Electrophysiologic patterns of oral-pharyngeal swallowing in parkinsonian syndromes

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Abstract—Objectives: To assess the presence, severity, and differences in dysphagia in Parkinson disease (PD), Parkinson variant of multiple system atrophy (MSA-P), and progressive supranuclear palsy (PSP), and to study the pathophysiology of swallowing abnormalities in these disorders. **Methods:** We applied an electrophysiologic method to evaluate oral-pharyngeal swallowing. We analyzed the following measures: duration of EMG activity of suprahyoid/submental muscles (SHEMG-D); duration of laryngeal-pharyngeal mechanogram (LPM-D); duration of the inhibition of the cricopharyngeal muscle activity (CPEMG-ID); interval between onset of EMG activity of suprahyoid/submental muscles and onset of laryngeal-pharyngeal mechanogram (I-SHEMG-LPM); and swallowing reaction time (SRT). **Results:** The prolongation of I-SHEMG-LPM was more typical in PD, whereas the most distinctive finding both in patients with PSP and MSA-P was the reduction or the absence of CPEMG-ID early in the course of the disease. **Conclusions:** Involvement of the pedunculo-pontine tegmental nucleus, with subsequent dysfunction of basal ganglia and of the medullary central pattern generator of swallowing, may account for the abnormalities detected in these parkinsonian syndromes. The method described was able to identify swallowing abnormalities also in patients without symptoms of dysphagia and to evaluate dysphagia severity in all patients.

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Parkinson disease (PD), multiple system atrophy (MSA), and progressive supranuclear palsy (PSP) are degenerative disorders of the CNS that share several common features, especially early in their course, so it is often difficult to differentiate one from the others. Swallowing abnormalities are a common problem in these disorders, and can manifest themselves as dysphagia or silent aspiration of food and liquids in the airways, conditions that can put the patient's life at risk.^{1,2} Radiologic and gastroenterologic dynamic procedures such as videofluoroscopy and manofluorography have been used to evaluate swallowing abnormalities in these disorders.^{2–4} Electrophysiologic investigations have also been proposed to study the functional aspects of the oral and pharyngeal phases of swallowing, in normal subjects⁵ and in patients with PD.⁶

Dysphagia appears earlier in PSP and MSA than in PD,⁷ but it is unclear whether each of these parkinsonian syndromes shows specific abnormalities of the oral or pharyngeal phases of swallowing.

In the present study we used electrophysiologic techniques to examine the oral and pharyngeal phases of swallowing in patients with PD, Parkinson variant of MSA (MSA-P), and PSP. Our aims were to

improve our knowledge of the pathophysiologic mechanisms of dysphagia in these parkinsonian syndromes; to examine differences in swallowing abnormalities between these disorders; and to assess the presence and the severity of swallowing abnormalities and to correlate them with clinical dysphagia.

Methods. All patients and control subjects gave informed consent to all procedures of the study, which was approved by the institutional ethical committee.

Population. We studied 28 patients with PD, 20 men and 8 women, all examined during the “on” phase of the levodopa response cycle (age range: 48 to 84 years); 9 patients with diagnosis of PSP,⁸ 4 men and 5 women (age range: 64 to 77 years); 9 patients with diagnosis of MSA-P,⁹ 6 men and 3 women (age range: 53 to 73 years); and 24 normal subjects, 12 men and 12 women (age range: 45 to 80 years) as the control group.

The clinical severity of PD, PSP, and MSA-P was assessed by the Unified PD Rating Scale (UPDRS).

The severity of dysphagia was assessed based on the patient's subjective complaint or problem, and was graded as follows: 0 (absence of dysphagia) when there were no subjective difficulties in swallowing; 1 (mild to moderate dysphagia) when the patient experienced a feeling of something getting stuck when swallowing, or had to cough during or after swallowing, or had to cut food finely and had to avoid certain difficult-to-particulate foods, or had to swallow liquids in small sips; 2 (severe dysphagia) when serious nutritional problems were present with need of a feeding tube.

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Electrophysiologic study of swallowing. Each subject was examined while seated with the head in a natural position. An electromyograph Key-point Medtronic (Skovlunde, Denmark) was used. The study was performed applying a previously described technique.⁵ The first channel was used to examine the EMG activity of suprahyoid/submental muscles (a muscle complex consisting of the mylohyoid, the genioglossus, and the ventral body of the digastric). Two surface electrodes were applied to the skin of the suprahyoid region at an interelectrode distance of 30 mm. The EMG activity of suprahyoid/submental muscles begins with the propulsive action of the tongue during the oral phase of swallowing and continues during the pharyngeal phase of swallowing.¹⁰ The second channel was used to examine the EMG activity of the cricopharyngeal muscle. Lidocaine spray solution (4%) was applied to the skin of the cricothyroid space. A concentric needle electrode was inserted through the skin at the level of the cricoid cartilage, 1.5 cm posterior to its palpable lateral border, in the posteromedial direction.⁵ At rest, the cricopharyngeal muscle shows tonic activity related to its function as the upper esophageal sphincter; such activity disappears (EMG silence) during the hypopharyngeal phase of deglutition. All EMG signals were rectified and bandpass filtered between 100 Hz and 2 KHz.

The third channel was used to record the signal obtained from a piezoelectric transducer which detected mechanical deformations produced by the pharyngeal and laryngeal structures involved in swallowing. In particular, this device provides data about the timing of elevation and return to the rest position of the laryngeal and pharyngeal structures during the pharyngeal reflex response of the deglutition. The transducer consisted of a rectangular strip (length, 37 mm; width, 12 mm) with a triangular rubber button in the center of the strip and was applied to the skin at the level of the cricothyroid membrane. The transducer was kept in place by adhesive tape applied around the neck, and showed linear force-to-signal ratio for forces ranging from 0.1 to 300 g; its signal was bandpass filtered between 0.01 and 30 Hz.

After a complete explanation of the given procedures to the patient, two different swallowing tests were performed. In the first, the subject had to swallow a small volume of water (2 mL) which had been put into his or her mouth with a disposable syringe without needle. We analyzed the following electrophysiologic measures: duration of EMG activity of suprahyoid/submental muscles (SHEMG-D); duration of laryngeal-pharyngeal mechanogram (LPM-D); duration of the inhibition of the cricopharyngeal muscle EMG activity (CPEMG-ID); and interval between onset of EMG activity of suprahyoid/submental muscles and onset of laryngeal-pharyngeal mechanogram (I-SHEMG-LPM) (figure 1). Signals were triggered when signal amplitude of suprahyoid/submental muscle EMG activity was equal to or greater than 50 μ V. Recordings obtained from five successive swallowing acts were stored and the average value of each electrophysiologic measure was evaluated.

The second test evaluated swallowing reaction time (SRT). Two milliliters of water were put into the mouth, a headset was applied to the subject, and the start order to swallow was indicated by an acoustic signal with the following measures: burst with internal frequency of 0.25 KHz, rise time of 2 msec, plateau of 4 msec, decrease time of 2 msec, decibel intensity equal to 1.3 times the acoustic threshold of the subject. The acoustic stimulus was synchronized with the starting of the sweep. The test measured the time interval between the acoustic stimulus and the onset of the EMG activity of the suprahyoid/submental muscles (figure 2). We evaluated the mean SRT value obtained from five successive swallowing acts.

The time interval between each deglutition was 1 to 2 minutes in both tests.

Statistical methods. **Correlations.** For each group of patients, we computed the Pearson's correlation coefficient between the electrophysiologic measures, the clinical variables UPDRS, and the disease duration.

Mean value comparisons. In each group of patients we compared the mean UPDRS values with the different degrees of the dysphagia by the analysis of variance.

For all the electrophysiologic measures, with the exception of CPEMG-ID, the mean values for the four groups of subjects (controls, PD, PSP, and MSA-P) were compared by analysis of variance; moreover, if the four groups' mean values proved to be different, we used a linear contrast to test the hypothesis that the mean values of controls were different from the mean values of all the patients (controls

Figure 1. Recording of oral-pharyngeal swallowing in a normal subject. Upper trace: rectified EMG activity of the suprahyoid/submental muscles (SHEMG); middle trace: EMG silence of the cricopharyngeal muscle; lower trace: laryngeal-pharyngeal mechanogram (LPM); the markers (arrows and lines) indicate SHEMG duration (SHEMG-D), LPM duration (LPM-D), interval between EMG activity of suprahyoid/submental muscles and laryngeal-pharyngeal mechanogram onsets (I-SHEMG-LPM), and duration of EMG inhibition of the cricopharyngeal muscle (CPEMG-ID).

vs all patients). In addition, we tested three other contrasts to compare the controls with each group of patients.

For CPEMG-ID, we used the Kruskal-Wallis and the Mann-Whitney tests.

We considered only the three groups of patients to evaluate the effect of two factors and of their interaction on the electrophysiologic measures of swallowing, with the exception of the CPEMG-ID. The two factors were the diagnosis (three levels: PD, PSP, and MSA-P) and the degree of dysphagia (three levels: absent, mild to moderate, and severe); the interaction between the diagnosis and the degree of dysphagia evaluates whether the different degree of dysphagia influences the value of a given measure depending on the kind of parkinsonian syndrome. When either of the factors had a significant effect, we considered two contrasts. The first contrast compared the first with the other two levels of the factor, namely PD vs PSP and PD vs MSA-P for the diagnosis factor, absent vs mild to moderate and absent vs severe for the dysphagia factor; the other contrast compared the third with the other two levels of the factor, namely MSA-P vs PD and MSA-P vs PSP for the diagnosis factor, severe vs absent and severe vs mild to moderate for the dysphagia factor.

As previously, for CPEMG-ID we used the Kruskal-Wallis and the Mann-Whitney tests.

Individual patient evaluation. For each measure, within each group of patients, we used the χ^2 test to evaluate the occurrence of values exceeding the normal limits, which were defined as the mean $\pm$ 2.5 SD computed in the control group.

Electrophysiologic score and discriminant analyses. For each subject we rated each measure as 0 if normal and as 1 if abnormal. The five values were added to compute an electrophysiologic score that could range from 0 (all measures normal) to 5 (all measures abnormal).

We correlated the electrophysiologic and the clinical dysphagia severity score.

We performed two discriminant analyses on the basis of the five electrophysiologic measures used. The first analysis considered all the patients. The second analysis considered the patients with disease duration of less than 6 years to compare swallowing dysfunctions for homogeneous disease duration among the parkinsonian syndromes examined, namely 10 PD, 9 PSP, and 9 MSA-P.

For all analyses, the significance level was set at $p = 0.01$.

Figure 2. Swallowing reaction time (SRT) in a normal subject (A) and in a patient with Parkinson disease (PD) who has severe motor impairment (B). First trace: EMG activity of the suprahyoid/submental muscles; second trace: EMG activity of the cricopharyngeal muscle; third trace: laryngeal-pharyngeal mechanogram. The arrows indicate the acoustic stimulus. Note the delay in the onset of the EMG activity of the suprahyoid/submental muscles in the patient with PD.

Results. Table 1 summarizes some characteristics of the population investigated. The mean age was not different among the four groups. The mean duration of the disease was different in the three groups of patients ($F = 10.4$, $p < 0.001$), and the contrast analysis showed that it was longer in the PD group than in the PSP ($t = 3.5$, $p = 0.001$) or in the MSA-P group ($t = 3.6$, $p = 0.001$). The UPDRS mean

score and the dysphagia severity score were not statistically different in the three groups of patients. In patients with PD, dysphagia was absent in 10 cases (35.7%), mild to moderate in 13 (46.5%), and severe in 5 (17.8%). Dysphagia was present in all patients with PSP, mild to moderate in 5 cases (55.6%), and severe in 4 (44.4%). In patients with MSA-P, dysphagia was absent in 2 cases (22.2%), mild to moderate in 3 (33.3%), and severe in 4 (44.4%).

Five out of the 10 patients with PD without dysphagia showed prolongation of SHEMG-D, I-SHEMG-LPM, and LPM-D; in particular, we found abnormal SHEMG-D in one patient, SHEMG-D and I-SHEMG-LPM in two patients, SHEMG-D and LPM-D in two patients.

Correlations. The correlations among clinical (UPDRS score and disease duration) and electrophysiologic measures in the PD group are shown in table 2.

In the PSP group, SRT increased as SHEMG-D decreased ($r = -0.784$; $p = 0.01$).

In the MSA-P group, SRT increased as LPM-D increased ($r = 0.968$; $p < 0.001$), and the UPDRS increased as I-SHEMG-LPM increased ($r = 0.825$; $p = 0.006$).

Mean values. In patients with PD the UPDRS was different depending on the degree of dysphagia; in particular when UPDRS increased also dysphagia increased (no dysphagia, UPDRS mean value: 19.1; mild to moderate dysphagia, UPDRS mean value: 32.4; severe dysphagia, UPDRS value: 52.6; $F = 31.9$, $p < 0.001$). Patients with MSA-P showed a similar trend (no dysphagia, UPDRS mean value: 28.0; mild to moderate dysphagia, UPDRS mean value: 33.3; severe dysphagia, UPDRS mean value: 66.0), nearly significant ($F = 7.22$, $p = 0.02$). All patients with PSP had dysphagia; the UPDRS mean values were almost the same ($F = 0.32$, $p = 0.58$) for the patients with mild to moderate dysphagia (UPDRS mean value: 39.6) and for those with severe dysphagia (UPDRS mean value: 43.0).

The mean values and standard errors of the electrophysiologic measures are summarized in table 3.

The four groups showed different mean values for the following electrophysiologic measures: SRT ($F_{(3,63)} = 4.2$; $p = 0.01$), SHEMG-D ($F_{(3,63)} = 7.0$; $p < 0.001$), I-SHEMG-LPM ($F_{(3,63)} = 8.2$; $p < 0.001$), LPM-D ($F_{(3,63)} = 18.9$; $p < 0.001$).

The first contrast analysis (controls vs all patients) showed that SRT ($t = 4.3$, $p < 0.001$), I-SHEMG-LPM ($t = 3.1$, $p = 0.003$), and LPM-D ($t = 9.2$, $p < 0.001$) mean values were shorter in controls than in patients.

The other contrast analyses compared the control group with each group of patients separately. In the PD group we found a prolongation of the following electrophysiologic measures: SRT ($t = 2.9$, $p = 0.008$), SHEMG-D ($t = 4.2$,

Table 1 General features of the population

Group	Number of patients (M/F)	Age, y		Disease duration, y		UPDRS score		DSS	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
Controls	24 (12/12)	62	45–80						
PD	28 (20/8)	66	48–84	9.5	1–20	32	8–68	0.8	0–2
PSP	9 (4/5)	71	64–77	4.0	3–6	41	29–59	1.4	1–2
MSA-P	9 (6/3)	65	53–73	3.8	2–6	38	28–89	1.2	0–2

UPDRS = Unified Parkinson Disease Rating Scale; DSS = Dysphagia Severity Score (0 = absent, 1 = mild to moderate, 2 = severe); PD = Parkinson disease; PSP = progressive supranuclear palsy; MSA-P = Parkinson variant of multiple system atrophy.

Table 2 Correlations among clinical (UPDRS score and disease duration) and electrophysiologic measures in patients with PD

		LPM-D	CPEMG-ID	I-SHEMG-LPM	SHEMG-D	UPDRS	Disease duration
SRT	r^*	0.637	0.641	0.029	0.495	0.766	0.454
	$p^\dagger$	<0.001	<0.001	0.884	0.007	<0.001	0.015
LPM-D	r^*		0.486	0.026	0.023	0.793	0.423
	$p^\dagger$		0.009	0.897	0.907	<0.001	0.025
CPEMG-ID	r^*			0.179	0.308	0.640	0.287
	$p^\dagger$			0.362	0.111	<0.001	0.139
I-SHEMG-LPM	r^*				0.119	0.010	0.042
	$p^\dagger$				0.545	0.960	0.833
SHEMG-D	r^*					0.212	0.006
	$p^\dagger$					0.278	0.976
UPDRS	r^*						0.544
	$p^\dagger$						0.003

The table shows the Pearson correlation coefficient (r^*) and the significance value ($p^\dagger$) between each pair of electrophysiologic and clinical variables in patients with Parkinson disease (PD).

UPDRS = Unified Parkinson Disease Rating Scale; LPM-D = duration of laryngeal-pharyngeal mechanogram; CPEMG-ID = duration of the inhibition of the cricopharyngeal muscle EMG activity; I-SHEMG-LPM = interval between onset of EMG activity of suprahyoid/submental muscles and onset of laryngeal-pharyngeal mechanogram; SHEMG-D = duration of EMG activity of suprahyoid/submental muscles; SRT = swallowing reaction time.

$p < 0.001$), I-SHEMG-LPM ($t = 4.9$, $p < 0.001$), and LPM-D ($t = 6.1$, $p < 0.001$). Three different patterns of abnormality of the SHEMG-D could be identified in patients with PD: SHEMG-D increase with continuous EMG activity in 14 patients, SHEMG-D increase with several EMG bursts in 4 patients, and SHEMG-D reduction in 3 patients (figure 3). The start hesitation of vocal and walking activity was present in 7 of our 28 patients with PD, including all 4 patients with SHEMG-D increase with several EMG bursts.

LPM-D was prolonged in both MSA-P ($t = 5.1$, $p < 0.001$) and PSP ($t = 7.6$, $p < 0.001$) vs controls.

The EMG silence of the cricopharyngeal muscle, normally seen during the hypopharyngeal phase of swallowing, was absent (CPEMG-ID = 0) in all of the PSP and in

all but two of the MSA-P patients. The Kruskal-Wallis test showed that CPEMG-ID was different in the four groups ($\chi^2 = 36.5$, $p < 0.001$). The Mann-Whitney test showed that CPEMG-ID was different in PSP ($z = -4.34$, $p < 0.001$) and MSA-P ($z = -4.15$, $p < 0.001$) vs controls, but similar between controls and patients with PD.

The diagnosis factor that was used to compare the three groups of patients influenced only SHEMG-D ($F_{(2,38)} = 5.2$; $p = 0.01$). In particular, contrast analyses showed that SHEMG-D was longer in PD than in PSP ($p = 0.01$).

All of the electrophysiologic measures, with the exception of the I-SHEMG-LPM, changed in relation to the severity of dysphagia: SRT ($F_{(2,38)} = 86.8$; $p < 0.001$), SHEMG-D ($F_{(2,38)} = 6.9$; $p = 0.003$), and LPM-D ($F_{(2,38)} = 19.6$; $p < 0.001$). SRT was longer for severe than it was for absent or mild to moderate dysphagia ($p < 0.001$). SHEMG-D was shorter for severe than it was for absent or for mild to moderate dysphagia ($p = 0.001$). LPM-D was shorter for absent than it was for mild to moderate ($p = 0.01$) or for severe ($p < 0.001$) dysphagia; LPM-D was also shorter for mild to moderate than it was for severe ($p < 0.001$) dysphagia.

The interaction between diagnosis and degree of dysphagia on the electrophysiologic measures was never significant; namely, when significant the effect of dysphagia showed the same behavior in the three groups of patients.

CPEMG-ID values were different in the three groups of patients (Kruskal-Wallis test: $\chi^2 = 25.46$, $p < 0.0001$). The Mann-Whitney test showed that CPEMG-ID was longer in the PD group than in the PSP ($z = 4.05$, $p < 0.0001$) and in the MSA-P ($z = 3.65$, $p < 0.0001$) groups, whereas the PSP and the MSA-P groups showed a similar CPEMG-ID ($z = 1.45$, $p = 0.44$).

In the PD group, CPEMG-ID values decreased as the degree of dysphagia increased, and the absence of the EMG silence of the cricopharyngeal muscle invariably corresponded to severe dysphagia. All of the patients with PSP presented with dysphagia score of 1 or 2 and no EMG silence of the cricopharyngeal muscle (figure 4). In the MSA-P group, CPEMG-ID was normal only in two patients without dysphagia; one of these two patients showed SHEMG-D prolonga-

Figure 3. Patterns of oral-pharyngeal swallowing in patients with Parkinson disease. Upper trace: EMG activity of the suprahyoid/submental muscles; middle trace: EMG activity of the cricopharyngeal muscle; lower trace: pharyngeal-laryngeal mechanogram. A: oral-pharyngeal bradykinesia; B: oral hypokinesia and pharyngeal bradykinesia; C: start hesitation of swallowing. Note the differences of the EMG activity of the suprahyoid/submental muscles.

Table 3 Mean values of the electrophysiologic measures of swallowing

Measure	Mean	Standard error
SRT (s)		
Control	0.43	0.03
PD	0.97	0.18
PSP	1.57	0.48
MSA-P	1.25	0.28
SHEMG-D (ms)		
Control	1,069	51
PD	1,782	161
PSP	983	189
MSA-P	1,111	186
I-SHEMG-LPM (ms)		
Control	205	20
PD	424	40
PSP	227	48
MSA-P	244	56
LPM-D (ms)		
Control	1,813	90
PD	2,869	148
PSP	3,485	199
MSA-P	3,021	221
CPEMG-ID (ms)		
Control	479	35
PD	352	34
PSP	0	0
MSA-P	47	35

SRT = swallowing reaction time; PD = Parkinson disease; PSP = progressive supranuclear palsy; MSA-P = Parkinson variant of multiple system atrophy; SHEMG-D = duration of EMG activity of suprahyoid/submental muscles; I-SHEMG-LPM = interval between onset of EMG activity of suprahyoid/submental muscles and onset of laryngeal-pharyngeal mechanogram; LPM-D = duration of laryngeal-pharyngeal mechanogram; CPEMG-ID = duration of the inhibition of the cricopharyngeal muscle EMG activity.

tion; all the other patients had dysphagia scores of 1 or 2 and absence of EMG silence of the cricopharyngeal muscle.

Individual patient evaluation. Table 4 reports the percentage of occurrence of abnormal values for a given electrophysiologic measure for each group of patients. For all of the measures, the occurrence of abnormal values failed to differ in the three groups of patients, with the exception of CPEMG-ID, which was reduced or absent more frequently in the MSA-P and in the PSP than in the PD group. In particular, the EMG silence of the cricopharyngeal muscle in the PD group was normal in 24 patients, reduced in 2 patients, absent in 2 other patients, all of whom had disease duration longer than 6 years.

Electrophysiologic score and discriminant analyses. The electrophysiologic score correlated to the dysphagia score both when the three groups of patients were considered together ($r = 0.883$, $p < 0.01$) or separately (PD: $r = 0.745$, $p < 0.001$; PSP: $r = 0.767$, $p = 0.01$; MSA-P: $r = 0.935$, $p < 0.001$). In the PD group, but not in the PSP or in the MSA-P groups, both the electrophysiologic scores ($r = 0.430$, $p = 0.01$) and the dysphagia scores ($r = 0.589$, $p = 0.001$) were related to disease duration. The electrophysiologic score was not different in the three groups of patients (mean values: PD = 2.03, PSP = 2.77, MSA-P =

Figure 4. Electrophysiologic pattern of swallowing in a patient with PSP. The duration of the EMG activity of the suprahyoid/submental muscles is reduced (upper trace); the EMG silence of the cricopharyngeal muscle is absent (middle trace); and the duration of the pharyngeal-laryngeal mechanogram is increased (lower trace).

2.55; mean ranks: PD = 21.4, PSP = 27.9, MSA-P = 25.56; $\chi^2 = 1.9$; $p = 0.38$). When the patients with a disease duration shorter than 6 years were analyzed, the differences among groups were still not significant ($\chi^2 = 5.1$; $p = 0.07$), although the mean value of the electrophysiologic score of the PD group dropped to 1.3.

In the first discriminant analysis, that considered the entire patient cohort, the stepwise method entered two variables, namely I-SHEMG-LPM and CPEMG-ID, in a discriminant function that was able to correctly classify 89.1% of the patients as either PD or as other parkinsonian syndromes (PSP and MSA-P). Of the five patients who were misclassified, four were PD patients with disease duration of at least 8 years, and one was a MSA-P patient without dysphagia and with normal electrophysiologic measures.

The second discriminant analysis considered the patients with disease duration of less than 6 years. The

Table 4 Occurrence of electrophysiologic abnormalities in patients

	PD	PSP	MSA-P	χ^2 *	p †
SRT	21.4	44.4	55.6	4.32	0.11
SHEMG-D	75.0	33.3	44.4	10.31	0.03
I-SHEMG-LPM	39.3	11.1	22.2	2.91	0.23
LPM-D	53.6	88.9	55.5	3.69	0.16
CPEMG-ID	14.3	100.0	77.8	22.40	<0.01‡

Values are percentages. The χ^2 * and p † values refer to the χ^2 test that compared these values.

‡ Significant.

PD = Parkinson disease; PSP = progressive supranuclear palsy; MSA-P = Parkinson variant of multiple system atrophy; SRT = swallowing reaction time; SHEMG-D = duration of EMG activity of suprahyoid/submental muscles; I-SHEMG-LPM = interval between onset of EMG activity of suprahyoid/submental muscles and onset of laryngeal-pharyngeal mechanogram; LPM-D = duration of laryngeal-pharyngeal mechanogram; CPEMG-ID = duration of the inhibition of the cricopharyngeal muscle EMG activity.

stepwise method again entered I-SHEMG-LPM and CPEMG-ID: 96.4% of the patients were correctly classified, i.e., all patients except for the MSA-P patient without dysphagia and with normal electrophysiologic measures. In particular, an abnormal CPEMG-ID (absence of the EMG silence of the cricopharyngeal muscle) was a peculiar finding of PSP or MSA-P patients, whereas a prolongation of I-SHEMG-LPM was more typical of PD patients.

Discussion. Videofluoroscopic studies of swallowing may provide clues about the cause of dysfunction, particularly in patients with upper esophageal dysfunction, to quantify severity of swallowing dysfunction and identify compensatory maneuvers. However, videofluoroscopy lacks the same temporal resolution of the electrophysiologic study to evaluate the timing of each functional swallowing event, and fails to provide a complete functional evaluation of the cricopharyngeal muscle activity as obtained by needle-EMG investigation. The videofluoroscopic and electrophysiologic methods are likely to complement each other in the study of swallowing.

In all of the patients the electrophysiologic and dysphagia scores were correlated; with the exception of the I-SHEMG-LPM, the electrophysiologic measures were related to the degree of dysphagia.

The dysphagia score and the electrophysiologic score correlated positively with disease duration in patients with PD. Also the UPDRS score of our patients with PD was related to the degree of dysphagia. These findings are in accordance with previous studies,¹¹ even though differences were also observed.^{12,13} Certainly, when dysphagia occurs during the first year of disease, the diagnosis of PD should be reconsidered.¹⁴

In this study 10 out of 28 patients with PD did not have dysphagia. Nevertheless, 5 of these 10 patients showed prolongation of SHEMG-D, I-SHEMG-LPM, or LPM-D. This is in keeping with the observation that in some patients with PD without symptoms of dysphagia, a silent aspiration of food or liquid occurs.^{12,13}

As shown in previous clinical, videofluorographic, and electrophysiologic studies,^{2-4,6} our investigation in PD detected different bradykinetic swallowing abnormalities: prolongation of SHEMG-D, I-SHEMG-LPM, LPM-D, and SRT. A deficit in movement sequence that involves both the voluntary and the involuntary phases of oral-pharyngeal swallowing can determine the prolongation of SHEMG-D, I-SHEMG-LPM, and LPM-D by two separate alterations of neural control mechanisms. On one side, SHEMG-D and I-SHEMG-LPM prolongation could be explained by the inappropriate planning of the voluntary swallowing activity in relation to dysfunctions of the cortical-subcortical loops connecting the basal ganglia to the premotor and supplementary motor areas of the frontal cortex.¹⁴ On the other side, LPM-D prolongation could be caused by the above mechanisms or by dysfunctions of the medullary central pattern generators involved in the involuntary control of swallowing.¹⁵ Alterations in registration or

processing of the stimulus, dysfunctions in the pre-programming of the motor response or in its initiation may all cause SRT prolongation.

The SHEMG-D mean value in patients with PD was longer than in controls, and SHEMG-D increase, with continuous EMG activity, was frequently observed (14 out of 28 patients). However, we identified two other abnormal patterns: the first, in 4 patients, was a SHEMG-D increase, with several EMG bursts; and the second, in 3 patients, a SHEMG-D reduction (figure 3). The SHEMG-D increase with several EMG bursts of suprahyoid/submental muscles is related to the repetitive pushing action of the tongue^{3,4} and we can label it as start hesitation of swallowing. Start hesitation is well-described and commonly observed in patients with PD who begin speaking or walking after standing up from a chair or bed. The pathophysiology of start hesitation is still not well understood¹⁶; it may be related to bradykinesia or it may represent a side-effect of long-term levodopa therapy.¹⁷ All of the 4 patients with PD with start hesitation of swallowing also showed start hesitation of vocal or walking activity.

SHEMG-D reduction could be explained by poverty of movement in the suprahyoid/submental muscles, possibly in relation to a "deficit of energization of the cortical motor output."¹⁸ In these patients SHEMG-D reduction was associated with SRT prolongation and this may be explained by brady-hypokinetic mechanisms of oral swallowing.

In contrast with previous studies that indicated that an absence of relaxation or poor relaxation of the cricopharyngeal muscle is common in PD,^{4,19} we found only two patients with reduced CPEMG-ID and two patients with absence of EMG silence. The relaxation of the cricopharyngeal muscle in the hypopharyngeal phase of swallowing is under the control of the medullary central pattern generators of swallowing.¹⁵ Oral-pharyngeal sensory afferents play a fundamental role in the coordination of the swallowing act by triggering and modulating inputs to the medullary central pattern generators, which in turn determines the timely relaxation of the cricopharyngeal muscle.^{15,20} The hypothesis that relaxation abnormalities of the cricopharyngeal muscle in patients with PD are caused by reflex neural dysfunctions is suggested by previous observations on cough intensity and cough reflex. Less impaired patients with PD showed only a deficit of the voluntary activity of the pharyngeal and laryngeal muscles; however, the most severely impaired patients with PD also had a dysfunction of the reflex cough activity, dependent on the sensory laryngeal-pharyngeal afferents.²¹ In accordance with these results, we observed that only patients with PD with severe dysphagia and the highest UPDRS scores showed a reduced or absent EMG inhibition of the cricopharyngeal muscle (table 2).

Our study confirmed that dysphagia is a common and early symptom in MSA and PSP as 7 out of 9 of the MSA-P patients and all of PSP patients showed symptoms of dysphagia.^{7,22,23} In contrast with PD, in MSA-P or PSP neither the dysphagia scores nor the

electrophysiologic scores were related to disease duration or to disease severity (UPDRS). These findings might be attributed to a shorter disease duration range with higher UPDRS values or to a smaller number of patients in both MSA-P and PSP groups. Another possible explanation is that dysphagia becomes more severe earlier in these patients than in patients with PD, as confirmed by other authors.⁷ As in patients with PD, LPM-D was prolonged in both MSA-P and PSP patients. This abnormality indicates that the bradykinesia may be responsible for swallowing difficulties also in PSP and MSA-P, in accordance with previous observations.²²⁻²⁴ However, absence of the EMG silence of the cricopharyngeal muscle was the most frequent electrophysiologic alteration observed in both PSP and MSA-P (table 4, figure 4). We already reported this electrophysiologic finding in MSA.²⁵ In the present study we found that this alteration appeared earlier and much more frequently in PSP and MSA-P than in PD.

Our study supports the hypothesis that the pedunculopontine tegmental nucleus (PPTN) is involved in the pathophysiology of dysphagia in all parkinsonian syndromes examined. PSP, MSA, and PD show a significant degeneration of the cholinergic neurons of the PPTN.²⁶⁻³⁰ The cholinergic part of this nucleus has reciprocal connections with various nuclei of the basal ganglia, including the subthalamic nucleus, the globus pallidus pars interna, and the substantia nigra pars reticulata.^{26,30} Cholinergic outputs from PPTN also project to the nucleus tractus solitarius, which is part of the medullary central pattern generators of swallowing.^{26,31-33}

The PPTN is thought to be involved in the initiation, modulation, and timing of stereotyped sequential motor automatisms,³⁰ such as those observed in the oral and the pharyngeal phases of swallowing. A deficit of the PPTN inhibitory (cholinergic) activity on the bulbar swallowing centers could explain the "disruption of the normal sequencing of the pharyngeal phase of swallowing"³¹ with reduction or absence of the cricopharyngeal muscle relaxation.³⁰⁻³² In MSA-P and PSP an additional cause of disruption of pharyngeal swallowing could be the primary and progressive degeneration of several brainstem structures of the central pattern generators of swallowing.³³⁻³⁵ The timing and the extent of the degeneration of the different PPTN projections to the structures mentioned above, in addition to the primary degeneration of the central pattern generators of swallowing, could differentiate MSA-P and PSP from PD.

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Figure. (A) Display of the dose plan done during gamma knife procedure (April 2005). The vestibular schwannoma was treated with conformal single dose radiotherapy with a maximum dose of 26 Gy. The 18, 13, 6, and 3 Gy isodoses are displayed. The outer circle represents the 3 Gy isodose (arrow). (B through D) MRI performed in March 2006. (B) MR angiography showing circumscribed angiopathy of the right vertebral artery and the basilar artery. The arrow shows a distal stenosis of the right vertebral artery. (C) Gadolinium-enhanced T1-weighted axial MR image. The gadolinium-enhancing vestibular schwannoma is in direct vicinity of the T1 hypointense cerebellar infarction (arrows). (D) Diffusion-weighted image showing the hyperintense cerebellar infarction (arrow).

Cerebellar infarction after gamma knife radiosurgery of a vestibular schwannoma

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A 77-year-old woman with hypertension and hypercholesterolemia developed vertigo, gait ataxia, and deafness in her right ear. A vestibular schwannoma was diagnosed, which was treated with gamma knife radiosurgery in April 2005. Since then, the size of the schwannoma remained stable with no further symptom progression. In March 2006, the patient developed right hemiataxia. Brain MRI revealed an area of restricted diffusion in the vascular territory of the right anterior inferior cerebellar artery supporting an acute ischemic cerebellar infarction. MR angiography exhibited

localized angiopathy predominantly affecting the right vertebral artery and the basilar artery. The area of infarction was near the irradiated schwannoma (figure). In September 2006, the clinical outcome was normal.

Irradiation-induced cerebral infarctions are rare and follow fractionated irradiation therapy by 5 to 10 years.¹ In patients with vascular risk factors, irradiation may accelerate the natural process of atherosclerosis.² However, as the probability of developing an infarction or radiation-associated vasculopathy after single dose gamma knife radiosurgery appears even lower, we hypothesize that the coincidence of single local treatment and vascular radiogenic lesion and eventually the local pressure induced by the schwannoma itself may have contributed to local angiopathy encouraging the arterial infarction.

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