

## Differential diagnosis between infantile and mature swallowing with ultrasonography

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**SUMMARY** In order to investigate the difference in tongue movement between visceral (infantile) and somatic (mature) swallowing patterns, 12 visceral (seven females, five males) and 14 somatic (eight females, six males) swallowers were examined with the B+M-mode ultrasound technique. Movements of the tongue tip and submental musculature during swallowing were recorded on video cassette and evaluated with a personal computer.

The results demonstrated that the tongue dorsal surface, which was thought to be ideal for observing tongue function, was not suitable for differentiating between visceral and somatic swallowing patterns. Conversely, the movements of the genioglossus muscle were found to be identical within groups but significantly different ( $P < 0.01$ ) from each other between the two swallowing patterns. Therefore, the genioglossus muscle can serve as a reliable means for differentiating between visceral and somatic swallowers.

### Introduction

The investigation of tongue function is an important part of oral diagnosis. Many studies have demonstrated that tongue thrust plays an important role in the aetiology of open bite as well as in the relapse of treated open bite patients (Brückl and Träger, 1962; Graber, 1963). In order to determine the aetiology of tongue dysfunction, it is important to identify patients with abnormal swallowing patterns.

Basically, three swallowing patterns have been described: visceral, somatic, and inconstant (Rakosi, 1970; Graber *et al.*, 1985). Visceral swallowing is that which exists at birth and is also termed 'infantile swallowing'. It is characterized by a forward movement of the tongue tip. A visceral type of swallow can persist well after the fourth year of life. However, it is then considered as a dysfunction or abnormality because of its association with certain malocclusions (Graber *et al.*, 1985). Normally, a visceral swallowing pattern changes gradually into a so-called mature or somatic swallowing pattern. Cranial movement of the tongue tip is typical of somatic swallowing and does not cause pressure on teeth, but on the incisive papilla. Inconstant swallowing is characterized as a pattern of swallowing during the transitional period between infantile and somatic swallowing (Graber *et al.*, 1985).

Many previous studies on swallowing have been carried out using radiocinematography (Ekberg and Nylander, 1982; Ekberg and Hillarp, 1986). However,

due to the exposure to radiation, use of this technique can only be limited. In addition, the contrast medium swallowed by patients during radiocinematography identifies only fluid or bolus swallowing patterns and not the more frequent saliva swallowing.

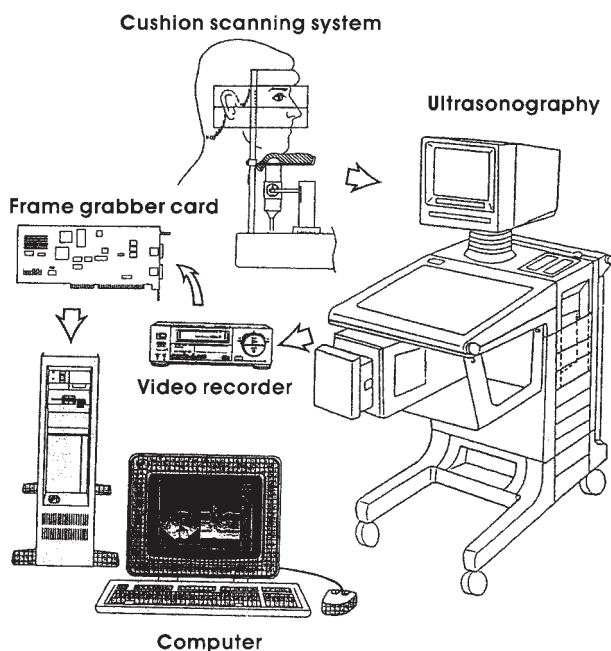
Electromagnetic articulography has also been employed in previous studies of tongue function (Tuller *et al.*, 1990; Schweska-Polly *et al.*, 1992). However, it has a number of disadvantages, e.g. it needs considerable chairtime to set up the equipment, and it is difficult for the subject to swallow normally with several electrodes plus wires attached to the dorsum of the tongue.

Ultrasonography has been used statically to investigate sialolithiasis, salivary glands, cysts and tumours in the oral region (Mann, 1984; Steiner, 1994). Dynamic investigations of tongue movement through submental scanning have also been described (Shawker *et al.*, 1983; Wein *et al.*, 1988; Müßig, 1992; Fuhrmann and Diedrich, 1993). However, these early ultrasound studies used direct transducer-skin coupling scanning. As the transducer was held by hand in direct contact with the submental skin surface it could be accidentally moved with the skin of the submental area during swallowing and articulation. Furthermore, the soft tissue of the submental area is likely to be compressed, resulting in unfavourable distortion of the submental morphology.

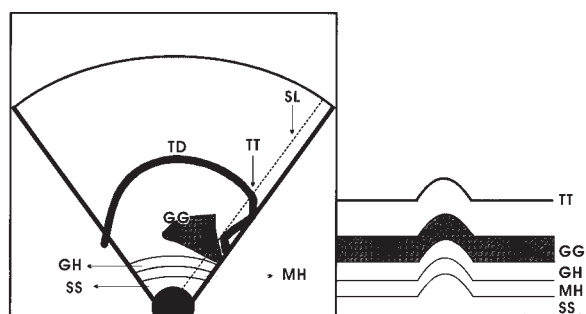
The cushion scanning technique (CST) was developed to eliminate these problems (Peng and Miethke, 1994; Peng *et al.*, 1996). Using an ultrasound probe holder

and a head support in combination with a cushion device, exact ultrasound imaging as well as quantitative measurement of tongue movements can be undertaken (Peng *et al.*, 2000).

The purpose of this study was to investigate non-invasively the visceral swallowing pattern and to compare it with the somatic swallowing pattern using CST and computer-aided B+M-mode ultrasonography, and to determine if a discernible difference exists between visceral and somatic swallowing which could be used as a means for differential orthodontic diagnosis.



**Figure 1** Experimental set-up for the cushion computer-aided B+M-mode ultrasonography.

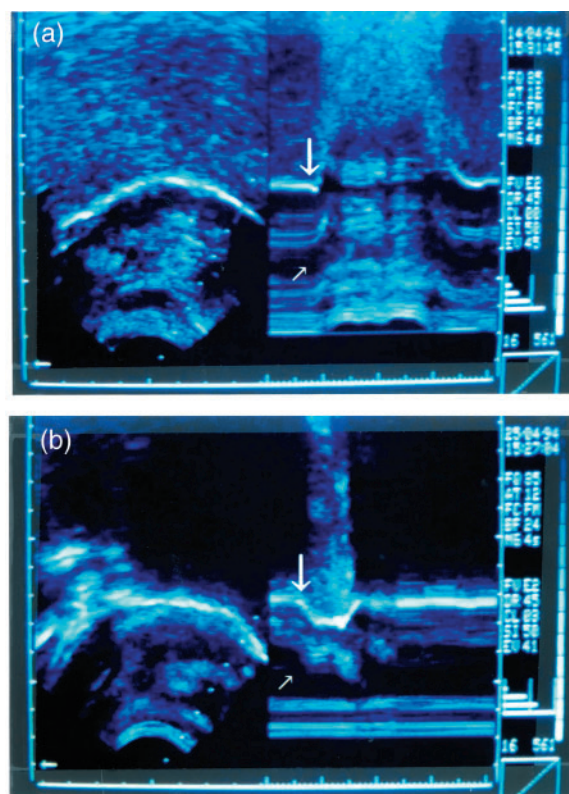


**Figure 2** Schematic illustration of the B+M-mode ultrasonogram and associated anatomical structures which can be viewed in the B- and M-mode images. SL, scan line; GG, genioglossus muscle; GH, geniohyoid muscle; MH, mylohyoid muscle; TD, tongue dorsum; TT, tongue tip; SS, submental skin and subcutaneous connective tissue.

## Subjects and methods

The experimental set-up used in the CST computer-aided B+M-mode ultrasonography technique is shown in Figure 1. The real-time ultrasound system was a mechanical sectoring scanner (Sonoline SL-1, Siemens, Berlin, Germany) with a 3.5 MHz transducer, a sectoring angle of 100 degrees, and a frame rate of 30 frames per second. The ultrasound signals were recorded on a video cassette recorder (EV-C45E, Sony, Tokyo, Japan) which allowed for replay and observation in slow motion or frame by frame mode.

The Sonoline SL-1 allows visualization of the scanned image in different modes. One is the so-called B-mode or brightness mode (Figures 2 and 3a,b), which provides two-dimensional black and white images in real time. The M-mode, or motion mode, shows the movements of certain points of the tongue along an adjustable scan line, the so-called M-position, on B-mode images. The



**Figure 3** (a) B+M-mode ultrasonogram of somatic swallowing. The left side shows the B-mode image with a scan line in the anterior tongue region. The M-mode image (right side) illustrates movements of various anatomical structures along the scan line as a time-amplitude diagram. Note the upward movement (slope) of both the anterior tongue dorsum (large arrow) and the genioglossus muscle (small arrow) in the initial phase of swallowing. (b) B+M-mode ultrasonogram of a visceral swallower. Note the downward movement (slope) of both the anterior tongue dorsum (large arrow) surface and the genioglossus muscle (small arrow) in the initial phase of swallowing.

change in grey scale along the M-position can be traced over time and yields a time-magnitude diagram. It permits measurement of form, size and volume. The B+M-mode image allows for simultaneous presentation of a B- and M-mode image on one sonogram, which is ideal for investigations of dynamic tongue functions.

The transducer was positioned perpendicularly with the scanning sector through the midsagittal plane (defined as a sagittal plane through the anatomic landmark 'nasion') with the transducer holder. The central beam of the scan sector was positioned in the middle of the distance between the posterior border of the symphysis and the anterior margin of the hyoid bone in the midsagittal plane. The M-position on the B-mode images was positioned through the tongue tip and also scans through the genioglossus, geniohyoid and mylohyoid muscles. Muscle movements were measured on the lower surface (the surface facing the ultrasound probe) of each muscle on the M-mode image.

For quantitative analysis, the B+M-mode images were transferred to an IBM compatible personal computer (Intel Pentium 200 MHz, 64 MB RAM, and Windows 98 as the operating system) via a frame grabber (VIGA Windows, Visionetics International, Taipei, Taiwan). Using the graphics program (PhotoImpact 4.0, Ulead Inc., Taipei, Taiwan) the M-mode images were digitized allowing the range of tongue movement to be determined in millimetres for various points along the scan line.

In order to compare visceral with somatic swallowing, subjects with an inconstant swallowing pattern or a history of myofunctional therapy were excluded from the final evaluation. Patients with lingual or palatal orthodontic appliances, such as transpalatal or lingual arch appliances, were also excluded. Twenty-six subjects fulfilled the criteria, 12 (seven females and five males) with visceral swallowing and 14 (eight females and six males) with somatic swallowing. The age distribution of the examined subjects is shown in Table 1. The patterns were confirmed clinically using traditional lip retracted inspection and were examined with CST computer-aided B+M-mode ultrasonography.

In an attempt to standardize swallowing while influencing the individual pattern as little as possible, all subjects were asked to swallow 3–5 ml of water. Following a 10 second rest period they were asked to

swallow once more without water (an empty swallow). Only empty swallows were evaluated in this study. A Student's *t*-test was used to compare the difference in direction and quantity of movements between visceral and somatic swallowing.

All measurements were performed by the same investigator to eliminate inter-examiner variability. The intra-examiner errors for the ultrasound measurements were investigated on repeated measurements of a randomly selected participant by the same examiner with a 7 day interval. The coefficient of variation (CV) was calculated for these measurements. The ultrasound measurement errors had a CV of 2.4 per cent for duration and 1.28 per cent for magnitude. In order to evaluate the intra-individual reproducibility, one randomly selected participant was asked to swallow 10 times at the same visit. The measurements of duration had a CV of 3.41 per cent and for magnitude of 3.66 per cent. In addition, standard reference material (SRM) was designed to evaluate the accuracy of the CST computer-aided B+M-mode ultrasonography technique. The results indicated that the distortion was 0.93 per cent between the dimensions of the SRM and that measured with the experimental set-up.

## Results

All M-mode images of both the visceral and somatic groups were carefully observed and correlated with tongue movements on the B-mode images during each phase of swallowing, referring to the definitions of Graber *et al.* (1985) (Figure 3a,b):

Phase I: the tongue tip moves from the rest position into contact with the palate while the middle of the tongue shows its most concave form.

Phase II: from the end position of phase I until the middle of the tongue becomes convex and contacts the palate.

Phase III: from the end position of phase II until the posterior tongue dorsum is in close contact with the palate while at the same time the hyoid bone is in its most anterior position.

Phase IV: from the end position of phase III until the tongue drops down to its original rest position.

**Table 1** The age distribution of the examined subjects.

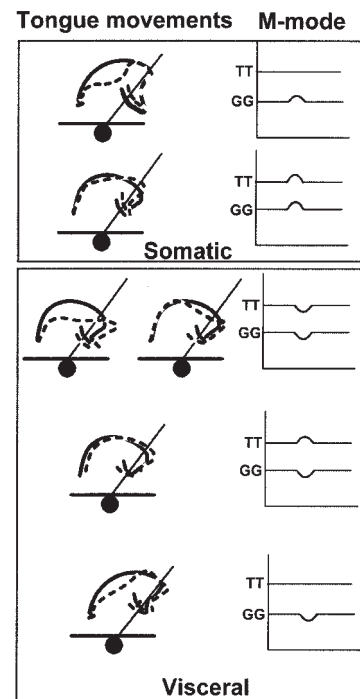
	Age range	Average age
Selected subjects ( <i>n</i> = 26)	8 years 3 months–25 years 7 months	14 years 7 months
Visceral group ( <i>n</i> = 12; 7 female, 5 male)	8 years 3 months–13 years 1 month	10 years 3 months
Somatic group ( <i>n</i> = 14; 8 female, 6 male)	11 years 11 months–25 years 7 months	17 years 9 months

The M-mode signal of the tongue revealed a flat shape when the tongue was at rest (Figure 3). During the initial phase of swallowing (phase I) the tongue moved from its rest position which caused vertical changes in the previously flat M-mode lines. Typically, somatic swallowers revealed an identical upward movement of the tongue surface and genioglossus muscle, which was displayed on the M-mode images as upward slopes in the initial swallowing phase (Figure 3a). Three of the 14 somatic swallowers were found to have a relatively high tongue rest position with the tongue tip being in contact with the anterior palate or the upper anterior teeth before the swallowing exercises (Table 2). In these subjects the upward tongue movement during swallowing was quite small (less than 1 mm movement of the genioglossus) and an upward slope of the M-mode signal of the tongue tip was not clearly recognizable. However, the M-mode images of the genioglossus muscle revealed an upward slope in all somatic swallowers irrespective of the varying magnitudes of tongue tip movements.

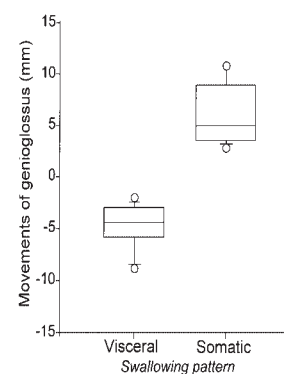
In the visceral group, tongue tip movements were found to be highly variable (Figure 4). In two of the 12 visceral patients the tongue tip moved upward and forward during the initial phase of swallowing (phase I) (Figure 3b), in six subjects it moved forwards with hardly any vertical changes, and in four subjects it moved downward and forward (Table 2). In contrast, the genioglossus muscle demonstrated a downward movement during the initial phase of swallowing in all visceral swallowers, which was in contrast to the genioglossus muscle movement of all somatic swallowers, who all showed upward movements in phase I of swallowing. Statistical evaluation of the genioglossus muscle movements between visceral and somatic swallowing revealed a highly significant difference ( $P < 0.01$ ) (Figure 5).

In the subsequent three phases of swallowing, despite some differences in the magnitude of movements, the tongue tip and genioglossus muscle demonstrated the same direction of movement in both the visceral and somatic groups.

The movements of the geniohyoid and mylohyoid muscles were found to be difficult to measure with the anterior M-position scan line as they contract in a horizontal rather than vertical manner.



**Figure 4** Schematic illustration of the observed movements of the tongue tip and the genioglossus muscle on B-mode images and associated movement patterns on M-mode images. TT, tongue tip; GG, genioglossus muscle.



**Figure 5** Significant difference ( $P < 0.01$ ) in the direction of movement of the genioglossus muscle between visceral and somatic swallowing.

**Table 2** Measured movements of the tongue tip (TT) and the genioglossus muscle (GG) of the experimental groups.

Swallowing pattern		Movements		
		Upward (>1 mm)	Slight (<1 mm)	Downward (>1 mm)
Visceral ( $n = 12$ )	TT	2	4	6
	GG	0	0	12
Somatic ( $n = 14$ )	TT	11	3	0
	GG	14	0	0



## Discussion

Observation of tongue movements during swallowing with the lips apart is the simplest clinical method for diagnosing visceral swallowing. However, the lips are actively involved in the act of swallowing (Rakosi, 1970; Graber *et al.*, 1985). Forced opening of the lips may disturb an individual swallowing pattern. Use of the ultrasound technique provides a non-invasive visualization of tongue movements while maintaining an individual's lip seal. A further advantage of ultrasonography is that no foreign body is required in the oral cavity, allowing more natural swallowing behaviour. In addition, as ultrasound causes no pathological side-effects, repeated application can be carried out. Ultrasound investigation of tongue movements requires only a short chairtime and the images can be recorded on video cassette and then replayed in slow motion.

Water swallowing has been ultrasonographically investigated in previous tongue studies (Shawker *et al.*, 1983; Wein *et al.*, 1988; Müßig, 1992; Fuhrmann and Diedrich, 1993). The results show that the tongue tip usually retracts while taking up water (Shawker *et al.*, 1983; Fuhrmann and Diedrich, 1993). However, as the tongue of visceral swallowers tends to move forward during swallowing, this pattern might be obscured or masked by swallowing water. The results of this study demonstrate that as phase I is the optimal phase for diagnosing visceral swallowing, water swallowing should be avoided when attempting to diagnose a visceral swallowing pattern. For this reason the participants in this study performed a standard empty swallow 10 seconds after swallowing 3–5 ml of water. An empty swallow as standard has the following advantages: (1) there is no need to determine the optimal volume of water for different oral cavities; (2) after swallowing, the remaining water in the oral cavity facilitates the ensuing empty swallow, which is considered to be equivalent to habitual saliva swallowing; (3) it may shorten the time span between two habitual swallowing exercises and thus save time.

The tongue is a muscular organ, the muscles of which can be divided into two types: extrinsic and intrinsic. Extrinsic muscles are the styloglossus, palatoglossus, hyoglossus, and geniohyoid. The intrinsic muscles are composed of longitudinal and transverse muscles and probably also vertical muscles. Among these muscles the genioglossus is the most important for forward movement of the tongue (DuBrul, 1988). The genioglossus originates on the genial tubercle of the mandible and inserts into the anterior and central parts of the tongue. In this study the selected M-position was directed through the genioglossus muscle near its origin. During genioglossus muscle contraction of a visceral swallower the tongue tip is pulled forward, while the muscles move downwards and forwards towards their origin. This

downward component of genioglossus muscle movement can be detected by M-mode sonography as a downward slope in the initial phase of swallowing. On the other hand, due to little or no (may be near isometric) contraction of the genioglossus muscle in somatic swallowers, the muscle tends to be raised with the rest of the tongue because of the action of elevating muscles and as a result an upward slope is demonstrated in the initial phase of swallowing.

In visceral swallowers the activity and strength of the genioglossus seems greater than in individuals with a somatic swallowing pattern. Even in patients in whom the tongue tip pressed on the anterior teeth or the incisive papilla preventing it from moving forward, a forward and downward contraction of the genioglossus could still be observed. As tongue tip movements proved to be inconsistent in visceral swallows, it is important that genioglossus muscle movements are used to distinguish between visceral and somatic swallowing even when the tongue tip moves atypically.

Three scan lines (anterior, middle and posterior M-positions) for producing tongue M-mode images were tested in the planning phase of this study. The posterior M-position proved to be unsuitable for investigating swallowing, because the hyoid bone always moved forward during swallowing which regularly caused ultrasound reflections that interfered with the observation of the posterior parts of the tongue. The middle M-position scans through the central part of the tongue were only rarely compromised by interference with the hyoid bone. However, the tongue tip and most of the genioglossus is excluded on the middle M-mode scan image. As a consequence, it is not suitable for differentiating a visceral or somatic swallowing pattern. In the anterior M-position as the scan line passes through mylohyoid, geniohyoid and genioglossus muscles and also the anterior tongue surface/tongue tip, this position was considered as the optimal M-position for studying visceral swallowing and was used in this investigation.

Ultrasound has the physical characteristic that it reflects more at the interface between two different media. Consequently, as ultrasound transmits into a muscle, a white acoustic line representing the muscle surface is displayed on the ultrasound image which helps in identifying the contour of the muscle, which is illustrated as darker in colour. In function, muscles may retract, changing both their shape and cross-sectional area; in order to simplify measurement in this situation, Hirai *et al.* (1989) and Peng *et al.* (2000) applied M-mode ultrasonography with a defined scan line. As a muscle functions as a unit, movements of the whole muscle can be broadly derived from the data from a single selected scan line.

The upper portion of the genioglossus muscle which passes into the tongue dorsum and the upper surface of

the muscle is difficult to identify ultrasonographically. In order to survey muscle movement in a standard manner, the movements of the lower surface (that facing the ultrasound probe) were measured on the M-mode image in this investigation, so providing a defined line for comparing muscle movement between subjects.

Previous studies (Shawker *et al.*, 1983; Wein *et al.*, 1988) have reported that, in conditions similar to the current investigation, during phase I (also referred to as the initial, collective, shovel or preparatory phase) the tongue is under voluntary control. In phases II, III and part of IV of swallowing, tongue movements are reflex. In the present study obvious differences in tongue movements between the visceral and the somatic groups could only be identified in phase I. In both groups, all tongue tips were kept in contact with the anterior teeth or palates during phases II and III, and then showed a downward pattern in phase IV when the tongue returned to its rest position. Therefore, phases II, III and IV were considered to be of limited value in distinguishing between visceral and somatic swallowing with the anterior M-position scan line. Further studies are needed to investigate: (a) whether visceral and somatic swallows also differ in the later phases, or whether phase I is the only phase that differentiates between the two patterns, (b) whether a visceral swallower can be trained to become a 'true' somatic swallower through myo-functional therapy which corrects mainly the tongue movement in phase I.

A visual soft tissue examination using ultrasonography is easy, safe and may be performed repeatedly at any time and in real time as required. With CST, quantitative analysis of tongue dynamics can also be accomplished. In this study, two groups with extremely different patterns were intentionally selected so as to exclude all inconstant patterns and borderline cases, but in future studies these should be included. The sensitivity and specificity of this ultrasound technique in differentiating and/or classifying swallowing patterns should be examined in a blind process.

## Conclusions

1. Ultrasound is a valuable tool for studying tongue function.
2. In the initial phase of swallowing, the genioglossus muscle is a means of differentiating between a visceral and a somatic swallowing pattern.
3. Observation of the dorsum of the tongue or tongue tip with ultrasonography is of limited value for the differentiation of visceral and somatic swallowing.
4. The genioglossus muscle appears to play an important role in visceral swallowing. Further studies on the genioglossus muscle may help to understand better the aetiology of persisting visceral swallowing.

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