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ORIGINAL COMMUNICATION

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Sonographic analysis of laryngeal elevation during swallowing

Abstract *Background* Swallowing disorders are common symptoms in many neurological diseases. The aim of this pilot-study was to analyse vertical laryngeal excursion during swallowing non-invasively using ultrasound sonographic techniques in patients with dysphagia compared with healthy volunteers. *Methods* Data were obtained from 42 healthy volunteers (mean age: 57 ± 19 years) and 18 patients (mean age: 63 ± 8 years) with dysphagia due to different neurological diseases using a 7.5 MHz linear array probe, which was placed in longitudinal position above the larynx. This allowed visualization of the contour and the acoustic shadow of the hyoid bone and the thyroid cartilage. The distance between the hyoid bone and the upper end of the thyroid cartilage during laryngeal elevation was readily assessed by video-mode function. *Results* In healthy subjects we found a mean distance of 220 (± 30) mm at rest; the shortest distance during swallowing of 5 or 10 ml water was 85 (± 11) mm and represents a reduction of 61 % (± 3) under physiological conditions. The mean relative laryngeal elevation in the patients with neurogenic dysphagia was reduced to only 42 % (± 10) ($p < 0.0001$). *Conclusions* Ultrasound is a viable and non-invasive method in the investigation of laryngeal elevation during swallowing. It allows direct visualization of impaired laryngeal motion in patients with neurogenic dysphagia.

Key words swallowing · ultrasonography · larynx · dysphagia

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Introduction

Swallowing disorders are common in many neurological diseases. Neurogenic dysphagia frequently occurs in patients with stroke, amyotrophic lateral sclerosis, multiple sclerosis, parkinsonism, dementia, myasthenia, and different forms of myopathy [1]. Swallowing difficulties have been associated with high case fatality and poor functional outcome, in addition to putting the patients at risk of aspiration, pneumonia, dehydration and malnutrition [2]. Despite the high incidence of dysphagia, and the known serious consequences, swallowing problems are often not sought systematically e. g., in patients admitted to hospital with acute stroke [3]. The question as to the most suitable method of screening for dysphagia is still controversial. Although videofluoroscopy is generally considered the "gold standard", it has a number of limitations, including the frequent lack of availability, practicability, and the exposure of patients to radiation. Laryngeal elevation is an essential component of the swallowing movement under physiological conditions [4]. It ensures occlusion of the larynx and thus prevents aspiration. The aim of this study was to analyse vertical laryngeal excursion during swallowing in healthy subjects and in patients with dysphagia using ultrasound sonographic techniques.

Methods

Normal data were obtained from 42 healthy volunteers (mean age: 57 ± 19 years). The subjects were placed in a supine position with a slightly elevated head. Swallowing was assessed with and without liq-

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uid swallow [5 ml (n = 33 volunteers and all patients) or 10 ml (n = 9) water]. A 7.5 MHz linear array probe (Philips SD 800, Irvine CA) was placed in a longitudinal position above the larynx to allow visualization of the contour and the acoustic shadow of the hyoid bone and the thyroid cartilage. The swallowing images were stored on a video recorder and the distance between the hyoid bone and the upper end of the thyroid cartilage during laryngeal elevation was assessed offline. Furthermore the image with the greatest and lowest distance between hyoid bone and thyroid cartilage was identified by cine-loop function (Figs. 1 and 2). Fig. 3 presents the assessed structures in an anatomical model. All swallowing trials were performed six times. The measured distances were averaged and mean values were calculated. Using the mean distance at rest and the shortest distance during swallowing we calculated the relative shortening (reduction) of distance during swallowing (relative laryngeal elevation). The complete examination time was approximately ten minutes. Previously, we could demonstrate that there is no significant difference in the relative laryngeal reduction between the genders and different ages [5].

18 patients (mean age: 63 ± 8 years) with different diseases leading to symptomatic neurogenic dysphagia were examined [multisystematrophy (n = 2), amyotrophic lateral sclerosis (n = 3), multiple sclerosis (n = 3), parkinsonism (n = 2), myasthenia gravis, chorea, myositis, stroke of the middle cerebral artery (n = 3) and the vertebrobasilar territory (n = 2)] (Table 1). Dysphagia was identified using the clinical bedside test established by DePippo et al. (80 ml/3-oz water swallow) [6]. The Mann-Whitney-U-test was used for statistical analysis for differences in the relative laryngeal reduction between healthy volunteers and patients with dysphagia. All subjects gave informed consent to participate.

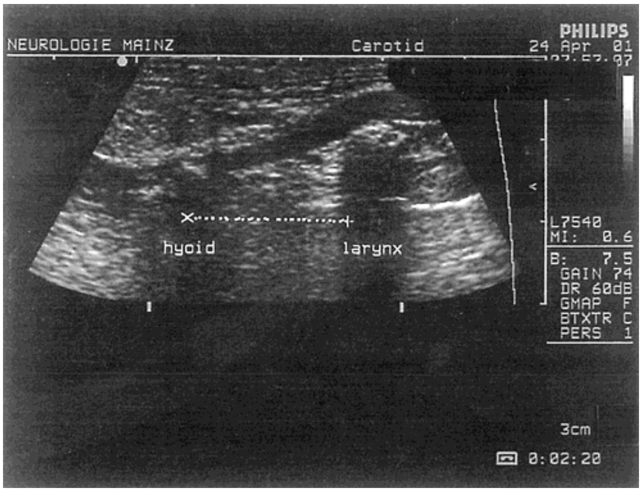

Fig. 1 B-mode image showing the hyoid–larynx distance at rest.

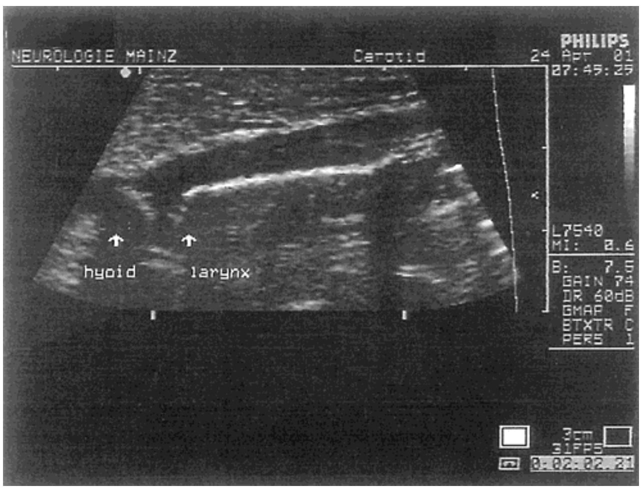

Fig. 2 B-mode image showing the minimal hyoid–larynx distance during swallowing in a normal subject.

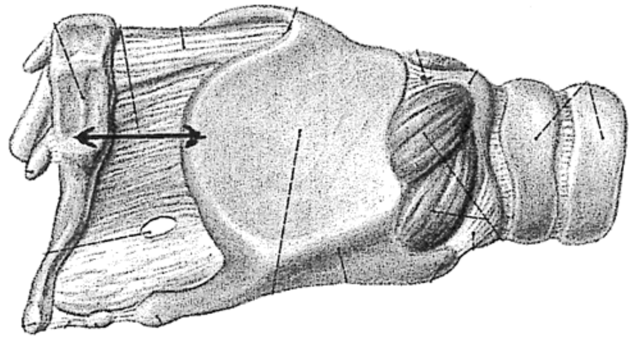

Fig. 3 Anatomical model of larynx and hyoid bone (Sobotta Atlas of Human Anatomy; 19th ed. Urban & Schwarzenberg; 1988)

Results

In healthy volunteers we found a mean distance of 220 (± 30) mm at rest; the shortest distance during swallowing of 5 or 10 ml water was 85 (± 11) mm and represents a relative laryngeal reduction of 61 % (± 3) under physiological conditions. Nine subjects were initially examined during a 10 ml water swallow; the volume was reduced to 5 ml in the course of the study in order to optimize swallowing and examining conditions. No differences were observed between swallowing of 5 or 10 ml liquid.

Two of these subjects were examined in both supine and in a sitting position. Both positions revealed identical results (relative laryngeal reduction 67 % in both subjects), which is why we performed all further examinations in a supine position. It is more convenient for the examiner and the risk for displacement of the ultrasound probe is lower.

In the 18 patients with dysphagia the relative laryngeal elevation was reduced to only 42 % (± 10). Fig. 4 shows the reduced laryngeal elevation in a patient with myositis (patient 18). The assessed mean distance between the hyoid bone and the upper end of the thyroid cartilage was 185 (± 45) mm at rest, which is not significantly different from controls, while the shortest distance during swallowing was 105 (± 18) mm. The most pronounced reduction in laryngeal elevation was found in the patients with myasthenia gravis and stroke. Table 1 shows the mean values calculated for each patient, allowing a comparative analysis. Statistical analysis revealed a highly significant difference in the absolute and

Table 1 Details on patients with dysphagia

Patient	Gender	Diagnosis	Age (years)	Distance at rest (mm)	Distance during swallowing (mm)	Relative laryngeal reduction (%)
1	F	Parkinsonism	56	250	119	52
2	F	Parkinsonism	72	103	96	33
3	F	MSA	56	220	111	50
4	M	MSA	63	142	71	50
5	F	MS	52	212	114	46
6	M	MS	55	142	102	28
7	M	MS	56	150	105	30
8	F	Myasthenia	60	182	133	27
9	M	ALS	62	226	114	50
10	M	ALS	62	287	129	55
11	M	ALS	64	161	78	52
12	M	Stroke (mca)	69	187	102	45
13	M	Stroke (mca)	67	188	109	42
14	F	Stroke (mca)	65	198	120	39
15	F	Stroke (vs)	66	141	104	26
16	F	Stroke (vs)	83	152	112	26
17	F	Chorea	73	188	87	54
18	M	Myositis	57	198	103	48

MSA multisystematrophy; *MS* multiple sclerosis; *ALS* amyotrophic lateral sclerosis; *mca* middle cerebral artery; *vs* vertebrobasilar system

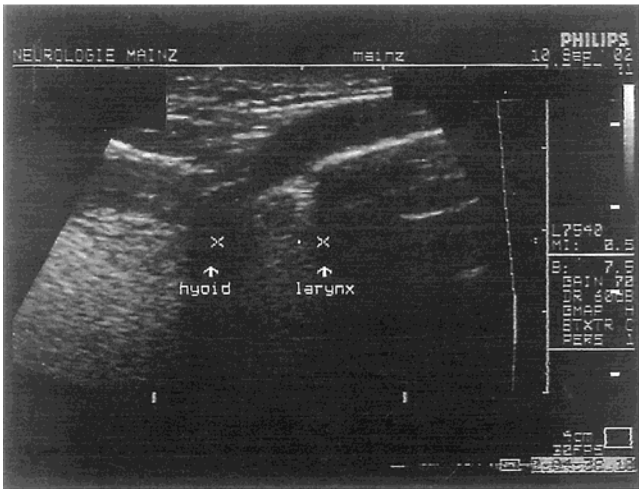

Fig. 4 B-mode image showing the minimal hyoid–larynx distance during swallowing in a patient with dysphagia due to myositis (patient 18)

relative laryngeal elevation between healthy subjects and the patients with dysphagia (p-value < 0.0001) (Table 2).

All patients had a pathological 3-oz water swallow bedside test which indicated the presence of dysphagia [6]. During the ultrasound examination, however, no patient showed signs of aspiration, which is probably due to the small bolus volumes.

Discussion

Up to 45 % of patients admitted to hospital with acute stroke show evidence of aspiration on bedside swallowing assessments [7, 8]. Dysphagia is also frequently found in patients with amyotrophic lateral sclerosis [4], parkinsonism [4, 9–11], dementia, myasthenia [4], and different forms of myopathy [12–14]. Clinical tests which can be performed at the bedside [6, 8, 15, 16] are characterized by a relatively low sensitivity for aspiration [17–19]. It has been shown that the frequently used

Table 2 Mean values of healthy volunteers and patients with dysphagia

	n	Age (years)	Distance at rest (mm)	Distance during swallowing (mm)	Relative laryngeal reduction (%)
Normal	42	56 (± 19)	220 (± 30)	85 (± 11)	61 (± 3)
Patients	18	63 (± 8)	185 (± 45)	105 (± 18)	42 (± 10)
p-value		0.540 (ns)	0.105 (ns)	< 0.0001	< 0.0001

ns not significant

'gag reflex' is an inaccurate and unreliable indicator of swallowing safety [16, 20]. The question as to the most suitable method of screening for dysphagia is still subject to controversy, although videofluoroscopy is generally regarded as the 'gold standard' [17].

Detection of dysphagia is possible by videofluoroscopy, which has, however, a number of limitations, including the lack of general availability, exposure of patients to radiation, and the use of radiological contrast media. Another disadvantage of the methods described is that patients are examined under unfamiliar and artificial conditions which may influence their swallowing performance and exert a negative effect on the validity of the results. Furthermore, most tests require patient cooperation and compliance, another limiting factor in the examination of patients with, e. g., dementia or aphasia. The fiberoptic endoscopic evaluation of deglutition is invasive and does not allow one to quantify swallowing movements [21, 22]. Recently, various kinetic high-speed magnetic resonance imaging sequences have been applied to examine some anatomical and functional properties of deglutition [23]. Owing to severe movement artifacts this technique is actually not capable of allowing exact distance measurements [23]. To circumvent these disadvantages, ultrasound techniques have also been previously applied for swallowing assessment [for a review: see 24]. However, ultrasound images have only been used to investigate the oropharyngeal phase of swallowing [e. g. 25–27] or to describe the hyoid and larynx structures non-quantitatively [28, 29]. To our knowledge, only one group measured the hyoid bone motion during swallowing indirectly using doppler shift spectra [30], but laryngeal elevation was not considered.

Incomplete laryngeal elevation and adduction is assumed to be one of the major mechanisms in dysphagia and often leads to aspiration. Other mechanisms of dysphagia as e. g. poor oral control and delayed triggering of the swallow reflex as well as reduced pharyngeal 'peristalsis' or cricopharyngeal dysfunction have been identified [31].

The aim of the present pilot-study was to analyse and quantify the vertical laryngeal excursion as one relevant part of the complex swallowing movement non-invasively using ultrasound technique. Our findings show that laryngeal elevation can readily be measured by identification of the thyroid cartilage and the hyoid bone. Normal data were obtained in 42 healthy subjects for comparison with those of 18 patients with dysphagia caused by different neurological disorders. To exclude anatomical inter-subject differences concerning the absolute distance between hyoid bone and thyroid cartilage, we considered not only the absolute but also the relative reduction of the distance between these structures. All patients showed a highly significant reduction in relative laryngeal elevation.

Using videofluoroscopy spatial measurements of the hyoid and larynx elevation have been performed in large groups of healthy volunteers [32–35]. Videofluoroscopy is also frequently performed in neurogenic dysphagia due to different diseases [36–39], but quantitative measurements of the above mentioned parameters have not been reported for this condition. Only in the study of Sundgren et al. [32] was the laryngeal elevation quantified and showed no significant differences of the maximum laryngeal elevation between controls and dysphagic patients. However, a comparison of these results with our own data is difficult, because Sundgren et al. did not mention the etiology of dysphagia and included patients with a 'clinical history of dysphagia'. They did not state if the patients had still swallowing difficulties at the time of videofluoroscopy. In our study only patients with actual swallowing difficulties were included which might account for the reduced laryngeal elevation in our sample.

Several methodological restrictions of the present study should, however, be addressed. In older patients with dysphagia without an obvious medical or surgical cause for their dysphagia an increased extent of hyoid displacement was recently described [40]. In this case the relative laryngeal elevation should also be reduced, but this has not been investigated. We can not exclude that this effect was also present in our patients, because the absolute extent of hyoid elevation could not be measured owing to a limited imaging window with lacking reference point. A further limitation of ultrasonography is the lacking correlation of hyoid and larynx movements to the bolus position [27]. Only distances between anatomical structures can be considered using B-mode imaging but without timing aspects of hyoid and larynx movements. The number of examined patients is relatively small in the present study and the sample group is heterogeneous with few patients in each disease group. In an ongoing study we investigate a larger number of patients to perform further subgroup analyses.

In summary, the assessment of swallowing by ultrasound represents a non-invasive method allowing the quantification of laryngeal elevation and repeated examinations, e. g. before and after swallowing therapy. In an ongoing study, we compare the findings using sonographic analysis with quantitatively assessed laryngeal elevation in videofluoroscopy.

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