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ORIGINAL COMMUNICATION

Predictors of drooling severity in people with Parkinson's disease

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Abstract

Background Drooling, defined as the unintentional loss of saliva from the anterior oral cavity, remains poorly understood in terms of the underlying clinical factors in people with Parkinson's disease (PwP). This study aims to clarify these factors by analyzing predictors and secondarily the correlates with the severity of drooling in PwP.

Methods We conducted a cross-sectional study involving 42 PwP with drooling and 59 without drooling. Clinical assessments were performed, and the primary outcome was the item 2.2 Saliva and drooling of the Movement Disorder Society-Unified Parkinson's Disease Rating Scale. The Mann–Whitney test was used to compare the distribution differences in clinical variables between PwP with and without drooling. The Spearman test was used to examine correlations with drooling, and ordinal logistic regression was used to examine predictors of drooling.

Results PwP with drooling showed significantly greater impairments in axial signs, posture, facial expression, speech, swallowing, oromotor, motor and non-motor domains than PwP without drooling. Longer disease duration, higher disease severity, levodopa equivalent daily dose, axial signs, unstimulated salivary flow rate, and impairments in speech, posture, facial expression, swallowing, oromotor, motor and non-motor domains were significantly correlated with a higher score on the item 2.2. Male sex, poorer swallowing, oromotor and speech functions were strong predictors of higher scores on the item 2.2 Saliva and drooling.

Conclusions Male PwP with swallowing disorders, oromotor and speech impairments are significantly more likely to have severe drooling. Targeted interventions aimed at these swallowing, oromotor, and speech impairments may offer promising approaches to reducing drooling severity in PwP.

Keywords Parkinson's disease · Drooling · Sialorrhea · Saliva control · Salivation

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Introduction

Drooling is defined as the unintentional loss of saliva from the anterior oral cavity [1]. The terms "drooling" [2–21], "sialorrhea" [2, 3, 16, 22–34], "hypersalivation" [2, 35, 36] and "ptyalism" [2, 3, 22] are often used interchangeably in research and clinical practice. Previous studies have reported that the frequency of drooling in people with Parkinson's disease (PwP) ranges from 9.3 to 84% [4, 23, 37–40]. This wide variation in prevalence may be attributed to factors such as the heterogeneity of PD, an unclear definition of drooling, the use of different diagnostic tools for drooling [4], and a lack of understanding of salivary leakage and its potentially associated factors.

The pathophysiological mechanisms underlying drooling in PwP are not yet fully understood [18, 19, 41]. In this context, one of the hypotheses that have been proposed is that the overproduction of saliva may lead to drooling [4]. However, research have shown that PwP have less salivary flow compared to individuals without Parkinson's disease (PD) [42–48]. Notably, to our knowledge, no study has specifically explored the differences in salivary flow rate among PwP with drooling. Another aspect that has been investigated was the role of swallowing disorders in drooling, with several studies demonstrating an association between both factors [6, 19, 21, 37]. Nevertheless, some of them rely on patient-reported outcomes measures [19, 37] or on clinical assessments limited to thin liquid testing [6], which may compromise the reliable characterization of swallowing disorders. Additionally, it has been hypothesized that postural impairments in PwP—particularly hypomimia, stiffness, rigid immobile posture, and a bowed head—may exacerbate anterior saliva loss [6, 14]. Cognitive impairment is another feature that appears to be associated with drooling in PwP [14, 49]. Specifically, cognitive tasks requiring divided attention may increase drooling frequency [14]. In contrast, other studies have found no significant association between cognitive impairment and drooling in PwP [10, 18, 37]. The oromotor function (e.g., tongue and lips) plays a key role in the saliva control and management. Surprisingly, no study has yet thoroughly investigated oromotor performance and its relationship to drooling.

To address these gaps and inconsistencies, this study primarily aims to investigate the predictors of drooling severity, specifically focusing on swallowing, sex, age, disease duration, cognition, facial expression, posture, motor, oromotor and speech functions. The secondary aim of this study is to explore clinical factors correlated with drooling severity.

Methods

Study design and setting

A cross-sectional study was conducted with PwP from February to July 2023 at Centro Hospitalar de Lisboa Ocidental (CHLO), Hospital de Egas Moniz, Lisbon, Portugal. The study received ethical approval from the Health Care Ethics Committee of the CHLO, Lisbon, Portugal (Ref. No. 2284). All eligible participants provided written informed consent after receiving a detailed explanation of the study.

Participants

A convenience sample of PwP was used and potential participants were recruited by neurologists from the Department of Neurology of the Hospital de Egas Moniz. PwP with a confirmed diagnosis of PD for at least 3 years, according to the UK PD Brain Bank criteria [50], were eligible to participate in the study. Exclusion criteria included a diagnosis of Sjögren's syndrome and/or the presence of another neurological disorder that impaired saliva control.

Data collection

Primary outcome measure

The Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS)—item 2.2. Saliva and drooling was defined as the primary outcome measure. This item required the patient and/or caregiver to be asked: "Over the past week, have you usually had too much saliva during when you are awake or when you sleep?". The answer options are: Normal (0) = Not at all (no problems); Slight (1) = I have too much saliva, but do not drool; Mild (2) = I have some drooling during sleep, but none when I am awake; Moderate (3) = I have some drooling when I am awake, but I usually do not need tissues or a handkerchief; Severe (4) = I have so much drooling that I regularly need to use tissues or a handkerchief to protect my clothes [51].

Currently, there is no validated clinical instrument to measure the severity of drooling in PwP. Given this limitation, MDS-UPDRS—item 2.2 was chosen to determine the severity of drooling. According to the MDS-UPDRS, each item is anchored with five responses, ranging from normal (0) to severe (4) and considers the progression of disability or impairment [52].

Two groups were formed through the score of the MDS-UPDRS—item 2.2. Participants who reported nighttime or

daytime saliva loss were allocated to the "PwP with drooling" group (score ≥ 2). Participants who did not report saliva loss were allocated to the "PwP without drooling" group (score ≤ 1).

Secondary outcome measures

Sociodemographic data was collected through structured interviews. A clinical neurological assessment was performed using the MDS-UPDRS [51]. The assessment is divided into four parts: Non-motor experiences of daily living (Part I); Motor experiences of daily living (Part II); Motor examination (Part III); and Motor complications (Part IV). The sum score ranges from 0 to 260, with a higher score indicating a more severe impairment [51].

Total axial signs were calculated by summing the scores of the following MDS-UPDRS items: 3.1 (speech); 3.3 (neck rigidity only); 3.10 (gait); 3.11 (freezing); 3.12 (postural stability); 3.13 (posture). The total score ranges from 0 to 24, with higher scores indicating more severe axial signs [53, 54].

PD severity was assessed using the Hoehn and Yahr scale, a rating system ranging from 0 to 5, with a higher score reflecting greater severity [55].

The oromotor and speech motor functions were assessed with the Frenchay Dysarthria Assessment, second edition (FDA-2). This instrument was designed for individuals with neurological disorders and includes 28 dimensions across various sections, including reflexes, respiration, lips, palate, laryngeal, tongue, and intelligibility. The total score varies between 0 and 104, with higher total scores indicating better performance [56].

To evaluate swallowing disorders, the Swallowing Clinical Assessment Score (SCAS-PD) was employed. This assessment involved the administration of 20 ml of water, 10 ml of yogurt, and one cookie. Changes in the oral phase, pharyngeal phase, and signs of penetration/aspiration were measured. The SCAS-PD scores range from 0 to 354, with higher scores indicating greater swallowing disorders [57].

The Functional Oral Intake Scale (FOIS) was used to assess functional oral intake of food and liquid. The scale ranges from no oral intake (level 1) to full oral intake (level 7) [58].

Participants underwent a cognitive assessment using the Montreal Cognitive Assessment (MoCA). Higher scores on the MoCA, a 30-point scale, indicate better cognitive performance [59, 60].

Stimulated and unstimulated saliva samples were collected. To minimize potential confounding factors, participants were instructed to refrain from smoking, eating, drinking, oral hygiene, and chewing gum for at least 1 h prior to collection. Collection was performed between 8:00 am and 1:00 pm to minimize the influence of the circadian rhythm on saliva flow.

Before the unstimulated saliva collection, the participants rinsed their mouths with deionized water and relaxed for five minutes. Participants then sat comfortably for five minutes with their eyes open, head tilted downwards and mouth slightly open. A funnel was held under the lower lip to direct the saliva into a measuring tube. Participants were instructed to minimize movements, particularly orofacial movements, during saliva collection [61].

A tasteless paraffin wax (Saliva-Check buffer, GC, reference: GC720000) was used to obtain stimulated saliva. Participants were asked to chew the wax and spit the saliva into a funnel with the graduated tube every 60 s for 5 min. As the number of chews can affect the saliva flow rate, a metronome was used and set to 70 chews per minute to reduce this limitation. To familiarize participants with the procedure, a two-minute trial run was carried out, which was not included in the collection [61]. The stimulated and unstimulated saliva obtained was converted into ml/min.

Statistical analysis

This study is based on a sample of participants in an ongoing research project investigating self-perceptions of drooling impact in PwP. The original cohort included 101 PwP and 101 sex- and age-matched control subjects without PD. The selection criteria for the PD participants were identical to those used in the present study, and the participants in this research represent a subgroup of PwP under observation. The data analyzed were collected during the clinical assessment at baseline.

Statistical analysis was carried out using the IBM Statistical Package for Social Sciences SPSS (version 29.0.1.0), and R (version 4.2.2, http://www.r-project.org/).

Descriptive analyses, which included measures of central tendency and dispersion, were performed for both sociodemographic and clinical data.

Given that the data did not follow a normal distribution, the Mann–Whitney test was applied for inferential analysis. This test was used to compare PwP with and without drooling considering the following variables: age, disease (duration, Hoehn and Yahr scale, levodopa equivalent daily dose), cognition (MoCA), motor and non-motor domains (MDS-UPDRS—total score, Part III, item 3.13 Posture, and axial signs), oromotor and speech function (MDS-UPDRS—item 3.1 Speech, item 3.2 Facial expression, FDA-2 total score and sections—reflexes, respiration, lips, palate, laryngeal, tongue, intelligibility), swallowing function (MDS-UPDRS—item 2.3 Chewing and swallowing, SCAS-PD total score and sections—oral phase, pharyngeal phase, sign of penetration/aspiration, and FOIS), and saliva and drooling (MDS-UPDRS—item 2.2, unstimulated and stimulated total

salivary flow rate). Benjamini–Hochberg procedures were used to adjust p values obtained by multiple comparisons. Results were considered statistically significant if the p value was ≤ 0.05.

Correlation analysis was performed using the Spearman's test to determine associations between drooling severity (MDS-UPDRS—item 2.2) and age, disease (duration, Hoehn and Yahr scale, and levodopa equivalent daily dose), cognition (MoCA), motor and non-motor domains (MDS-UPDRS—total score, Part III, item 3.13, and axial signs), oromotor and speech function (MDS-UPDRS—item 3.1 and item 3.2, FDA-2 total score and sections—reflexes, respiration, lips, palate, laryngeal, tongue, intelligibility), swallowing function (MDS-UPDRS—item 2.3, SCAS-PD total score and sections—oral phase, pharyngeal phase, sign of penetration/aspiration, and FOIS), and saliva and drooling (unstimulated and stimulated total salivary flow rate). The correlations were categorized as strong (≥ 0.70), moderate (0.40–0.69), or low (≤ 0.39) [62]. Benjamini–Hochberg correction for multiple comparisons was applied. The significance level was defined as $p \leq 0.05$ for correlation analyzes.

A logistic ordinal regression model was performed to examine the relationship between drooling severity (MDS-UPDRS—item 2.2) and potential predictors, namely, age, sex, disease duration, cognition (MoCA), motor domain (MDS-UPDRS—Part III), facial expression (MDS-UPDRS–item 3.2), posture (MDS-UPDRS—item 3.13) oromotor and speech function (FDA-2) and swallowing disorders (SCAS-PD total score). The regression analysis was performed using the *polr* function from the *MASS* R package. Brant's test was applied to make sure the proportional odds assumption held for every predictor, validating the results. A stepwise forward Akaike Information Criterion-based selection method was adopted, using the *step* function from the *stats* R package. The significance level was defined as $p < 0.10$. Odds ratios (OR), 95% confidence intervals (CI), standard errors (SE), and p values of the variables included in the model were reported.

Results

A total of 101 PwP were enrolled in the study. Of these, 42 (41.58%) reported drooling, while 59 (58.42%) did not. The majority of PwP with drooling were male (73.8%), while just over half of PwP without drooling were female (50.8%). In both groups, most participants had completed primary or secondary school, were retired, and lived with their families in their own homes (Table 1).

Regarding drooling severity (MDS-UPDRS—item 2.2), 46.5% ($n = 47$) reported no problems with saliva (normal), 11.9% ($n = 12$) had too much saliva but no drooling (slight), 16.8% ($n = 17$) reported some drooling during sleep but no drooling while awake (mild), 11.9% ($n = 12$) experienced some drooling while awake but usually did not need tissues or a handkerchief (moderate), and 12.9% ($n = 13$) reported drooling so much that they regularly needed to use tissues or a handkerchief to protect their clothes (severe).

Comparison of clinical characteristics of people with Parkinson's disease with and without drooling

When comparing PwP with and without drooling, those with drooling had significantly more impairments in motor and non-motor domains (MDS-UPDRS—total score, Part III, item 3.13, and axial signs) global oromotor and speech functions (MDS-UPDRS—items 3.1, 3.2, FDA-2—sections reflexes, lips, palate, tongue, intelligibility, and total score), global swallowing functions (MDS-UPDRS—2.3, SCAS-PD—sections pharyngeal phase, signs of penetration/aspiration, total score, and FOIS) and saliva and drooling (MDS-UPDRS—item 2.2) (Table 2).

No significant differences were found between PwP with and without drooling regarding age, disease (duration, Hoehn and Yahr stage, and LEDD), cognitive function (MoCA), specific oromotor domains (FDA-2—respiration and laryngeal sections), oral phase of swallowing, as well as saliva flow rate (unstimulated and stimulated saliva flow rate) (Table 2).

Correlations with drooling severity

In PwP, significant, moderate, and positive correlations were found between the severity of drooling (MDS-UPDRS—item 2.2) and global motor and non-motor impairments (MDS-UDPRS—total score), posture (MDS-UPDRS—item 3.13), axial signs, speech (MDS-UPDRS—item 3.1), facial expression (MDS—item 3.2). Significant, moderate and negative correlations were obtained between drooling severity and oromotor and speech functions (FDA-2—reflexes, lips, palate sections, and total score) as well as FOIS. Moreover, significant, weak, and positive correlations were found between drooling severity and levodopa equivalent daily dose (LEDD), motor impairments (MDS-UPDRS—Part III), swallowing function (MDS-UPRDS—item 2.3, SCAS-PD—oral phase, pharyngeal phase, signs of penetration/aspiration sections, and total score), unstimulated total salivary flow rate and disease (duration, Hoehn and Yahr Scale). Finally, significant, weak, and negative correlations were found between the severity of drooling, specific oromotor and speech domains (FDA-2—laryngeal, tongue, and intelligibility sections).

Drooling severity did not correlate significantly with age, cognition (MoCA), respiration, and stimulated total saliva flow rate (Table 3).

Table 1 Sociodemographic data

	PwP with drooling ($n=42$)	PwP without drooling ($n=59$)
Sex *n* | %		
Males	31 | 73.8%	29 | 49.2%
Females	11 | 26.2%	30 | 50.8%
Age (years)		
Mean ± standard deviation	72.7 ± 8.0	71.8 ± 10.7
Range	48–90	45–89
Level of education (ISCED classification) *n* | %		
Primary school education (0–4)	16 | 38.1%	25 | 42.4%
Secondary school education (5–12)	14 | 33.3%	20 | 33.9%
Post-secondary (non-tertiary education)	0 | 0%	0 | 0%
Short-cycle tertiary education	0 | 0%	1 | 1.7%
Tertiary education (graduation and postgraduation)	12 | 28.6%	13 | 22.0%
Occupational status *n* | %		
Working	1 | 2.4%	8 | 13.6%
Unemployed	1 | 2.4%	2 | 3.4%
Retired	40 | 95.2%	49 | 83.1%
Residence *n* | %		
Own home	40 | 95.2%	57 | 96.6%
Family member's home	2 | 4.8%	1 | 1.7%
Retirement home	0 | 0%	1 | 1.7%
Cohabitation *n* | %		
Family	39 | 92.9%	51 | 86.4%
Caregiver	1 | 2.4%	4 | 6.8%
Alone	2 | 4.8%	4 | 6.8%

PwP People with Parkinson's Disease, *ISCED* International Standard Classification of Education

Predictors of drooling severity

The results of the ordinal logistic regression analysis suggested that poorer swallowing function (SCAS-PD) [OR = 1.03 (95% CI 1.00–1.06), $p=0.032$], worse oromotor and speech function (FDA-2) [OR = 0.96 (95% CI 0.92–1.00), $p=0.081$] and male sex [$OR_{female}=0.41$ (95% CI 0.17–0.97), $p=0.043$] predicted higher drooling severity (MDS-UPDRS—item 2.2). However, facial expression (MDS-UPDRS—item 3.2) [OR = 1.54 (95% CI 0.89–2.66), $p=0.124$] and posture (MDS-UPDRS—item 3.13) [OR = 1.36 (95% CI 0.90–2.07), $p=0.148$] were not significant predictors of drooling severity (Table 4).

Age, disease duration, cognition (MoCA), and motor domain (MDS-UPDRS—Part III) were found to be irrelevant variables for the prediction of the model and were therefore not included.

Discussion

Drooling severity was most strongly predicted by the severity of swallowing disorders. This finding may have several explanations. Spontaneous swallowing, a reflexive act that occurs unconsciously while awake and asleep, may be impaired in PwP. Compared to older people without PD, PwP exhibit a higher frequency of spontaneous swallowing [63]. Additionally, PwP with drooling tend to swallow more frequently than those without drooling [6]. Although this difference is not statistically significant, it may suggest a compensatory mechanism for reduced swallowing efficiency [6]. Despite increased frequency, inefficient swallowing may cause saliva to remain in the oral cavity, contributing to drooling. In this study, spontaneous swallowing was not analyzed, but we found that PwP with drooling had more pronounced swallowing disorders with liquids and food, which aligns with previous findings [7, 12, 19]. We can hypothesize that similar problems are likely to occur with saliva swallowing.

This study provides the first evidence that oromotor and speech impairments are predictors of increased drooling. Such results support the role of motor control, as well as speech and swallowing biomechanics, in the pathophysiology of drooling. Previous research investigated the functional connectivity network underlying drooling, identifying impaired connectivity between specific brain areas [64]. For example, reduced effective connectivity from the Rolandic

Table 2 Clinical characteristics of people with Parkinson's disease with and without drooling

	PwP with drooling ($n=42$)			PwP without drooling ($n=59$)			Significance
	Median	Mean ± *SD*	Range	Median	Mean ± *SD*	Range	
Age	73	72.7 ± 8.0	48–90	73	71.8 ± 10.7	45–89	$U=1236$, $z=-0.021$, $p=0.936$
Disease							
Duration (years)	8.5	9.4 ± 5.4	3–28	6	7.5 ± 4.8	3–23	$U=946$, $z=-2.030$, $p=0.058$
Hoehn and Yahr stage	2	2.4 ± 1.0	1–5	2	2.1 ± 0.5	1–4	$U=1092.5$, $z=-1.424$, $p=0.196$
Daily levodopa equivalent dose (mg)	750	849.7 ± 580.1	160–3300	650	788.3 ± 570.9	80–2580	$U=1129$, $z=-0.756$, $p=0.504$
Cognition							
Montreal Cognitive Assessment—total score	19	19.0 ± 6.1	4–29	20	18.9 ± 5.9	8–30	$U=1222.5$, $z=-0.114$, $p=0.936$
Motor and non-motor domains							
MDS-UPDRS—total score	75.5	83.5 ± 33.2	34–167	53	54.4 ± 25.6	14–139	$U=618.5$, $z=-4.276$, $p=0.000$
MDS-UPDRS—Part III	37.5	43.5 ± 37.5	17–99	34	31.6 ± 15.5	9–80	$U=836$, $z=-2.778$, $p=0.009$
MDS-UPDRS—item 3.13 Posture	2	1.9 ± 1.1	0–4	1	1.0 ± 1.1	0–4	$U=709.5$, $z=-3.780$, $p=0.000$
Axial signs	8.5	9.4 ± 4.8	2–23	5	5.6 ± 3.3	1–15	$U=628$, $z=-4.225$, $p=0.000$
Oromotor and speech functions							
MDS-UPDRS—item 3.1 Speech	2	2.0 ± 1.0	0–4	1	1.2 ± 0.8	0–3	$U=710.5$, $z=-3.840$, $p=0.000$
MDS-UPDRS—item 3.2 Facial expression	2	1.9 ± 1.0	0–4	1	1.3 ± 0.7	0–3	$U=772$, $z=-3.840$, $p=0.000$
Reflexes	9	8.3 ± 2.6	2–11	11	10.9 ± 1.3	7–12	$U=361.5$, $z=-6.130$, $p=0.000$
Respiration	7	6.7 ± 1.9	0–8	7.5	6.9 ± 1.4	1–8	$U=1190.5$, $z=-0.348$, $p=0.784$
Lips	15.5	14.3 ± 4.0	0–19.5	17	16.5 ± 2.3	9–20	$U=769.5$, $z=-3.096$, $p=0.004$
Palate	12	11.5 ± 1.0	6–12	12	11.9 ± 0.4	10–12	$U=829.5$, $z=-3.983$, $p=0.000$
Laryngeal	11.8	10.8 ± 4.0	0–15.5	12	11.8 ± 3.3	3–16	$U=1008$, $z=-1.594$, $p=0.148$
Tongue	17.6	16.9 ± 5.0	4–24	19.5	19.2 ± 3.2	10.5–24	$U=910.5$, $z=-2.266$, $p=0.035$
Intelligibility	9	8.4 ± 2.5	0–12	10	9.9 ± 1.6	6–12	$U=749.5$, $z=-3.339$, $p=0.004$
FDA-2—total score	81.5	76.5 ± 18.3	12–100	89.5	87.4 ± 10.3	60.5–103.5	$U=757.5$, $z=-3.339$, $p=0.004$
Swallowing function							
MDS-UPDRS—item 2.3 Chewing and swallowing	1	1.5 ± 1.0	0–3	1	0.9 ± 1.0	0–3	$U=799$, $z=-3.202$, $p=0.004$
Oral phase	0	1.7 ± 3.0	0–15	0	0.9 ± 1.2	0–4	$U=1094$, $z=-1.131$, $p=0.314$
Pharyngeal phase	0	8.1 ± 12.8	0–40	0	1.4 ± 4.4	0–22	$U=941.5$, $z=-3.121$, $p=0.002$
Signs of penetration/aspiration	0	8.9 ± 10.2	0–30	0	4.5 ± 8.1	0–30	$U=941.5$, $z=-2.384$, $p=0.028$
SCAS-PD—total score	15	18.8 ± 20.4	0–80	1	7.0 ± 11.7	0–49	$U=786.5$, $z=-3.076$, $p=0.002$
Functional Oral Intake Scale	6	6.0 ± 1.0	4–7	7	6.6 ± 0.7	5–7	$U=837$, $z=-3.124$, $p=0.004$
Saliva and drooling							
MDS-UPDRS—item 2.2 Saliva and drooling	3	2.9 ± 0.9	2–4	0	0.2 ± 0.4	0–1	$U=0$, $z=-9.054$, $p=0.000$
Unstimulated total salivary flow rate (ml/min)	0.0	0.2 ± 0.2	0–1.1	0.0	0.1 ± 0.2	0–0.7	$U=948.5$, $z=-2.067$, $p=0.057$
Stimulated total salivary flow rate (ml/min)	1	1.1 ± 0.9	0–5	0.8	0.9 ± 0.5	0–2.3	$U=1008$, $z=-1.024$, $p=0.357$

PwP People with Parkinson's Disease, *MDS-UPDRS* Movement Disorder Society—Unified Parkinson's Disease Rating Scale, *FDA-2* Frenchay Dysarthria Assessment-Second Edition, *SCAS-PD* Swallowing Clinical Assessment Score in Parkinson's Disease

operculum to the postcentral gyrus, involved in speech production and motor control, was observed [64]. Additionally, PwP with drooling showed enhanced connections from the postcentral gyrus to the precentral gyrus [64]. Another study revealed higher activation in the precentral gyrus and supplementary motor area in people with swallowing disorders [65]. Specifically, the precentral gyrus is crucial for initiating oropharyngeal and tongue movements, while the postcentral gyrus processes oropharyngeal sensory information during swallowing [64]. Since oromotor structures are

Table 3 Spearman's correlation values between MDS-UPDRS—item 2.2 Saliva and drooling and clinical variables

	PwP ($n = 101$)	
	r	*p* value
Age	0.049	0.312
Disease		
Duration (years)	0.255	0.008
Hoehn and Yahr stage	0.183	0.042
Daily levodopa equivalent dose (mg)	0.171	0.050
Cognition		
Montreal Cognitive Assessment—total score	− 0.063	0.277
Motor and non-motor domains		
MDS-UPDRS—total score	0.497	0.000
MDS-UPDRS—part III	0.345	0.000
MDS-UPDRS—item 3.13 Posture	0.416	0.000
Axial signs	0.490	0.000
Oromotor and speech functions		
MDS-UPDRS—item 3.1 Speech	0.433	0.000
MDS-UPDRS—item 3.2 Facial expression	0.419	0.000
Reflexes	− 0.672	0.000
Respiration	− 0.151	0.073
Lips	− 0.409	0.000
Palate	− 0.418	0.000
Laryngeal	− 0.225	0.017
Tongue	− 0.332	0.000
Intelligibility	− 0.392	0.000
Frenchay Dysarthria Assessment—2nd Edition—total score	− 0.429	0.000
Swallowing function		
MDS-UPDRS—item 2.3 Chewing and swallowing	0.349	0.000
Oral phase	0.179	0.044
Pharyngeal phase	0.393	0.000
Signs of penetration/aspiration	0.318	0.002
Swallowing Clinical Assessment Score in Parkinson's Disease—total score	0.395	0.000
Functional Oral Intake Scale	− 0.401	0.000
Saliva and drooling		
Unstimulated total salivary flow rate (ml/min)	0.196	0.034
Stimulated total salivary flow rate (ml/min)	0.104	0.166

PwP People with Parkinson's Disease, *MDS-UPDRS* Movement Disorder Society—Unified Parkinson's Disease Rating Scale

Table 4 Ordinal logistic regression with the MDS-UPDRS—item 2.2 Saliva and drooling

Variables	OR	β	*SE*	*p* value
Male sex	0.41	− 0.90	0.40	0.043
MDS-UPDRS—item 3.13 Posture	1.36	0.31	0.21	0.148
MDS-UPDRS—item 3.2 Facial expression	1.54	0.43	0.28	0.124
Frenchay Dysarthria Assessment—2nd Edition—total score	0.96	− 0.04	0.02	0.081
Swallowing Clinical Assessment Score in Parkinson's Disease—total score	1.03	0.03	0.01	0.032

MDS-UPDRS Movement Disorder Society—Unified Parkinson's Disease Rating Scale, *SE* standard error

crucial for both swallowing and saliva control, their impairment may affect both processes.

Bradykinesia, which affects orofacial muscles, has also been linked to increased drooling [8]. In particular, tongue bradykinesia is considered a key factor impacting oropharyngeal transport during swallowing [66]. Indeed, PwP with drooling showed significantly more tongue impairment in this study. Slowed movements of facial components, including the lips, tongue, cheeks, and jaw, contribute to reduced oral control and swallowing efficiency. In addition, one study found that PwP with swallowing disorders had significantly lower tongue strength compared to those without [67]. Although tongue pressure was not measured in the present study, the higher tongue impairments observed in PwP who drool suggest an impact on saliva swallowing efficiency.

Male sex was also a predictor of increased drooling severity, consistent with previous findings [6, 10, 18, 68, 69]. These differences may be attributed to genetic factors and sex hormones. Estrogen, which is present at higher levels in women, possesses anti-inflammatory properties that may offer protection against neuroinflammation [70]. Such physiological differences could account for the variations in drooling severity observed between the sexes. However, the predominance of males in our sample (59.4%) should be considered, as it may have influenced the present findings.

Other predictors such as impairment of facial expression and posture were examined in the developed model, but did not reach significance. Facial expression impairment, known as hypomimia in PD, was not found to be significant. However, it was significantly correlated with drooling severity. Such impairment may cause the lips to part or the jaw to drop at rest, affecting lip closure and intraoral pressure, both of each are critical for saliva control and effective swallowing [71]. Consequently, these changes could lead to saliva accumulation in the mouth and potentially increase drooling. Posture impairment did not reach statistical significance, although it was significantly correlated with drooling severity. Indeed, PwP may exhibit camptocormia, lateral flexion, and antecollis [6, 72]. These postural changes, more severe in PwP with drooling, may exacerbate saliva spillage due to gravitational effects [6].

In addition to the modeling of predictors, other potential clinical factors correlated with drooling severity were explored. In this context, this study is the first to compare salivary flow rate in PwP with and without drooling, revealing no significant differences between groups. Specifically, this data suggests that drooling in PwP does not appear to be attributable to saliva overproduction. In contrast, a greater unstimulated saliva flow rate was positively correlated with drooling severity. Accordingly, it is expected that PwP with a higher flow rate may have more difficulty managing an increased volume of saliva, even in the absence of overproduction. Interestingly, there was no significant correlation between stimulated saliva flow and drooling severity. The production of saliva induced by mechanical stimulation engages distinct biomechanisms compared to unstimulated saliva, with pronounced activation of the parotid gland [73]. In daily life, mechanically stimulated saliva secretion is limited to specific and short-term tasks such as eating or oral hygiene. Most saliva released into the oral cavity during the day and at night is produced by non-stimulated processes. This may explain why unstimulated saliva was positively correlated with drooling severity, while stimulated saliva was not.

No significant differences in cognitive function were found between PwP with and without drooling, nor was there a significant correlation between cognition and drooling severity. This suggests that cognitive function may not play a crucial role in drooling pathophysiology. However, most of the participants in this study were at an early stage of PD, which could limit the extent of cognitive decline observed. As a result, the sample may be less representative of the full spectrum of the disease.

LEDD was correlated with the severity of drooling. Previous studies reported inconsistent results: some found no significant correlations [10, 19, 37], while others found a correlation between LEDD and drooling [17, 74]. PwP with longer disease duration [75, 76] and more severe motor impairments [76] present higher LEDD, which results in higher LEDD being associated with drooling in PwP.

Longer PD duration and greater disease severity were associated with increased drooling, consistent with previous research [6, 10, 18]. As PD progresses, worsening motor problems further impair salivary control [68].

In this study, drooling was found to be common (41.6%), which falls within the range of prevalence of previous studies (9.3% to 84%) [4, 23, 37–40]. The obtained frequency is close to the pooled prevalence of 56% reported in a meta-analysis on drooling in PwP [13]. To our knowledge, this study is the first to determine the frequency of self-reported drooling in the Portuguese population with PD.

Limitations and future research

As with any study of this type, we are aware of certain limitations. Eligible participants with motor difficulties were unable to travel to the hospital to participate, which limits the representativeness of the PD population. The ethics committee decided that the risks associated with the home visits outweighed the benefits due to the nature of the study procedures. Future studies could explore strategies such as providing transportation to accommodate participants with motor impairments at the data collection site.

The lack of a validated clinical instrument to assess drooling severity was a limitation of this study. The high variability of drooling frequency, and the fact that it is not always

observed during clinical consultations, poses a challenge for clinicians to accurately determine its severity. Since the assessment of drooling relies only on self-perception in this study, it may not accurately reflect the actual severity in everyday life.

Four participants (3.9%) were identified as being at high risk of airway obstruction or potential aspiration of food, liquids, or paraffin wax. Consequently, specific procedures for swallowing assessment and measurement of stimulated total saliva flow rate were not performed in these cases. This decision was made in accordance with the ethical principles outlined in the Declaration of Helsinki, prioritizing the safety and well-being of participants by avoiding potentially harmful procedures [77]. Future research should increase the sample size to improve the generalizability of the results.

Given the potential role of impaired swallowing efficiency in the pathophysiology of drooling, it would be relevant to investigate the efficiency of spontaneous swallowing in PwP with drooling. One possible assessment could include measuring tongue pressure during spontaneous swallowing, a factor that has yet to be studied in this population.

Swallowing was assessed by a clinical swallowing evaluation. While this study relied on clinical outcomes, using instruments such as Flexible Endoscopic Evaluation of Swallowing (FEES) or the Videofluoroscopic Swallow Study could provide additional insights into swallowing functionality. These examinations would, for instance, facilitate the detection of silent aspiration, which is common in PwP [32].

Future studies could benefit from analyzing posterior saliva loss, pharyngeal saliva pooling, and the potential for saliva penetration and aspiration. Given that saliva aspiration can affect respiratory health and increase morbidity [78], it would be valuable to investigate drooling with and without salivary aspiration. The use of the FEES and the Secretion Severity Rating Scale [79] could be particularly relevant in identifying and classifying the presence and location of saliva accumulation in the pharynx and/or larynx.

Cognition was assessed with the MoCA, a brief cognitive screening tool [80]. Considering the inconsistent findings regarding the role of cognitive function in drooling, future studies could incorporate a neuropsychological assessment. This would allow a more reliable assessment of the different cognitive functions, especially divided attention, as previous research has reported an increased frequency of drooling during multitasking activities [14].

Conclusion

Drooling severity in PwP was predicted by swallowing disorders, male sex, oromotor and speech impairments. Additionally, drooling severity was associated with impairments in motor and non-motor domains, posture, axial signs, hypomimia, and global oromotor, speech, oral intake, and swallowing function. It has also been related to an enhanced unstimulated total salivary flow rate, disease duration and severity, and LEDD.

Given the importance of oromotor, speech, and swallowing disorders in predicting drooling severity, clinicians should consider these clinical factors during drooling assessment. Additionally, these factors serve as promising targets for therapeutic interventions aimed at minimizing drooling and its negative impact on quality of life.

Author contributions DN: Conceptualization, Project Administration, Methodology, Validation, Investigation, Formal analysis, Data Curation, Writing—Original Draft, Writing—Review and Editing. BM: Resources, Validation, Writing—Review and Editing. LG: Methodology, Validation, Formal analysis, Writing—Review and Editing. DA: Methodology, Writing—Review and Editing. TFO: Writing—Review and Editing. IG: Conceptualization, Project Administration, Methodology, Validation, Writing—Review and Editing, Supervision. JJF: Conceptualization, Project Administration, Methodology, Resources, Validation, Writing—Review and Editing, Supervision.

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Data availability Not applicable.

Declarations

Conflicts of interest The authors declare no competing interests.

Ethical approval The study was conducted in agreement with the Declaration of Helsinki. This study was approved by the Health Care Ethics Committee of the Centro Hospitalar de Lisboa Ocidental, Lisbon, Portugal (Ref. No. 2284). Written consent was obtained from all participants prior to study participation.

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