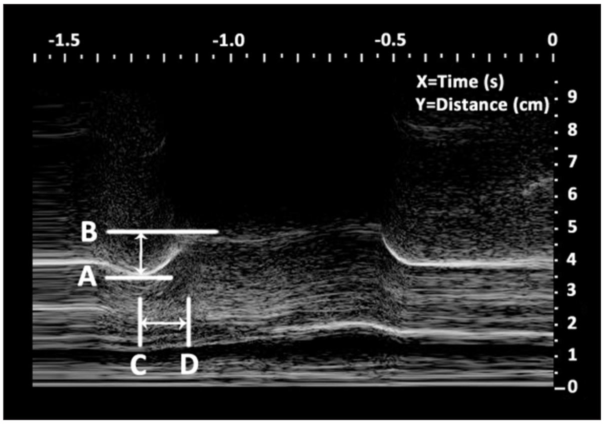

Figure 7. Ultrasound image demonstrates quantitative measuring using M-mode. Range (A, B) denotes the tongue's swallow-related radial displacement during phase IIa and the duration of tongue movement (C, D).

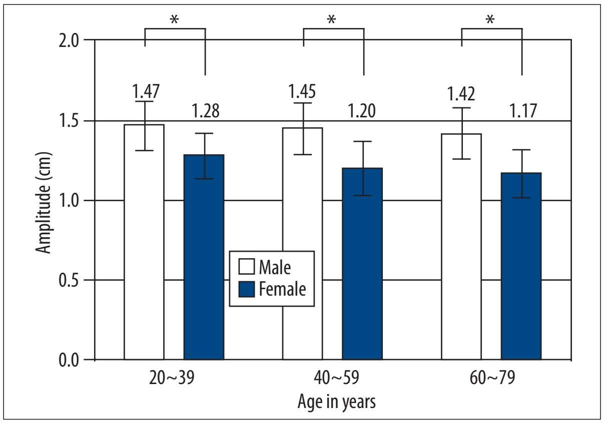

Figure 8. Age and sex comparison of tongue swallow-related radial displacement during phase IIa.

Table 2. Distribution ratio of different types in the four swallowing phases.

Phase	Phase I	Phase IIa	Phase IIb	Phase IIIa and IIIb
Type 1	82.60%	–	28.10%	67.80%
Type 2	17.40%	–	71.90%	11.50%
Type 3	–	–	–	20.70%

was much higher than type 2. In phase IIb, type 2 was more frequent than type 1, because the mid-portion of the tongue typically dipped instead of remaining in contact with the palate. In phase III, type 1 outnumbered both type 2 and type 3. However, in phase IIa, no variations were observed. All subjects displayed a continuous upward trace in M-mode images of phase IIa during 3 saliva swallows.

For this reason, spatial and temporal measurements of phase IIa were made from the M-mode images. The swallow-related radial displacement of the mid-tongue surface during phase IIa was measured, as well as the duration of tongue movement (Figure 7).

Range of tongue swallow-related radial displacement during phase IIa

Figure 8 shows the average swallow-related radial displacement of the mid-tongue surface during phase IIa. The average displacement gradually decreased with age in both females and

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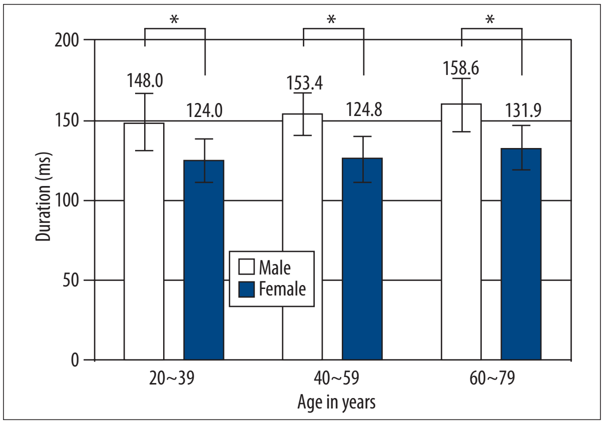

Figure 9. Age and sex comparison of the duration of tongue movement during swallowing during phase IIa.

males, but these trends did not reach statistical significance among the 3 age groups (*P*=0.116 and *P*=0.726, respectively). However, males demonstrated a significantly greater degree of displacement than females across all age groups (*P*=0.002, *P*<0.001, and *P*<0.001, respectively).

Duration of tongue movement during phase IIa

Figure 9 shows the average duration of tongue motion during phase IIa. The average duration during phase IIa gradually increased with age in both females and males, although these trends did not reach statistical significance among the 3 age groups (*P*=0.284 and *P*=0.237, respectively). However, males had a significantly longer swallowing duration than females across all age groups (*P*<0.001, *P*<0.001, and *P*<0.001, respectively).

Discussion

The stages of swallowing are divided into oral, pharyngeal, and esophageal phases. Because ultrasonography is not well suited to analyze the esophageal and pharyngeal phases, our study is limited to the oral phase only. Because the floor of the mouth is an accessible and relatively small area, ultrasonography is able to provide valuable information about deglutitive tongue movements, and the B+M-mode imaging technique allows us to depict tongue muscle contractions and positional changes of the tongue surface as time-amplitude diagrams.

In this study, the cushion scanning technique (a latex bag filled with water placed under the chin) [31] was not used because this stabilizing design increases the distance between the transducer and the floor of mouth, and the dispersal of the ultrasound waves through the cushioning layer could decrease image resolution [28]. Instead, our subjects were examined in the upright position with the head and transducer fixed by a special device, which ensured that the subject's head and transducer remained in a constant position. Furthermore, because the volume [32,33], taste [34–36], consistency [32,37,38], and position [39] of the bolus being swallowed affect tongue movements, the subjects were instructed to perform saliva swallows and drink 3–5 ml of water between the swallowing to create the most reproducible swallows.

In the M-mode images, it is practically impossible to find 2 subjects with identical swallow-related traces, as there are variations in tongue innervation, size, and anatomy of the oral cavity. The subjects in our study differed in both age and sex, and we observed both inter-individual and intra-individual differences during the 3 saliva swallows for each subject. Although characteristic variants were observed in most of the individual M-mode swallowing phases, phase IIa was depicted as a steep upward trace in all subjects. This finding is closely related to the transport function of the tongue. After "scooping up" saliva in phase I, the tongue moves upward to contact the palate in phase IIa. Since no variants were found in this phase, we considered spatial and temporal measurements of phase IIa as the optimal common measurement reference.

Most early studies have compared the parameters of the M-mode traces between normal subjects and patients with dysphagia. Catriona et al. found that tongue movements during swallowing have age-related changes [30,40]. In our study, the swallow-related radial displacement and duration of phase IIa in the M-mode images were measured and compared across the 3 age groups. It was suggested that the amplitude of phase IIa decreased gradually with age, while its duration increased gradually with age. These trends were not statistically significant across age groups. Because the effect of age on tongue movement is small, this method of assessing swallowing function does not need compensation for patient age.

In our study, statistically significant sex-related differences were observed in both the amplitude and duration of tongue movement during phase IIa in all 3 age groups. Male subjects demonstrated longer tongue movement distance than females, which could potentially be due to overall larger tongue size and stronger muscular contractions. Males also showed a longer motion duration than females, which could be related to heightened sensitivity of the sensory receptors of the male respiratory tract [41].

Deglutitive tongue movements are frequently examined using videofluoroscopy in ENT and speech therapy. According to Watkin, ultrasonography can also serve this purpose [42]. However, when deglutitive tongue movements were investigated by B+M-mode ultrasonography in the past, researchers encountered inherent ultrasonographic limitations, such as artifacts, noise, refractions, and extraneous reflections. Furthermore, as the M-mode traces themselves varied significantly, it has been

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difficult to determine common features or establish measurement references, which has hindered the application of B+M-mode ultrasonography. Our findings suggest that the spatial and temporal measurements of phase IIa within the M-mode traces can be used as the common measurement reference.

This investigation is limited to swallowing in the oral phase, since B+M ultrasound is not particularly well suited to analyzing the pharyngeal and esophageal phase. Videofluoroscopy or cine-MRI would be much more appropriate for such an analysis. Despite its limitations, ultrasonography still provides valuable information about tongue movements.

Conclusions

In the M-mode traces of tongue movement during swallowing, a linear upward slope was detected in phase IIa, which could be readily quantitatively measured using real-time B+M-mode ultrasonography. The swallow-related radial displacement of the tongue and the duration of phase IIa can thus be used for comparison among various swallowing types and treatments to evaluate outcomes. This method can serve as a practical, noninvasive tool for preliminary evaluation of tongue deglutitive movements.

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Conflict of interest

None.

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