

# Piecemeal deglutition and dysphagia limit in normal subjects and in patients with swallowing disorders

Cumhur Ertekin, İbrahim Aydoğdu, Nur Yüceyar

## Abstract

**Objective**—Before the advanced evaluation of deglutition and selection of a treatment method, objective screening methods are necessary for patients with dysphagia. In this study a new electroclinical test was established to evaluate patients with dysphagia.

**Methods**—This test is based on determining piecemeal deglutition; which is a physiological phenomenon occurring when a bolus of a large volume is divided into two or more parts which are swallowed successively. The combined electrophysiological and mechanical method used to record laryngeal movements detected by a piezoelectric transducer, and activities of the related submental integrated EMG (SM-EMG)—and sometimes the cricopharyngeal muscle of the upper oesophageal sphincter (CP-EMG)—were performed during swallowing. Thirty normal subjects and 66 patients with overt dysphagia of neurogenic origin were investigated after detailed clinical evaluation. Twenty patients with a potential risk of dysphagia, but who were normal clinically at the time of investigation, were also evaluated to determine the specificity of the test. All subjects were instructed to swallow doses of water, gradually increasing in quantity from 1 ml to 20 ml, and any recurrence of the signals related to swallowing within the eight seconds was accepted as a sign of dysphagia limit.

**Results**—In normal subjects as well as in the patients without dysphagia, piecemeal deglutition was never seen with less than 20 ml water. This volume was therefore accepted as the lower limit of piecemeal deglutition. In patients with dysphagia, dysphagia limits were significantly lower than those of normal subjects.

**Conclusion**—The method is a highly specific and sensitive test for the objective evaluation of oropharyngeal dysphagia even in patients with suspected dysphagia of neurogenic origin. It can also be safely and simply applied in any EMG laboratory.

If a large amount of material is put into the mouth at one time, piecemeal deglutition usually occurs in all normal adult human subjects. Piecemeal deglutition refers to division of the bolus into two or three swallows successively rather than swallowing the entire bolus in one.<sup>1</sup>

Various aspects of piecemeal deglutition are unknown. First of all what is the upper limit of the amount of material that can be swallowed in one portion in normal adult subjects? So far, this has not been determined. Therefore one aim of the study was to delineate the upper limit of amount of liquid that is swallowed as one portion in the normal population and in patients with overt and suspected dysphagia, and to establish any difference between the two groups. It was hoped that this may provide a useful test for the evaluation of patients with dysphagia.

The second aim was to understand which mechanism underlies the phenomenon of piecemeal deglutition. There is no known satisfactory explanation as to which physiological factors are involved, but some ideas are put forward based on our clinical and electrophysiological findings.

Although they are different from each other in the clinical sense, we generally preferred to use of the term "dysphagia limit" instead of "piecemeal deglutition" because, even in some normal subjects "a kind of choking sensation" was experienced if they attempted to drink or to swallow the larger amounts of water used.

A preliminary account of this study has been reported elsewhere.<sup>2</sup>

## Materials and methods

Investigations were made on 30 normal adult subjects (10 women, 20 men) most of whom were hospital staff and colleagues who did not have any oropharyngeal or gastrointestinal problems. They ranged in age from 20 to 71 (mean age 43.0 (SD 17.6)).

Sixty six patients with overt dysphagia or suspected dysphagia were investigated both clinically and electrophysiologically. The patients ranged in age from 20 to 82 (mean age 55.7 (SD 17.3)). Overt dysphagia is defined when the patient needs a nasogastric catheter. The term suspected dysphagia is used for the patients who describe dysphagic complaints<sup>1</sup> but who can still swallow without any auxiliary aid. Another group of 20 patients with neurological disorders (10 women, 10 men, mean age 46.9 (SD 14.2), age range

Department of Clinical Neurophysiology and Neurology, Ege University Medical School Hospital, Bornova, İzmir, 35100, Türkiye  
C Ertekin,  
I Aydoğdu  
N Yüceyar

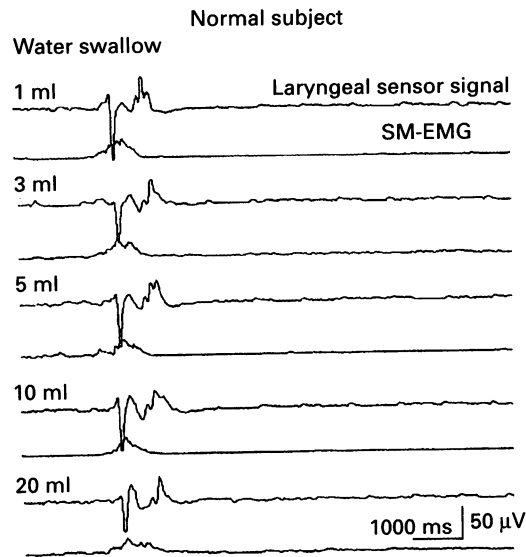
Correspondence to:  
Professor Cumhur Ertekin,  
Department of Neurology  
and Clinical  
Neurophysiology, Ege  
University Medical School  
Hospital, Bornova, İzmir  
35100, Turkey.

Received 26 March 1996  
and in revised form  
5 June 1996  
Accepted 27 June 1996

(*J Neurol Neurosurg Psychiatry* 1996;61:491-496)

Keywords: oropharyngeal dysphagia; piecemeal deglutition; dysphagia limit

**Figure 1** Laryngeal sensor signals (top traces in each pair) and integrated submental EMG activities (lower traces in each pair) during swallowing different amounts of water, increasing in quantity step by step from 1 to 20 ml. Note that all volumes were swallowed at one go up to 20 ml. Time calibration marks are 1000 ms in all traces and the amplitude value relates to muscle activity, in this and all subsequent figures.



25–76) were also separately examined either because they had no dysphagia, or they had recovered from dysphagia and were completely normal at the time of investigation for deglutition. Thus 86 patients in total were examined (33 women, 53 men). Their ages ranged from 20 to 82 (mean age 53.7 (SD 17.0)), and they were selected from the Departments of Neurology and Gastroenterology. The table gives the list of clinical diagnoses.

All patients were diagnosed using CT, MRI, EMG, and other appropriate methods in addition to clinical criteria. Time between the onset of the medical-neurological problem and the investigation ranged from seven days to 35 years. Time between the onset of dysphagia and investigation ranged from seven days to 10 years. Informed consent was obtained from all patients and the study was accepted by the local ethics committee.

The normal subjects and patients sat on an examination couch and were instructed to hold their heads in a natural upright position. Then the electrophysiological method described previously<sup>3</sup> was applied. In brief, EMG activity was recorded on a Medelec model MS-20 EMG apparatus using bipolar silver chloride EEG electrodes taped under the chin over the mylohyoid-geniohyoid-anterior digastric muscle complex (SM-EMG). The EMG signals were band pass filtered (100 Hz–10 kHz), amplified, rectified, and integrated.

For detection of laryngeal movements (upward and downward) a mechanical sensor that consisted of a simple piezoelectric wafer with a  $4 \times 2.5$  mm rubber bulge fixed at its centre was placed on the coniotomy region between the cricoid and thyroid cartilages at the midline.<sup>3,4</sup> The sensor output was connected to another channel of the EMG apparatus. The sensor amplifier output was also band pass filtered (cut off frequencies 0.01–20 Hz). The sensor gave two deflections of generally opposing polarity during each swallow, the first of which was often a positive (downward on the screen as in fig 1) deflection or vice versa. The leading or trailing edge of the first deflection was used to trigger the

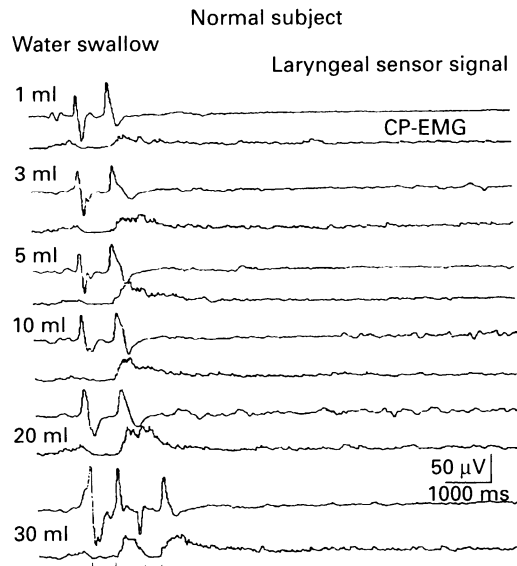
delay line circuitry of the recording apparatus so that all signals were time locked to the same instant. The first deflection of the laryngeal sensor signal represents the upward movement of the larynx and the second deflection, its downward movement.<sup>3</sup>

Because the SM-EMG activity coincided with the laryngeal upward movement, the rectified-integrated SM-EMG activity was also time locked to the laryngeal sensor signals. The total sweep time was set at 10 seconds and the delay line was started two seconds after the onset of the single sweep of the oscilloscope. Therefore after an amount of water was drunk, the effect of the bolus was followed up for eight seconds. Occasionally, an analysis time of 18 seconds was used.

Normal control subjects and patients were each given 1, 3, 5, 10, 15, and 20 ml of water in a stepwise manner, and began to swallow immediately after being instructed to do so by the examiner. After the water was delivered into the mouth by a graduated syringe; swallows were initiated with the water positioned on the tongue and the tongue tip touching the upper incisors.<sup>5</sup> Oscilloscopic traces were started at the examiner's order to swallow. In this way laryngeal sensor signals and integrated signals of SM-EMG activity were recorded at the beginning of the long sweeps (two seconds after the onset of each sweep). As each volume of liquid was swallowed, single sensor and SM-EMG signals were usually recorded at the beginning of the recording, and any recurrence of the two signals together within the eight second period of the recording was accepted as piecemeal deglutition or as a sign of dysphagia limit. In some normal subjects the amount of liquid increased up to 35 ml. In patients with dysphagia the examination was stopped if the patient showed any piecemeal deglutition or any sign of subglottic aspiration such as coughing or wet voice. If there was any suspicion of piecemeal deglutition, the same procedure was repeated and recorded for a second time with the same quantity of water.

The EMG of the cricopharyngeal muscle of the upper oesophageal sphincter was also recorded in five normal subjects and in some patients (40 out of 66 dysphagic patients and five out of 20 non-dysphagic patients) in addition to the SM-EMG recordings. The cricopharyngeal muscle EMG was recorded using concentric needle electrodes (Medelec disposable needle electrode DMC-37; diameter 0.46 mm, recording area 0.07 mm<sup>2</sup>). The needle electrode was inserted through the skin at the level of the cricoid cartilage, about 1.5 cm lateral to its palpable lateral border in the posteromedial direction. High frequency, tonic EMG activity appeared on the oscilloscopic screen as the electrode penetrated the muscle. During swallowing of dry and liquid material, this tonic activity disappeared for a short time (400 ms–500 ms).<sup>3</sup> Activity of the cricopharyngeal muscle was also rectified—integrated during all types of swallowing. The filter settings were the same as those used for the SM-EMG activity recording. The specificity and sensitivity of this method were also calculated.<sup>6</sup>

Figure 2 As fig 1 except the lower traces, which show integrated EMG activities from the cricopharyngeal muscle of the upper oesophageal sphincter (CP-EMG). Note that with more than 20 ml water, this normal subject divided the bolus into two aliquots which were swallowed successively; this constitutes piecemeal deglutition. (Each line just below the CP-EMG trace at swallowing 30 ml water indicates the disappearance of the tonic activity of the cricopharyngeal muscle which represents swallowing action.)



**Results**

As all signals were time locked and stabilised on the screen by triggering the oscilloscope with the leading edge of first deflection, it became possible to determine whether the amount of the liquid was swallowed at once, or divided into two parts, or aspirated during a period of eight seconds after the first deglutition. Figure 1 shows the swallowing behaviour of a normal subject for different amounts of bolus from 1 ml to 20 ml. Whatever the amount of water drunk, there was no piecemeal deglutition and all water was swallowed at one go at the beginning of the oscilloscopic traces within eight seconds. The duration between the onset points of the two sensor signals and the duration of the SM-EMG increased with the increase of the bolus volume. This is a well known phenomenon related to the longer relocation time of the larynx and the longer lasting pulling effect of the submental muscles with larger bolus volume.<sup>7</sup>

In all normal subjects, piecemeal deglutition was never found within the amount of 20 ml water swallowed. But with more than 20 ml water, some normal subjects could not swallow the material all at once and the bolus volume was divided into two aliquots and successively swallowed (fig 2). In the normal subject depicted in fig 2, piecemeal deglutition was found with 30 ml water. The important feature of normal piecemeal deglutition was that the divided piece of material was swal-

Figure 3 Dysphagia limits of patients with dysphagia. Note the peak of dysphagia limits of patients showing signs of aspiration while swallowing 1 ml water, and the peak of dysphagia limits of patients without significant aspiration while swallowing 10 ml water or more.

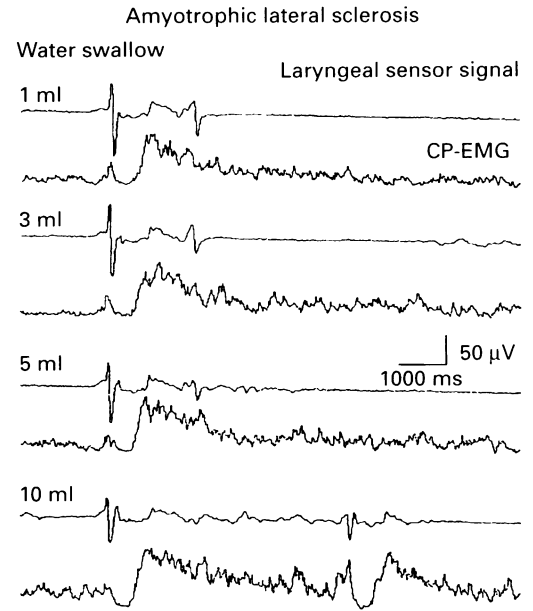
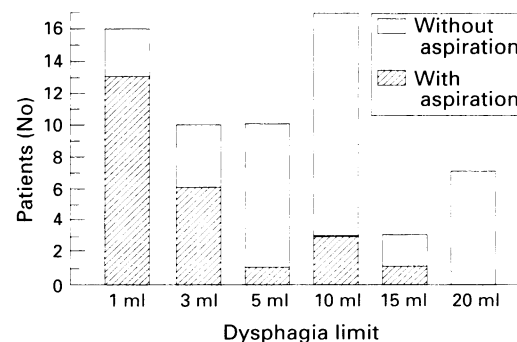


Figure 4 Laryngeal sensor signals (upper traces in each pair) and integrated activities of cricopharyngeal muscle of the upper oesophageal sphincter (CP-EMG) (lower traces in each pair) recorded from a case of amyotrophic lateral sclerosis while swallowing different amounts of water increasing in quantity step by step from 1 to 10 ml. Note the double swallows when drinking 10 ml water. (Each line just below the CP-EMG trace at 10 ml water swallowing indicates the disappearance of the tonic activity of the cricopharyngeal muscle which represents swallowing action.)

lowed successively without a significant time interval. Figure 2 shows that the successive swallowing of the material of deglutition could also be accompanied by successive EMG pauses of the cricopharyngeal muscle, which normally occur with increased SM-EMG activity.<sup>3</sup>

Swallowing 20 ml water was accepted as the lower limit of piecemeal deglutition in all 30 normal subjects and the term of "dysphagia

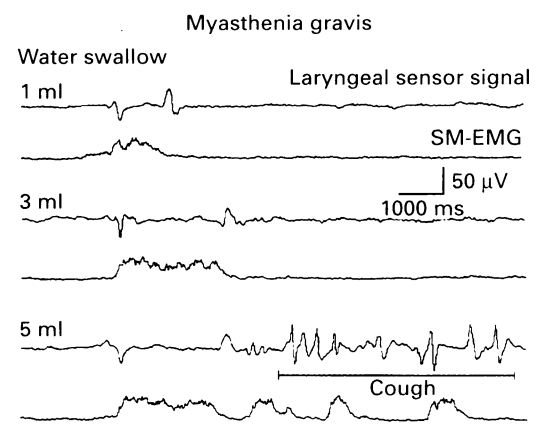


Figure 5 Laryngeal sensor signals (top traces in each pair) and integrated submental EMG activities (lower traces in each pair) recorded from a patient with myasthenia gravis with overt dysphagia while swallowing different amounts of water, increasing in quantity step by step from 1 to 5 ml. While swallowing 5 ml water the patient began to cough in addition to exhibiting piecemeal deglutition. This indicates laryngeal aspiration. Note the prolonged sensor artefacts related to coughing which were also clinically noted (the line just below the sensor signal at 5 ml water swallowing).

## Dysphagia limits obtained from all the patients with and without dysphagia

Groups of patients (No)	Dysphagia limits (ml water)*							Normal limit†	Total
	1	3	5	10	15	20			
ALS (13)	+ -	2 2	2 2	1 4	4 1	1 0	0 0	0 3	10 3
Myasthenia gravis (19)	+ -	3 3	3 3	1 1	1 0	0 0	0 10	1 10	9 10
Polymyositis dermatomyositis (7)	+ -	3 3	1 1	0 0	0 0	0 0	0 1	1 2	5 2
Myotonic dystrophy (4)	+ -	0 0	0 0	0 1	1 0	0 2	0 1	0 1	3 1
Stroke (16)‡	+ -	5 2	2 2	2 6	0 0	1 1	0 0	16 0	16 0
Pseudobulbar palsy (11)	+ -	2 1	3 2	2 2	2 1	1 0	0 0	11 0	11 0
Movement disorders (13)§	+ -	1 1	1 1	2 0	0 3	1 4	9 4	9 4	9 4
Basis cranii compression (3)	+ -	0 0	2 1	0 0	0 0	0 0	3 0	3 0	3 0
Total	+ -	16 0	10 0	10 0	17 0	3 0	7 0	3 20	66 20

\*Volumes swallowed in two or more stages.

†Volumes (20 ml or more) swallowed at one go, same as in normal subjects.

‡Mainly vertebrubasilar infarction (12).

§Parkinson's disease (nine cases); oromandibular dystonia (two); Huntington's chorea (one); Chorea-acanthocytosis (one). ALS = amyotrophic lateral sclerosis; + = with dysphagia; - = without dysphagia.

limit" was used even for the normal subjects. In the range of 25–40 ml, the amount of water which could not be drunk in one bolus varied from subject to subject, and whenever piecemeal deglutition was found, the subject experienced some kind of unpleasant sensation, although liquid was never aspirated.

In all but three of the 66 patients with overt or suspected dysphagia; the dysphagia limits were consistently lowered, by between 20 ml and 1 ml (fig 3). The dysphagia limits were severely reduced to 1 ml water in patients fed by nasogastric tube. In the patients with suspected dysphagia but who were still feeding without aid, dysphagia limits were lowered to 1 ml–20 ml with a peak of 10 ml. Another qualitative feature of "piecemeal deglutition" in dysphagic patients was that the divided amounts swallowed were considerably sepa-

rated from each other in time and often divided into more than two swallows (fig 4). An important finding was the occurrence of laryngeal aspiration during the piecemeal deglutition with amounts of water less than 10 ml, especially in patients with overt dysphagia and with nasogastric catheters. This has sometimes been recorded clinically and graphically (fig 5).

In 20 patients without dysphagia, dysphagia limits were the same as the normal control groups (table). These patients could all easily swallow the different amounts of water including the 20 ml dose. They had recovered from the dysphagic period in the course of their diseases—for example, myasthenia gravis, stroke, or polymyositis—or they had shown no dysphagia up to the present investigation as in three patients with amyotrophic lateral sclerosis without bulbar symptoms and in some patients with Parkinson's disease.

The specificity and sensitivity of this method were 100% and 95.4% respectively.

The method of "dysphagia limit" seemed to be useful in following up the patient's dysphagia. Dysphagia limits rose into the normal range as patients recovered (fig 6).

### Discussion

The objective evaluation of dysphagia is important for the selection of a treatment method.<sup>1</sup> Videofluoroscopic and manometric evaluations may be indicated for such patients, but these methods are expensive and time consuming, and care of the neurologically impaired patient during examination is sometimes difficult. It has therefore been necessary to develop clinical screening methods to identify patients with suspected or established dysphagia who are at risk of aspiration. The bedside swallowing evaluation has long been criticised for its lack of accuracy for patients with dysphagia and aspiration. It has been reported that even the most experienced clinicians fail to identify about 40%–50% of aspi-

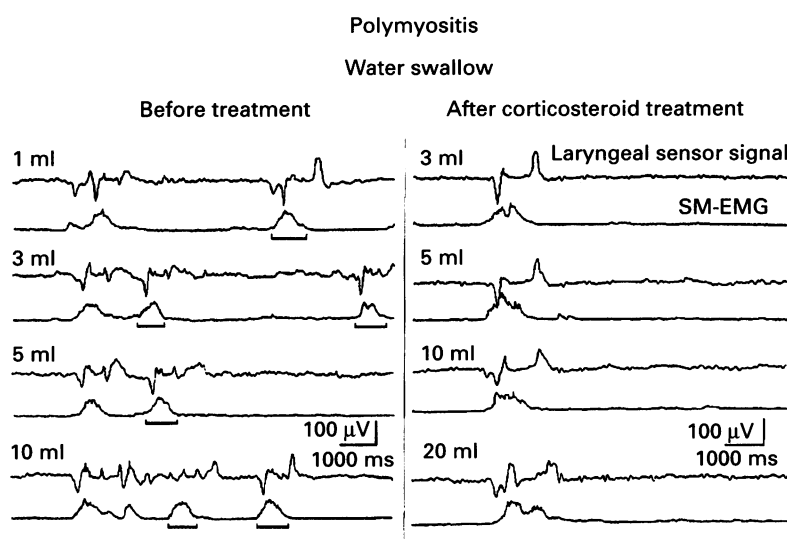


Figure 6 Laryngeal sensor signals (top traces in each pair) and integrated submental EMG activities (lower traces in each pair) recorded from a patient with polymyositis before and after treatment. The patient was swallowing different amounts of water, increasing in quantity step by step. Note the piecemeal deglutition which began to occur even at 1 ml of water before treatment. The patient could swallow all the volumes from 3 ml to 20 ml when she recovered from dysphagia after treatment. (Lines just below the SM-EMG activity at 1–10 ml water drinking indicate the swallowing actions after the first one.)

rating patients during a bedside examination.<sup>18</sup> It was recently found that several clinical factors correctly predict about two thirds of both those who aspirate and those who do not.<sup>9</sup>

Some simple screening tests have recently been developed for use before further radiological, manometric, and advanced electrophysiological evaluation of deglutition in patients with overt or suspected dysphagia and silent aspiration.<sup>8 10-14</sup> Most of these tests usually depend on clinical findings and subjective evaluations while patients are drinking a cup of water varying considerably in amount from 50 ml to 200 ml. Basically, careful observations were made of the timing of swallowing or the amount swallowed, or laryngeal movements were counted for each swallow, using a stopwatch and a medicine container. Clinical results such as coughing and signs of aspiration were noted. These methods proved to be somewhat better than bedside examination for evaluation and diagnosis of dysphagia; but they have not approached the diagnostic value of videofluoroscopy for example. Besides this; continuous drinking of such a large amount of water in patients with overt or silent aspiration or in uncooperative patients may carry some risks. Therefore these methods could not be easily performed in such patients. Increasing amounts of water up to a teaspoonful as tolerated by the patient's capabilities have been judged by an examiner in one study.<sup>8</sup> This method is similar to ours in respect of presentation of water step by step in increasing amounts. This technique is safer than others mentioned above.

In our method of diagnosis by "dysphagia limit" there is a combination of both clinical and electrophysiological tests for drinking behaviour. Therefore the results are objective, recordable, and obviously repeatable at any time. Due to the gradual increase of the quantity of water, from 1 ml to 20 ml, which are considerably smaller amounts than in the other water drinking tests except those of Splaingard *et al.*,<sup>8</sup> the method is safer and could also be used for the patients with overt dysphagia. Both sensitivity and specificity of this method are very high (100% specific and 95.4% sensitive), and the dysphagia limits were below 20 ml in all but three of 66 patients with overt dysphagia or suspected dysphagia in whom clinical longitudinal studies showed the problem of dysphagia becoming overt. On the other hand; clinically normal patients without dysphagia at the time of investigation and normal subjects were capable of drinking an amount of 20 ml or more. As a result; the clinical/electrophysiological method of "dysphagia limit" can be a rapid, specific and sensitive test for diagnosing oropharyngeal dysphagia with neurogenic origin.

What is the mechanism for piecemeal deglutition and dysphagia limits? It is well known that when oropharyngeal swallowing is impaired but compensated, such patients could change their eating habits—that is, frequent small meals make eating easier, and the patient may reduce the individual bolus

size. Swallowing for a second time with each bolus helps to clear retained material from the pharynx.<sup>15</sup> Besides the voluntary compensations for impaired swallowing of which the patient may be aware, the compensation is also "involuntary"—that is, it takes place through adjustments in the swallowing apparatus itself.<sup>15</sup> Thus patients with a subclinical swallowing impairment may subconsciously alter the consistency of ingested food and the speed of eating and drinking and there may be no overt symptoms of dysphagia.<sup>16</sup>

Occasionally, abnormal deglutition occurs physiologically even in healthy young adults.<sup>17</sup> Indeed, most of our normal control subjects could not easily tolerate more than 20 ml water. Above their tolerance level they swallowed twice but successively. Therefore there must be a physiological limit for the volume of each swallow. It has been reported that a normal single swallow of water for an adult averages about 17 ml, varying from 14 ml for women to 21 ml for men.<sup>18</sup> These results are very close to our upper limit of 20 ml for each swallow in both sexes of normal adults.

A high density of mechanical or chemical receptors implicates the tongue as the main sensory region for determining the size of the bolus.<sup>19 20</sup> This kind of sensation in the tongue and the other tissues around the entrance of the pharynx could be important for piecemeal deglutition because the entrance of the oropharyngeal region can cause an adjustment in the neural mechanism according to the size of bolus, dividing it into two pieces. Thus the peripheral determinants of bolus size could give rise to a very important fast peripheral feedback mechanism that would affect the central motor programme of swallowing in the brainstem.

This opinion is supported by the SM-EMG, which did not usually change in shape or size as piecemeal deglutition occurred. However, this proposed mechanism probably could not operate in the case of purely muscular disorders with dysphagia, because there were no known abnormalities related to oral sensation in these patients. They may not have had a strong capability to keep or to drive the bolus in one portion, even in small sizes; therefore, some escaped bolus pieces could stay in oral or pharyngeal spaces and be swallowed involuntarily some considerable time after the first swallow. Therefore, the successively occurring two or more swallows for one bolus would have longer intervals in cases of oropharyngeal dysphagia.

The swallowing centre is defined as a group of neurons the coordinated action of which produces a stereotyped response. Three properties exist for the functional centre.<sup>20</sup>

(1) The neurons of the centre are triggered into action by a specific sensory pattern suggesting an afferent portal of the centre.

(2) The inherent organisation of these neurons reproduces the patterned response through effective inhibition and excitation of motor neurons.

(3) The neurons of the centre have a pre-emptory command of the motor neurons that

supersedes other synaptic influences such as the respiratory drive.

In the light of the findings of dysphagia limits and piecemeal deglutition the following facts regarding the swallowing centre and its apparatus are important.

(1) Swallowing jitter can be adjusted from one swallow to another according to the peripheral conditions.<sup>3</sup>

(2) Sensory feedback to the centre is one mechanism which prolongs the duration of pharyngeal swallowing processes with increased bolus volume.<sup>3,7,21,24</sup>

(3) If the bolus is big enough, it is not sufficient to change the jitter and to increase the time of swallowing events; instead, it becomes necessary to divide the bolus and swallow it successively in piecemeal deglutition.

(4) All these arrangements must be operated by the sensory-motor integration of the swallowing centre.

(5) If there is any disturbance in the neuromuscular or sensory-motor system of the swallowing apparatus, swallowing may be adapted by modification of piecemeal deglutition and reduction of the dysphagia limit to less than 20 ml bolus size.

Despite this attempt to compensate, the residual bolus volume remaining in the spaces of the pharynx will escape either into the airway or down through the upper oesophageal sphincter opened for a second time a considerable interval after the first swallow.

Apart from its use in studying the physiological nature of piecemeal deglutition, the dysphagia limit is a very useful, reliable, and recordable electroclinical test for patients with swallowing disorders. It can be a pragmatic candidate for a screening test before the evaluation of videofluoroscopic investigations for selected patients with dysphagia.

This study was supported by a grant from the Turkish Scientific and Technological Research Council (TUBITAK) project No:TBAG-U/17-4.

<sup>1</sup> Logeman J. *Evaluation and treatment of swallowing disorders*. Austin TX, Pro-ed, 1983:76.

- 2 Ertekin C, Aydođdu I, Yüceyar N. *Dysphagia limits in normal subjects and patients with dysphagia*. 13th national congress of clinical neurophysiology, İstanbul, Turkey, 1995; summary book 118.
- 3 Ertekin C, Pehlivan M, Aydođdu I, et al. An electrophysiological investigation of deglutition in man. *Muscle Nerve* 1995;18:1177-86.
- 4 Pehlivan M, Yüceyar N, Ertekin C, et al. An electronic technique measuring the frequency of spontaneous swallowing (digital phagometer). *Dysphagia* 1996 (in press).
- 5 Dantas RO, Kern MK, Massey BT, et al. Effect of swallowed bolus variables on oral and pharyngeal phases of swallowing. *Am J Physiol* 1990;258:G675-81.
- 6 Nirikko AC, Rösler KM, Hess CW. Sensitivity and specificity of needle electromyography: a prospective study comparing automated interferences pattern analysis with single motor unit potential analysis. *Electroencephalogr Clin Neurophysiol* 1995;97:1-10.
- 7 Ertekin C, Aydođdu I, Pehlivan M, et al. *Effects of bolus volume on the oropharyngeal swallowing: an electrophysiological study in man*. 13th national congress of clinical neurophysiology, İstanbul, Turkey, 1995; summary book 116.
- 8 Splaingard ML, Hutchins B, Sulton LD, Chaudri G. Aspiration in rehabilitation patients: videofluoroscopy vs bedside clinical assesment. *Arch Phys Med Rehabil* 1988;69:637-40.
- 9 Linden P, Kuhlmeier KV, Patterson C. The probability of correctly predicting subglottic penetration from clinical observations. *Dysphagia* 1993;8:170-9.
- 10 Gordon C, Hewer RL, Wade DT. Dysphagia in acute stroke. *BMJ* 1987;295:411-4.
- 11 Depippo KL, Holas MA, Reding MJ. Validation of the 3-oz water swallow test for aspiration following stroke. *Arch Neurol* 1992;49:1259-61.
- 12 Nathadwarawala KM, Nicklin J, Wiles CM. A timed test of swallowing capacity for neurological patients. *J Neurol Neurosurg Psychiatry* 1992;55:822-5.
- 13 Nilsson H, Ekberg O, Sjöberg S, Olsson R. Pharyngeal constrictor paresis: an indicator of neurological disease? *Dysphagia* 1993;8:239-43.
- 14 Hughes TAT, Wyles CM. Clinical measurement of swallowing in health and in neurogenic dysphagia. *Q J Med* 1996;89:109-16.
- 15 Bucholz DW, Bosma JF, Donner MW. Adaptation, compensation and decompensation of the pharyngeal swallow. *Gastrointest Radiol* 1985;10:235-9.
- 16 Jones B, Ravich WJ, Donner MW, Kramer SS, Hendrix TR. Pharyngoesophageal interrelationships: observations and working concepts. *Gastrointest Radiol* 1985;10:225-33.
- 17 Felson B, Klatte EC. Pharyngeal and upper esophageal dysphagia. *JAMA* 1976;235:2643-6.
- 18 Jones DV, Work CE. Volume of a swallow. *Am J Dis Child* 1961;102:427.
- 19 Darian-Smith I. The trigeminal system. In: Iggo A, ed. *Handbook of sensory physiology*. Vol 2. New York: Springer Verlag, 1973:271-314.
- 20 Miller AJ. Deglutition. *Physiol Rev* 1982;62:129-84.
- 21 Kahrilas PJ, Logemann JA. Volume accommodation during swallowing. *Dysphagia* 1993;8:259-65.
- 22 Kahrilas PJ, Dodds WJ, Dent J, et al. Upper esophageal sphincter function during deglutition. *Gastroenterology* 1988;95:52-62.
- 23 Kahrilas PJ, Lin S, Logemann JA, et al. Deglutitive tongue action: volume accommodation and bolus propulsion. *Gastroenterology* 1993;104:152-62.
- 24 Jacob P, Kahrilas PJ, Logemann JA, et al. Upper esophageal sphincter opening and modulation during swallowing. *Gastroenterology* 1989;97:1469-78.