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Clinical measurement of swallowing in health and in neurogenic dysphagia

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Summary

We studied clinical features potentially related to dysphagia and three indices from a timed test of swallowing—average volume per swallow (ml), average time (s) per swallow and swallowing capacity (ml/s)—in 181 screened healthy adults and 30 patients with motor neurone disease (MND). In healthy adults, age, sex and height accounted for 44.3% and 55.6% of the variance of log average volume per swallow and log swallowing capacity, respectively. Symptoms and signs were more prevalent in the MND group and were associated with reduced swallowing capacity and reduced average volume per swallow; repeatability studies on these two indices in both groups showed that the median difference between the mean of two recordings on successive days and the mean of all recordings (6–15 over 3 days) was <5% (maximum third quartile 12.8%, indices expressed as percent predicted according to age and sex). Using this simple bedside test, swallowing function can be quantified on a ratio scale and expressed as percent of that predicted by age and sex; such information may improve the predictive value of clinical assessment and provides a practical way of monitoring change in patients with dysphagia.

Introduction

If a patient is observed drinking water, qualitative aspects of swallowing including slowness, coughing, altered voice quality post swallow or breathlessness can be noted; if the volume swallowed, the number of swallows used and the time taken are also recorded, three quantitative indices can be calculated, viz. average volume per swallow (ml), average time per swallow (s) and swallowing capacity (ml/s). These indices might be useful in screening those at risk of dysphagia or its complications, and in monitoring. During initial repeatability and validity studies for swallowing capacity,[1–4] we became aware of a lack of normal data related to both symptoms of disordered swallowing and neurological signs of bulbar dysfunction. Therefore we have systematically investigated symptoms and signs commonly used in the assessment of neurogenic dysphagia, together with all three quantitative indices of swallowing in a carefully screened population. To illustrate the possible clinical value of the approach, comparison is made with a group of patients presenting with motor neurone disease (MND).

Methods

Normal subjects and patients

Healthy adult volunteers from hospital staff and the general public who had answered 'No' to the question 'Do you have a problem with your swallowing?' were screened. Those with a past medical history of major surgery on or above the neck, thyroid disease, neurological disease (apart from idiopathic epilepsy), head injury with loss of consciousness or recent use of drugs with sedative, anticholinergic or antidopaminergic actions were excluded: subjects who had

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consumed alcohol in the previous 9 h and pregnant or breast-feeding women were also excluded. Subjects were examined to exclude those with clinically obvious thyroid disorders (including goitre) or neurological disease. A minimum of ten male and ten female subjects in each 10-year band between 15 and 75 years, and aged >75 years, were recruited. In total, 181 subjects (90 men, median age 47.4 years (range 18.9–87.6) and 91 women, median age 55.4 years (range 18.9–91.3) satisfied these criteria and formed the 'normal' group in this study.

Thirty patients (13 male, median age 65.2 years (range 44.8–76.6), 17 female, median age 67.6 years (range 39.3–85.3 years) with motor neurone disease formed the MND group; patients were seen a mean of 30 days after first presentation to a neurologist.

Approval for the study was obtained from the ethics committee of the South Glamorgan Health Authority and all subjects gave written consent.

Techniques

The following descriptions are common to both groups unless stated. Each subject completed a questionnaire (available on request) about swallowing-related symptoms. A detailed neurological examination of the lower cranial nerves was performed, and height, weight and neck circumference were measured. The timed test of swallowing was then done. Each subject, seated comfortably, was asked to drink a known volume of water (see below) from a plastic beaker 'as quickly as is comfortably possible'. Subjects were observed from the side, and the number of swallows used counted by observing the movements of the thyroid cartilage. All subjects were able to hold the beaker of water to their own mouth. A stopwatch was started when the water first touched the bottom lip, and stopped when the larynx came to rest for the last time; the latter event was usually accompanied by other clues suggesting completion of the last swallow e.g. exhalation, phonation, or opening of the mouth. Coughing during and coughing, drooling or altered voice quality after the test were noted. If MND patients were not able to complete the test, the volume swallowed was calculated from that left in the beaker. The timed test was performed at times 0, 5 and 20 min in the normal group, in all of the MND group at time 0 min, and in 24 of the MND group at time 5 min. Normal subjects aged less than 75 years were given 150 ml water; older subjects were given 100 ml. In 17 MND subjects, the volume given on both occasions was the same (150 ml in 10, 50 ml in six, 20 ml in one), but in five the volume was increased (20 to 50 or 100 ml ($n=2$), 50 to 100 or 150 ml ($n=3$)) and in two decreased (50 to 10 and 150 to 50 ml) according to how subjects coped with the first volume.

In 77 normal subjects (38 women, 39 men, including a minimum of five of each sex in each age band) this triplet of three swallows at times 0, 5 and 20 min was repeated twice during the first day (day 1) at two-hourly intervals, and again one and two weeks later (days 2 and 3); therefore these 77 normals performed 15 timed tests of swallowing. In eight patients with MND (three females aged 52–55 years, five males aged 54–77 years, four at presentation and four additional patients), with varying degrees of dysphagia, the test was repeated in a similar way; six subjects performed 15 tests, one 9 tests and one 6 tests, the latter being, respectively, 2 and 3 triplets on the first day. The volume given was the same on each occasion, i.e. 150 ml in six subjects and 25 ml in two. Still bottled water was used in all the normal subjects and tap water in all the MND subjects.

Statistical analysis

The distributions of primary data and the residuals from regression analyses were routinely examined and Normality tested formally using an equivalent of the Shapiro-Wilk test (Minitab version 8.2 for Apple Macintosh). A correction for multiple comparisons has not been applied to the p values shown; a p value $\leqslant 0.01$ was accepted as statistically significant.

Results

Indices of swallowing

In healthy adults, average volume per swallow and swallowing capacity were greater in men than women (Mann-Whitney test on average volume per swallow, unpaired t test for swallowing capacity, $p<0.0001$): average time per swallow was non-significantly shorter in men (Mann-Whitney test, $p=0.082$). There was a clear decline in both average volume per swallow and swallowing capacity with age, therefore subjects were grouped into four age groups: 1 (18–34.9 years), 2 (35–54.9 years), 3 (55–74.9 years) and 4 (75–91 years). The age- and sex-grouped values for the three indices are shown in Table 1.

Stepwise regression analysis in normal subjects showed that age (years), sex (male=0, female=1) and height (m) accounted for 43.4% (R squared) of the variance of log average volume per swallow ($y=0.818-0.128*\text{sex}-0.00286*\text{age}+0.434*\text{height}$, $p<0.001$) and 55.6% of the variance of log swallowing capacity ($y=0.484-0.141*\text{sex}-0.00511*\text{age}+0.636*\text{height}$, $p<0.001$). Height

Table 1 Median plus first and third quartiles (Q1, Q3) for average volume per swallow (V/S), and average time per swallow (T/S), and mean ± SD swallowing capacity (V/T) in MND patients and normal subjects

Sex	Normal subjects Age group	Age (years) Median (range)	*n*	V/S (ml)	Q1	Q3	T/S (s)	Q1	Q3	V/T (ml/s)
Male	1	25.7 (18.9–34.1)	27	37.5	25.0	50.0	1.2	1.0	1.3	31.9 ± 9.5
	2	44.6 (35.6–54.6)	25	30.0	21.4	37.5	1.2	1.0	1.4	24.8 ± 7.8
	3	66.6 (56.5–73.0)	26	23.2	20.8	30.0	1.3	1.2	1.4	18.7 ± 5.2
	4	77.3 (75.7–87.6)	12	20.0	15.7	25.0	1.5	1.3	1.8	14.6 ± 5.9
Female	1	25.8 (18.9–34.1)	23	18.8	15.0	30.0	1.1	1.0	1.3	18.7 ± 6.0
	2	44.0 (35.5–54.7)	22	16.7	13.6	21.4	1.3	1.1	1.7	13.6 ± 4.8
	3	64.5 (55.4–74.9)	35	16.7	13.6	21.4	1.5	1.1	2.1	12.3 ± 4.9
	4	79.9 (75.4–91.3)	10	10.6	9.1	13.0	1.5	1.4	1.8	7.5 ± 3.3
	MND patients									
Male	No problem	63.0 (52.8–69.9)	7	21.4	11.5	21.4	1.3	1.1	1.8	16.2 ± 7.2
	Problem	67.2 (44.8–76.6)	6	7.3	4.5	13.8	2.3	1.4	3.5	3.1 ± 6.3
Female	No problem	63.0 (50.8–73.7)	7	13.6	9.4	18.8	1.6	1.2	2.4	9.4 ± 6.5
	Problem	73.0 (39.3–85.3)	10	4.0	2.0	5.3	3.2	2.4	4.3	1.6 ± 1.5

Patients were divided according to how they answered the question 'Do you have a problem with your swallowing?'

added only 2–3% to the value of R squared; to simplify the regression, analysis was done separately in each sex looking at the effect of age alone. Plots of swallowing capacity and average volume per swallow vs. age in men and women are shown in Figure 1, together with the predicted values, 95% CIs for the population mean and the prediction intervals for an individual.

Average time per swallow increased with age group in men and women (Kruskal Wallis, adjusted for ties, $p<0.001$ and $p=0.014$, respectively).

The indices of swallowing in the MND patients (Table 1) are shown according to their answer to the question 'Do you have a problem with your swallowing?' Those MND patients who perceived a swallowing problem took smaller bolus volumes, and spent longer on each swallowing cycle, both of which led to a reduced swallowing capacity (Mann-Whitney tests for average volume per swallow $p=0.001$ and average time per swallow $p=0.0003$; unpaired t test for swallowing capacity $p=0.0007$). Average volume per swallow and swallowing capacity in the MND group are also shown in Figure 1. Indices of swallowing in those MND patients who denied a problem were not significantly different to Group 3 of the normals.

Variability of swallowing indices

Analysis of variance of the three swallowing indices in normals showed a large between-subject effect and very small (but statistically significant) effects related to day, triplet and swallow. To establish how representative one or two initial observations are, we compared indices from the first swallowing test, the mean of indices from the first two swallowing tests on day 1, and the mean of indices from the first tests on days 1 and 2 (i.e. the first and the tenth swallowing test), to the mean of the indices from all swallowing tests performed. In both groups, indices were expressed as percent predicted according to age and sex using the regression equations shown in the legend to Figure 1. The difference (ignoring sign) between the mean of indices from first swallowing tests on days 1 and 2 and the mean of all swallowing tests performed was the smallest (Table 2).

Symptoms and signs

The prevalence of symptoms and signs in the normals and the MND group are shown in Table 3. In the normal group (results not tabulated) dentures, regular prescribed medication and current medical problems were more common in the older (age groups 3 and 4 combined) than younger subjects (age groups 1 and 2 combined, χ^2 analysis with Yates' correction, all $p<0.001$). There were no significant differences between the sexes in the incidence of any symptoms or signs. Signs detected during swallowing were more common than traditional cranial nerve signs; ten normal subjects (incidence 5.5%, 95% CI 2.0–8.9%) had a brief episode of coughing after their first timed test, whilst only two had a definite jaw jerk. Symptoms and signs in the MND group were compared to normal males and females of a similar age (group 3, Table 1) using 2 by 2 tables and χ^2 or Fisher's exact tests. The majority of symptoms and signs were more common in the MND group (Table 3); one notable exception was nasal regurgitation. In the MND group a reduced swallowing capacity and reduced average volume per swallow,

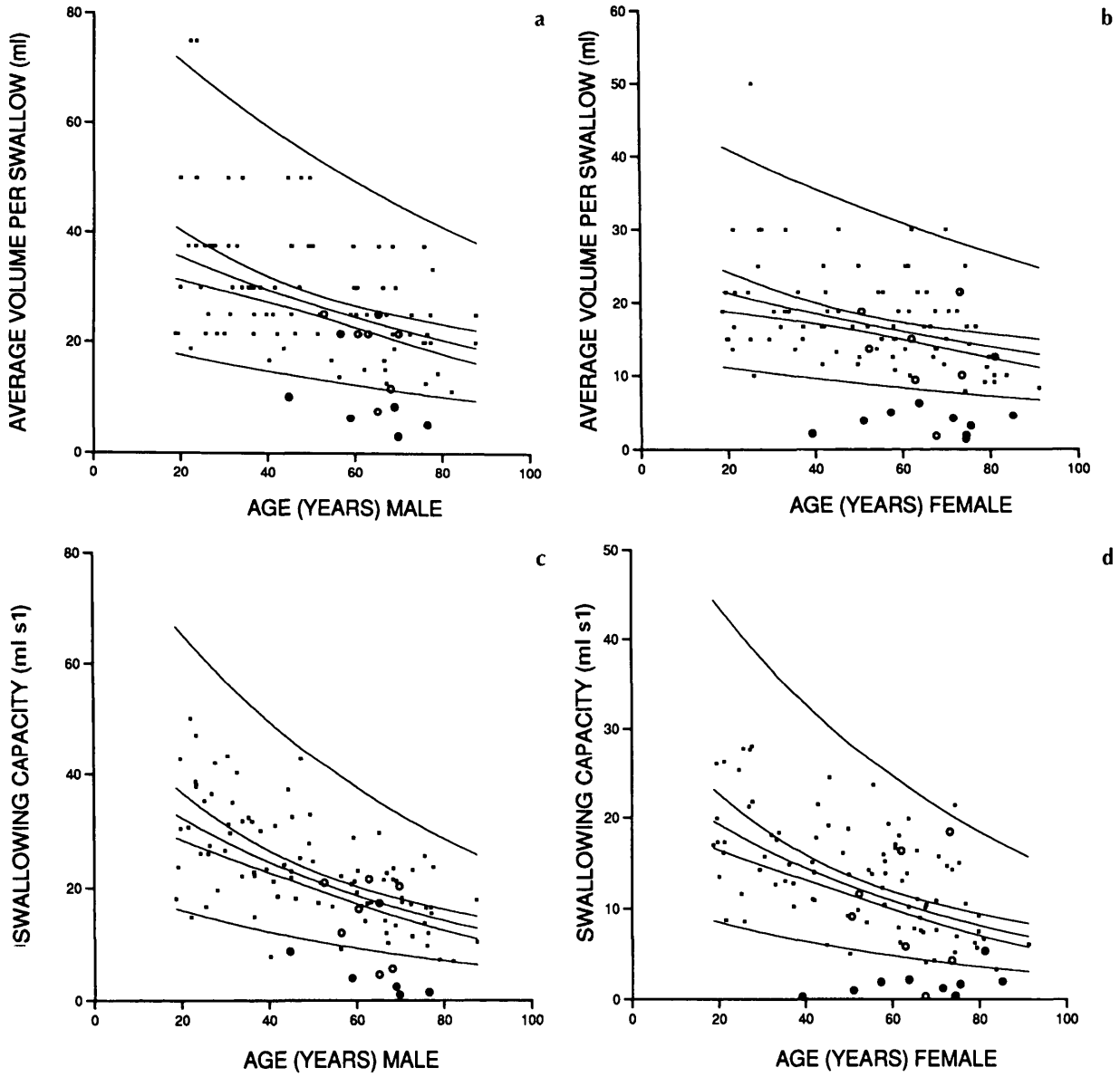

Figure 1. Graphs showing average volume per swallow and swallowing capacity (y axes) plotted against age (x axes) in men and women. Data points for the normals are shown as dots. Predicted value, 95% CIs for the population mean and 95% CIs for an individual are shown. **a** (volume per swallow, men): $\log_{10}y = 1.63\text{-}0.004x$ ($r = 0.47$, residual standard deviation of y about the regression line (Sres) $= 0.1471$, $p < 0.0001$); **b** (volume per swallow, women): $\log_{10}y = 1.39\text{-}0.003x$ ($r = 0.39$, Sres $= 0.1372$, $p < 0.0001$); **c** (swallowing capacity, men): $\log_{10}y = 1.63\text{-}0.006x$ ($r = 0.62$, Sres $= 0.1485$, $p < 0.0001$); **d** (swallowing capacity, women): $\log_{10}y = 1.41\text{-}0.006x$ ($r = 0.57$, Sres $= 0.1713$, $p < 0.0001$). Mean ages (standard deviation) were 49.5 years (19.7) for men and for women, 51.9 years (19.37) for swallowing capacity and 51.7 years (19.42) for average volume per swallow, since the number of swallows used was not recorded in one woman. Worked examples showing calculations of confidence intervals are available on request. Superimposed on each graph is the corresponding data from the MND group: shaded circles and empty circles denote, respectively, patients who answered 'Yes' and 'No' to the question 'Do you have a problem with your swallowing?'

both expressed as percent predicted according to age and sex, was associated with the presence of a number of symptoms and signs which were rare or did not occur in the normals (columns 5 and 6, Table 3). A detailed analysis of the palatal and pharyngeal reflexes will be presented separately; no subject had an absent palatal or pharyngeal reflex on more than three occasions if tested five times over a two-week period.

Discussion

Clinical features commonly assessed in neurogenic dysphagia are symptoms related to swallowing, the integrity of the lower cranial nerves and the occurrence of chest infections; observation of a patient actually swallowing may be overlooked. Studies which have included observation of patients swallowing water have found it a revealing adjunct to

Table 2 Median differences (ignoring sign) between mean indices of test results: first, first and second, first and tenth vs. mean of all tests

	1st–All	Mean of 1st + 2nd–All	Mean of 1st + 10th–All
Swallowing capacity			
Normal subjects ($n=77$)	10.19 (3.73–18.43)	8.35 (2.9–14.52)	4.97 (1.84–9.04)
MND patients ($n=8$)	8.11 (2.57–34.42)	13.65 (2.26–33.99)	4.26 (1.08–8.34)
Average volume per swallow			
Normal subjects ($n=76$)	10.11 (3.93–16.37)	5.48 (2.34–11.35)	4.24 (2.13–10.95)
MND patients ($n=8$)	8.76 (5.23–13.62)	7.98 (3.39–14.87)	3.52 (1.71–12.84)

All data are medians (IQ range). Swallowing capacity and average volume per swallow were expressed as percent predicted by age and sex using the regression equations of Figure 1. Data for MND group in final column are for six patients only.

the neurological examination, which may provide a useful indication of aspiration, pulmonary complications and outcome.[5–10] A natural extension of observing patients is to time them drinking a known volume and to count the number of swallows used.

The indices yielded by this test are measures of dysphagia at the level of disability, as defined by the World Health Organisation;[11] alone they give little or no indication of the nature (or severity) of an underlying pathology (e.g. myositis) or impairment (e.g. weakness). In this regard, the test is measuring illness at the same level as a timed test of walking, the indices from which give little or no indication of the pathologies or impairments underlying a gait abnormality.

In normals age, sex and height are the major determinants of swallowing function. Height was included in the final regression model in preference to weight, although both accounted for a similar proportion of overall variability. The effect of height may be related to a larger oral and pharyngeal cavity, allowing larger bolus volumes to be swallowed.

A reduction in swallowing capacity can be due to a reduction in average bolus volume, or a prolongation of average time per swallow, or a combination of both. Pausing to breathe will lead to prolongation of the average time per swallow and a reduced swallowing capacity; volume per swallow is less affected by respiratory function and in this regard is a better measure of swallowing function alone. Changes in average time per swallow and average bolus volume contribute to the significant reduction in swallowing capacity seen with sex and age in normal subjects and to the reduced swallowing capacity of those MND patients with a swallowing problem; 'taking smaller sips' and spending longer on each swallow are obvious ways of reducing the risk of overt decompensation occurring.

Being able to express indices in patients as percent predicted according to age and sex has obvious advantages. Single measures from males and females of any age are rationalized and made more meaningful as is routine in the measurement of vital capacity. Changes in the indices are also rationalized. In an MND patient with a greatly reduced swallowing capacity, two successive recordings of 0.5 and 1.0 ml represents a percent change of 100%, which intuitively seems clinically misleading; if the predicted swallowing capacity in this example was 20 ml, the change becomes 2.5 in units of percent predicted.

The repeatability studies suggest that, in both normals and MND patients, the mean of the indices (swallowing capacity and average volume per swallow) from two tests performed on separate days provides a better estimate of the 'true' value than either the indices from the first test alone or the mean of two tests performed consecutively on the first day. However, some subjects obviously exhibited greater variability than others, and we recommend establishing variability in individuals if the indices are to be used for monitoring.

The data for the prevalence of symptoms and signs in normal adults provides a useful backcloth against which to judge findings in patients. Symptoms and signs traditionally thought of as being confined to patients with neurogenic dysphagia do occasionally occur in normals and conversely, some of those expected in neurogenic dysphagia did not occur excessively in this particular group of patients. Within the MND group, a reduced swallowing capacity and a reduced average volume per swallow were associated with a number of symptoms and signs indicative of a swallowing problem providing further evidence of the validity of these indices as measures in patients with neurogenic dysphagia.

Videofluoroscopy,[12] manofluorography,[13] nasendoscopy,[14] scintigraphy[15] and the Exeter Dysphagia assessment technique[16] allow many different aspects of swallowing function to be studied in considerable detail and in some cases measured, however, they cannot easily be incorporated into a ward round or out-patient clinic as a means of quickly observing and quantifying swallowing function. We see this timed test as an adjunct to the examination of patients who have, or are potentially at risk of

Table 3 Prevalence of symptoms and signs

Symptom or feature (Yes/No)	Percent of normals ($n=181$)	Percent of MND patients ($n=30$)	p Gp 3 vs. MND	Swallowing capacity* p MND yes/no	Average volume per swallow* p MND yes/no
Problem swallowing	0.0	53.3	N/A	0.001	0.002
Voice change in the last year	7.7	80.0	<0.001	0.003	0.005
Need to be careful when eating	6.6	60.0	<0.001	<0.001	<0.001
Avoiding certain foods	3.3	43.3	<0.001	<0.001	0.001
Difficulty keeping food or drink in mouth	0.0	40.0	<0.001	0.001	0.004
Food needs special preparation	0.0	23.3	<0.001	0.002	0.003
Able to take tablets without difficulty	98.3	63.3	<0.001	0.02	0.01
Need a glass of water when eating	2.8	33.3	<0.001	0.06	0.07
Dentures	35.9	70.0	>0.2	0.35	0.38
Regular prescribed medication	35.4	66.7	>0.2	0.69	0.76
Smoker	20.4	25.0	>0.2	0.02	0.03
Medical problems	34.3	30.0	<0.05	0.35	0.4
Dentures not fitting well	83.1	80.1	>0.2	0.28	0.38
More than one chest infection in last year	5.5	10.0	>0.2	0.51	0.76
Symptoms > 1/month (Yes/No)					
Coughing episodes when eating	5.5	56.6	<0.001	0.005	0.004
Problems with excessive saliva	4.4	41.7	<0.001	0.01	0.009
Difficulty using tongue when eating	0.0	37.5	<0.001	0.001	0.003
Things going down the wrong way	5.0	46.7	<0.001	0.03	0.03
Problems with a dry mouth	20.4	58.7	<0.01	0.86	0.54
Food in mouth after eating	1.7	40.0	<0.001	0.02	0.007
Nocturnal coughing episodes	4.4	30.0	<0.001	0.43	0.33
Food stuck in the throat after swallowing	0.0	33.3	<0.001	0.43	0.46
Difficulty chewing	0.6	20.8	<0.01	0.11	0.19
Short of breath when eating	0.6	17.2	<0.01	0.36	0.53
Heartburn	8.8	14.3	>0.2	0.79	0.65
Painful to swallow	0.0	3.6	>0.2	0.67	0.42
Nasal regurgitation	0.0	3.3	>0.2	0.27	0.33
Sign (Present/Absent)					
Slow tongue movements	0.0	60.0	<0.001	<0.001	<0.001
Abnormal speech	0.0	73.3	<0.001	<0.001	0.001
Weakness of mouth	0.0	50.0	<0.001	0.001	<0.001

Abnormal cough	0.0	56.7	<0.001	0.001	0.003
Jaw weakness	0.0	43.3	<0.001	0.003	0.001
Jaw jerk	1.1	53.3	<0.001	0.08	0.04
Weakness of neck flexion	0.0	33.3	<0.001	0.005	0.003
Tongue fasciculations	0.0	63.3	<0.001	0.07	0.07
Coughing after timed swallowing test	5.5	23.3	<0.05	0.009	0.01
Coughing during timed swallowing test	0.0	30.0	<0.001	<0.001	<0.001
Altered voice quality post swallow	0.6	13.6	<0.05	0.03	0.12
Drooling post swallowing test	3.3	20.0	>0.05	0.02	0.006

p values are for χ^2 and Fisher's exact test (Group 3 vs. MND) or Kruskal-Wallis test (last two columns, MND patients with the symptom/sign vs. those without).
* Expressed as percent predicted.

developing, neurogenic dysphagia. Through the mandatory observation of swallowing, the test ensures that a neurological examination is supplemented by a functional assessment. In addition, three ratio measures of swallowing can be obtained and, if helpful, average volume per swallow and swallowing capacity can be expressed as percent predicted using the regression equations derived from the normals in this study. The normal bolus volume has been researched,[17–20] and in our own earlier work[1–3] we described guideline normal values for swallowing capacity, but we believe this to be the first paper describing three indices of swallowing in a healthy adult population.

The predictive value of swallowing indices for morbidity and death due to nutritional failure or pulmonary complications now needs to be determined in different conditions, in order to decide how and whether abnormal values should inform clinical interventions.

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