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Swallowing and deep brain stimulation in Parkinson's disease: A systematic review

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Abstract

The purpose of this review is to assess the current state of the literature on the topic of deep brain stimulation (DBS) and its effects on swallowing function in Parkinson's disease (PD). Pubmed, Cochrane review, and web of science searches were completed on all articles addressing DBS that contained a swallowing outcome measure. Outcome measures included the penetration/aspiration scale, pharyngeal transit time, oropharyngeal residue, drooling, aspiration pneumonia, death, hyolaryngeal excursion, epiglottic inversion, UPDRS scores, and presence of coughing/throat clearing during meals. The search identified 13 studies specifically addressing the effects of DBS on swallowing. Critical assessment of the 13 identified peer-reviewed publications revealed nine studies employing an experimental design, (e.g. "on" vs. "off", pre- vs. post-DBS) and four case reports. None of the nine experimental studies were found to identify *clinically significant* improvement or decline in swallowing function with DBS. Despite these findings, several common threads were identified across experimental studies and will be examined in this review. Additionally, available data demonstrate that, although subthalamic nucleus (STN) stimulation has been considered to cause more impairment to swallowing function than globus pallidus internus (GPi) stimulation, there are no experimental studies directly comparing swallowing function in STN vs. GPi. Moreover, there has been no comparison of unilateral vs. bilateral DBS surgery and the coincident effects on swallowing function. This review includes a critical analysis of all experimental studies and discusses methodological issues that should be addressed in future studies.

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Keywords

DBS; Dysphagia; Swallow; Aspiration pneumonia; Parkinson's disease; Review

1. Introduction

Deep brain stimulation (DBS) is a common treatment modality for individuals with advanced Parkinson's disease (PD) who have become refractory to oral medications [1–3]. It is particularly effective against motor fluctuations and tremor. The procedure involves placement of quadripolar electrical leads through a trajectory that traverses the frontal lobe and extends into the deep structures of the basal ganglia, specifically the subthalamic nucleus (STN), globus pallidus internus (GPi), or thalamus ventralis intermedius nucleus (VIM) [1,4,5]. Unilateral or bilateral leads can be implanted to deliver continuous electrical impulses of variable intensity to the STN, GPi, or VIM regions. Following optimal lead implantation, programming, and medication adjustments, DBS effectively ameliorates motor fluctuations, dyskinesia, and medication refractory tremor [3,6,7]. In some cases there may also be a concomitant medication reduction.

DBS implantation, like any surgery, is associated with adverse events and complications which can be acute and/or long-term. As will be highlighted in this review, most studies reporting negative effects of DBS on swallowing are not experimental studies and do not test changes in swallowing as a function specifically of DBS. Instead, these findings have been extrapolated from case reports or from larger, single or multi-center longitudinal studies where aspiration pneumonia, percutaneous gastrostomy (PEG) tube placement, and drooling were listed among other reported complications and/or adverse events. Reports of swallowing-related adverse events following STN DBS vary. There are some reports of minimal swallowing-related adverse events where, for example, only one or two study participants developed dysphagia or aspiration pneumonia post-STN DBS implantation [8–14]. Other studies have observed the occurrence of more frequent swallowing specific adverse events with 15% or more of the study population developing dysphagia post-STN DBS [15–19]. Similarly, there are varied reports of adverse events when comparing STN and GPi targets for DBS in PD. Some have reported more dysphagia-related adverse events with STN DBS [14] and others have alternatively reported more dysphagia related adverse events with GPi DBS [19].

Dysphagia, or disordered swallowing, is an inevitable result of the disease progression in PD [20]. Aspiration pneumonia secondary to dysphagia is a leading cause of death in PD [21–23]. A limited amount of literature exists on the potential effects of DBS on swallowing function in PD. Within the available studies, there has been little consensus and conflicting reports as to whether swallowing function improves or declines following implantation. Therefore, research detailing the specific impact of DBS on swallowing function is both timely and of critical importance. The purpose of this manuscript is to critically review the current literature (published in English) on DBS and swallowing function in PD.

2. Methods

A Pubmed, Cochrane review, and Web of Science search of all available DBS studies which included a swallowing related outcome was completed. Selected swallowing related outcomes included: the penetration/aspiration scale, pharyngeal transit time, pre-swallow spill, oropharyngeal residue, drooling, aspiration pneumonia, death, hyolaryngeal excursion, swallowing severity score, epiglottic inversion, Unified Parkinson's disease rating scale (UPDRS) scores, and presence of coughing/throat clearing during meals. The six search words included were: DBS, deglutition, dysphagia, swallow, aspiration pneumonia, and

Parkinson's disease (disorder). Ethical and IRB approval was waived for completion of this review article.

Once the studies were identified, they were critically assessed for: 1) presence of an experimental design with proper control of extraneous variables confounding effects of DBS on swallowing function, 2) presence of clinically relevant findings based on inclusion of proper outcome measures and robustness of results, and 3) contribution of the study to the body of literature on swallowing in DBS.

3. Results

The search identified 13 studies specifically addressing the effects of DBS on swallowing. Critical assessment of the 13 identified peer-reviewed publications revealed nine studies employing an experimental design, (e.g. "on" vs. "off", pre- vs. post-DBS) [5,24–31] and four case reports [32–35]. None of the nine experimental studies were found to identify *clinically significant* improvement or decline in swallowing function with DBS (Table 1). To follow, we will first present a brief overview of findings from case reports describing swallowing changes in patients post-DBS. We will then present the experimental studies in chronological order, providing a critical analysis of the methods and results, and highlighting the contributions of each experimental study to the body of literature on DBS and swallowing.

4. Case reports

Kataoka and colleagues [33] reported the case of an 87-year-old man with PD who underwent bilateral STN DBS implantation, requiring lead revision one month post-surgery. Following this surgery, the patient developed hallucinations, sleep apnea, stridor, dyspnea, and increased walking difficulty. Due to respiratory distress, a fiberoptic endoscopic evaluation of swallowing (FEES) was performed and revealed a rigid epiglottis that remained fixed during breathing and swallowing. By manipulating STN stimulator settings, the researchers discovered that the rigidity of the epiglottis was aggravated by increasing the voltage of stimulation, and it was relieved by decreasing the voltage.

A case study reported by Allert and colleagues [34] described a woman with a history of PD and oropharyngeal muscle dystrophy who they followed for several years and who at the age of 67 years was first considered for DBS surgery. At that time she was reporting significant dysphagia with a 7 kg weight loss. More specifically, she had pharyngeal residue, evidence of choking, and the need for repeated swallows. Given her high aspiration risk, a PEG tube was placed. One month following STN DBS surgery a FEES was completed which revealed severe pharyngeal residue with saliva, puree, and solid consistencies, but no aspiration or penetration. The PEG tube was removed nine months post-DBS. As time went on the patient's swallowing continued to be impaired, but she reported that it was better than before DBS. Despite this claim, she continued to lose weight and the PEG was re-inserted at 21 months post-surgery.

Fagbami and Donato [32] evaluated a 74-year-old man with PD post-bilateral STN DBS implantation who subsequently reported a weak cough, stridor, tachypnea, and aspiration. His swallowing function was assessed "on" stimulation during videofluoroscopic (VFS) examination and revealed aspiration of thin liquids. VFS is considered by most speech-language pathologists to be the gold standard for visualization of oropharyngeal swallowing function. Following a 1 h washout period in the stimulation "off" condition, aspiration was not observed, and the patient reported a subjective 80% improvement of cough and swallowing function. Similarly, he experienced a 15% improvement in pulmonary function testing with stimulation in the "off" condition. The researchers postulated that the marked

improvement with DBS “off” may have resulted from dystonia or dyskinesia of the upper airway muscles, secondary to DBS stimulation.

Finally, Asahi et al. [35] published a case study of a 43-year-old male with young onset PD and a history of severe dysphagia, who received bilateral STN DBS implantation. Prior to DBS surgery, a PEG tube was placed secondary to aspiration pneumonia. The patient was evaluated pre- and post-DBS surgery using VFS while swallowing a pudding consistency (yogurt). The baseline evaluation revealed piecemeal deglutition, oral residue, residue in the valleculae and pyriform sinuses, delayed hyolaryngeal excursion, aspiration, coughing, and inadequate cricopharyngeal opening. The evaluation three years post-DBS surgery revealed improved swallowing function as the “contrast medium smoothly moved to the esophagus,” and the patient was consuming “the foods of his choosing.” No post-DBS information regarding PEG tube status or any other swallowing outcomes was provided.

5. Experimental studies

Zibetti and colleagues [30] prospectively compared the motor and non-motor symptoms of 36 participants with PD pre- and post-bilateral STN DBS implantation. The swallowing-specific outcome variables analyzed were the UPDRS item six (salivation) and item seven (swallowing) obtained from clinical neurological evaluations. Baseline evaluations were conducted pre-DBS surgery both “on” and “off” dopamine medication (where a 12 h washout period was required for “off” medication testing). The participants were then tested again 12 and 24 months post-DBS “on” STN stimulation and “on” dopamine medication. Results revealed that pharmacological treatment significantly improved salivation and swallowing in the pre-DBS condition. This improvement was maintained when comparing UPDRS scores pre-DBS “off” dopaminergic therapy to UPDRS scores “on” STN stimulation and “on” dopaminergic therapy. The authors highlighted that post-DBS, participants required reduced levels of dopaminergic therapy. Participants were not tested in the “off” medication condition following STN DBS. Because swallowing remained better than baseline after DBS and with reduced pharmacological intervention, Zibetti and colleagues postulated that DBS may have improved bradykinesia at the pharyngeal level. Although the authors utilized a reasonably sized cohort ($n = 36$), appropriate medication wash-out periods (12 h), and assessments pre- and post-DBS implantation, there are methodological issues which limit the interpretation of these results. Primarily, the UPDRS as a measure of swallowing effectiveness is inadequate. Assessment of swallowing physiology and its effectiveness requires the use of tools which allow for visualization of the anatomy during swallowing. Therefore, the conclusion that “DBS may improve bradykinesia at the pharyngeal level” cannot be made based on these data. Additionally, there was no report of significant differences between patients swallowing pre-DBS “on” medications and post-DBS “on” medications, limiting our understanding of the changes which may have been secondary to medication vs. stimulation in this sample of patients.

Ciucci and colleagues [5] prospectively tested swallowing function post-STN DBS implantation in a cohort of 14 participants with PD. Participants were assessed in the “on” stimulation condition, and then again 1 h later in the “off” stimulation condition. Participants were “on” medication for both stimulation conditions. The participants were asked to swallow a variety of bolus consistencies under VFS. Outcome measures for this study included pharyngeal transit time, maximal hyoid bone excursion, and oral and pharyngeal composite scores. No significant improvement was observed in hyoid bone excursion or in oral composite scores in “off” vs. “on” stimulation conditions. The investigators observed that “on” stimulation, pharyngeal transit time significantly decreased (faster swallow) by 23% and pharyngeal composite scores improved significantly. Although these changes to the pharyngeal stage were significant, further inspection of the data revealed that changes to

pharyngeal composite scores were only marginal, with about a one point improvement between “off” and “on” stimulation conditions. Additionally, oral and pharyngeal composite scores were very low on average (8 points on a 35 point scale) suggesting that patients were very mildly impaired in terms of their swallowing severity. The authors concluded that DBS in the “on” state resulted in a more efficient swallow, likely due to reduced bradykinesia as evidenced by reduced residue throughout the swallowing mechanism. The authors appropriately utilized VFS and swallowing-specific outcome measures. Additionally, appropriate stimulation washout and counterbalancing of stimulation conditions was utilized. However, participants were not evaluated at baseline (pre-DBS) nor was it specified whether participants had unilateral or bilateral STN surgeries. Therefore, information related to changes in swallowing performance as a function of DBS surgery itself (not just stimulation) and number of leads (unilateral vs. bilateral) cannot be determined from this study.

Tassorelli and colleagues [27] completed a cohort study where they evaluated an array of motor and axial functions following bilateral STN DBS surgery in 34 PD participants. Participants were grouped by time since surgery. The groups included an acute group (one month post-DBS), a post-acute group (one month to one year post-DBS), and a stabilized group (greater than one year post-DBS). A clinical bedside evaluation of swallowing was conducted by a trained speech-language pathologist at the time points listed above. Nineteen of the 34 participants tested were found to have dysphagia post-DBS. The authors reported that 17 of these 19 cases with dysphagia were unrelated to DBS surgery. In these cases, dysphagia was present before surgery and persisted in the stimulator “off” condition. No information was provided regarding the criterion for assessing dysphagia with the bedside swallowing evaluation. No specifics regarding the severity of dysphagia, dysphagia characteristics or symptoms, or DBS-related changes to swallowing function were reported. Additionally, no statistical comparisons were provided. Therefore, no information related to specific changes to swallowing function with DBS can be made from this study.

Sundstedt and colleagues [28] evaluated pharyngeal swallowing function in eight participants with PD pre-DBS with re-evaluations at six and 12 months post-bilateral caudal zona Incerta DBS (cZI; slightly posterior medial to the posterior tail of the STN). The participants were tested pre-DBS “off” medication and “on” a dose of L-dopa which was 1.5 times their ordinary dose. Participants were then tested post-DBS in the stimulation “on” and “off” conditions and with their optimized dose of L-dopa. Each participant’s swallowing was evaluated with FEES while swallowing one solid and four different liquid boluses. Outcome measures included the penetration/aspiration scale (PA scale) [36], the secretion severity scale [37], pre-swallow spill, pharyngeal residue, pharyngeal clearance, and a quality of life visual analog scale (VAS). The results revealed no differences in swallowing outcomes pre-DBS as a function of medication condition. The only significant change to swallowing function pre- to post-DBS was found for pre-swallow spill, with pre-swallow spill being significantly decreased from baseline (during test dose of L-dopa) both “on” and “off” stimulation. The authors concluded that cZI stimulation did not negatively or positively impact deglutition. The results were determined based on standardized evaluative methods with appropriate outcome measures and proper experimental control. We agree with the authors in that no clinically significant decline or improvement to swallowing performance as a function of DBS surgery was revealed by these data. This was also influenced by the small sample size and minimally impaired dysphagia in this sample at baseline. Additionally, the influence of L-dopa on swallowing outcomes cannot be disentangled from the effects of stimulation or surgery on these outcomes.

Lengerer and colleagues [26] conducted a retrospective study of swallowing function in 18 participants with PD. Pre-DBS assessments were completed “on” medication. Participants

were reevaluated an average of 20 months post-bilateral STN DBS implantation and were tested “on” medication in the stimulation “on” and “off” conditions. Swallowing specific outcome measures were made from VFS and included both subjective and objective measures of swallowing. Subjective outcome measures included presence/absence of lingual control, laryngeal excursion, clearance of residue, aspiration/penetration, and mastication. Objective outcome measures included swallow transit times and maximal hyoid bone excursion. The authors reported that participants did not exhibit clinically significant signs of dysphagia in any condition pre- or post-surgery. Statistically significant changes to quantitative measures of swallowing physiology from pre- to post-surgery included: 1) decreased pharyngeal delay time for solid consistency; 2) decreased pharyngeal transit time with liquid bolus, 3) decreased pharyngeal response time with liquid bolus, and 4) decreased duration of cricopharyngeal opening with liquid bolus. The authors concluded, and we concur, that the results of this study demonstrate “no clinically relevant changes to deglutition” with STN DBS. They explained that given the data were compiled retrospectively, VFS recordings were analyzed at 15 frames per second as opposed to the standard 30 frames per second which is normally standard in scientific studies. Additionally, the sample was only minimally impaired, which may have caused a ceiling effect. Lastly, there was a very short stimulation washout (10 min). This being said, there were quantitative changes to several aspects of swallowing physiology which require further exploration and may indicate sensitivity of the pharyngeal swallowing mechanism to STN DBS.

Wolz and colleagues [29] evaluated non-motor symptoms in 34 participants with PD who underwent bilateral STN DBS implantation. The participants were observed “off” medication and in the “on” and “off” stimulation conditions. Swallowing was evaluated by having each participant swallow a 200 mL bolus of water after which the physician answered the following question: “does the patient have difficulties swallowing?” If yes, the physician rated the severity on a VAS, with 0 being no symptoms and 100 being most severe symptoms. Findings demonstrated no significant difference in frequency of dysphagia-related symptoms as a function of stimulation condition. Authors did report significant improvement in dysphagia severity (as measured by VAS) from “off” to “on” STN DBS conditions. No conclusions regarding the effect of DBS on swallowing can be made from this study. These results were based on one physician question, following a single observation of a patient’s swallow, with no standardized evaluative instrument to determine true swallowing performance, and with no blinding of physician raters. Additionally, there was no information regarding the reliability or validity of the survey question or VAS utilized in this study.

Kulneff and colleagues [25] evaluated 11 participants with PD who underwent either unilateral ($n = 5$) or bilateral ($n = 6$) STN DBS. Swallowing function was assessed at baseline, six months, and 12 months post-DBS surgery. Testing was completed “on” and “off” medication at baseline. Post-DBS, participants were tested “on” medication (1.5 times ordinary dose) and “on” and “off” stimulation. Swallowing function was evaluated by FEES during which participants swallowed a variety of consistencies. The outcome measures included the penetration/aspiration scale [36], secretion severity scale [37], and clinician ratings of pre-swallow spill, pharyngeal residue, and pharyngeal clearance. Although there were significant improvements in patient self-report of swallowing function pre- and post-DBS, there were no significant differences in objective measures of swallowing function with DBS stimulation at six or 12 months post-surgery. The authors concluded that STN DBS had no adverse effect on swallowing function in this sample. This small n study highlights the need for objective measures of swallowing as opposed to patient self-report to determine changes to swallowing function. In this case, patients reported improvement in swallowing function when “on” medication and stimulation as compared to “off” medication and stimulation. It is possible that overall improved motor functioning “on” medications

influenced the patient's sense of well-being therefore resulting in reports of improved swallowing function.

Silbergleit and colleagues [24] evaluated the swallowing of 14 participants with PD pre-DBS, three months post, and 12 months post-bilateral STN DBS. Participants were tested "on" and "off" medication and "on" and "off" stimulation. The participants were evaluated using VFS while swallowing boluses of various consistencies. The clinician-rated outcome measures included presence/absence of oral preparation impairment, delayed oral phase, delayed swallowing response, reduced pharyngeal contractions, penetration, and aspiration with and without cough. The authors reported no significant changes to quantitative measures of swallowing physiology pre- and post-surgery. As was found in Kulneff et al. [25], participants in this study also self-reported improvements in swallowing at 12 months post-surgery as compared to baseline. The authors concluded that STN DBS implantation did not impair swallowing function in this sample post-DBS. This is an appropriate claim given the selected outcome measures, experimental design, and small number of participants tested.

Most recently, in a letter to the editor, Kitashima and colleagues [31] reported swallowing-related outcomes in a sample pre- and six months post-bilateral STN DBS. In their preliminary study, the researchers compared the UPDRS Part III scores to swallowing outcomes from VFS in 10 participants. In their "main study" they evaluated 18 participants "on" and "off" stimulation. Swallowing outcome measures included oropharyngeal transit time, tongue movement, and laryngeal elevation delay time made from swallows of four differing consistencies. The authors reported no significant differences in VFS findings pre- and post-DBS. Additionally, they reported no significant improvement in swallowing function between "on" and "off" DBS stimulation conditions. The authors concluded that it appears that STN DBS did not significantly improve swallowing function in this group of participants. They did report that participants "on" stimulation exhibited increased tongue speed and decreased laryngeal elevation delay time with jelly consistency. The fact that swallowing-specific differences were only found for two outcome measures within one consistency limits the clinical significance of this finding. Additionally, stimulation "wash out" was only 10 min between stimulation conditions, the sample size was small, and very limited information was provided regarding the methodology.

6. Discussion

Improvement in non-axial related motor functioning (tremor, rigidity, bradykinesia, on-off fluctuations, dyskinesia) has been found to persist following DBS implantation in persons with PD [38]. However, significant gaps remain in our understanding of the effects of DBS on axial functions, and in particular swallowing function. Critical review of the literature related to DBS and swallowing identified nine studies employing an experimental design which specifically evaluated swallowing outcomes. All the experimental studies were completed in people who underwent STN DBS [5,24–27,29–31], with the exception of one study evaluating swallowing changes following cZI DBS [28]. Therefore, there is no empirical evidence to support the notion that STN or GPi are better or alternatively worse targets for swallowing function. Additionally, no information can be gleaned regarding the effects of unilateral vs. bilateral STN DBS implantation on swallowing function. All STN studies assessed swallowing changes with bilateral stimulation, except for Kulneff et al. [25] where unilateral and bilateral cases were collapsed. In the case of Ciucci et al. [5] we do not know whether participants had unilateral or bilateral surgeries. Although no studies were found to identify *clinically significant* robust functional improvement or decline in swallowing function with STN DBS, there were several common threads in the findings. In some studies, significant changes were found to measures of pharyngeal swallowing,

specifically timing measures, following STN DBS or when comparing STN with stimulation “off” vs. “on” [5,26,28]. These changes were not observed in the oral phase of swallowing. Additionally, two studies identified patient-reported improvement in swallowing following STN DBS; although this was not supported by physiological data [24,25]. Overall, these data reveal that the pharyngeal phase of swallowing seems to be ‘sensitive’ to STN stimulation, although the contribution of medication, stimulation, or the surgery itself is still unclear.

Some researchers have reported that STN DBS is more strongly associated with deterioration of swallowing function than GPi DBS [2,14]. The results of this critical review reveal that this is not supported by the data available from experimental studies. In fact, no experimental study has compared swallowing function in STN vs. GPi. Additionally, none of the case reports clearly define either improvement or worsening of dysphagia symptoms post-STN surgery. Moreover, there has been no comparison of unilateral vs. bilateral surgeries and its effects on swallowing function. In order to make evidence-based decisions regarding proper management of patients undergoing DBS it is essential that we better understand the true effects that DBS has on swallowing, if any.

The lack of consensus across studies is likely due to methodological differences and this should be addressed in future studies. First, in order to determine the effects of DBS on swallowing it will be essential that appropriate tools and measures are employed. The use of proper evaluative techniques such as VFS or FEES will allow for a sensitive and specific comparison of swallowing function over time. Second, it is necessary that DBS-specific parameters such as lead locations (GPi vs. STN), number of leads (unilateral vs. bilateral), appropriate stimulation washouts, and programming stability be controlled for, and reported. Additionally, PD-specific parameters such as disease duration, UPDRS, Hoehn & Yahr stage, and medication states (“on” vs. “off”) should be accounted for and appropriately reported for each participant. Significant gaps remain in our understanding of the effects of DBS on swallowing. Incorporating the above considerations into the design of future research studies will enhance the understanding of the specific impact of both GPi and STN DBS on individuals with PD. These data are critically important given the high aspiration risk in this population.

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Table 1

Experimental studies addressing deep brain stimulation and swallowing outcomes.

Authors	Total N =	Lead location	Method of swallowing evaluation	Medication conditions	Measurement points	Summary of DBS-specific results	Main limitations
Ciucci et al. (2008)	14	STN	VFS	On meds	Post-DBS on/off stim	Pharyngeal transit times and pharyngeal composite scores improved significantly "on" stimulation	No mention of unilateral or bilateral STN DBS placement, minimally impaired cohort with marginal change in swallowing function
Kitashima et al. (2012)	18	Bilateral STN	VFS	On meds	Pre-DBS Post-DBS on/off stim	Significantly increased tongue speed and decreased laryngeal elevation delay time with jelly consistency on stim; no other significant findings	Very few details provided regarding methodology, multiple comparisons, short stim washout
Kulneff et al. (2012)	11	Unilateral STN (5) bilateral STN (6)	FEES	On/off meds (Pre-DBS) on meds (Post-DBS)	Pre-DBS Post-DBS (3 mos) on/off stim Post-DBS (6 mos) on/off stim	Significant improvement in patient self-report of swallowing function; no other significant differences	Small sample with multiple statistical comparisons
Lengrer et al. (2012)	18	Bilateral STN	VFS	On meds	Pre-DBS Post-DBS (12 mos) on/off stim	Post-DBS: Dec. pharyngeal delay time for solids, dec. pharyngeal transit time with liquids, dec. pharyngeal response time with liquids, dec. CP opening duration with liquid	No clinically significant signs of dysphagia pre- or post-DBS, retrospective study, short stim washout
Silbergleit et al. (2012)	14	Bilateral STN	VFS	On/off meds (Pre/Post-DBS)	Pre-DBS Post-DBS (3 mos) on/off stim Post-DBS (12 mos) on/off stim	Significant improvement in patient self-report of swallowing function; no other significant differences	Multiple statistical comparisons
Sundstedt et al. (2012)	8	Bilateral cZI	FEES	On/off meds (Pre DBS) on Meds (Post DBS)	Pre-DBS Post-DBS (3 mos) on/off stim Post-DBS (6 mos) on/off stim	Pre-swallow spill significantly decreased from baseline in both "on" and "off" stimulation conditions	Small sample with multiple statistical comparisons
Tassorelli et al. (2009)	34	Bilateral STN	Bedside clinical swallowing evaluation	On meds	Pre-DBS Post-DBS	19 of 34 had dysphagia post DBS; 17/19 were unrelated to DBS	No statistical comparisons, no criterion for assessing dysphagia, no objective measures of dysphagia pre- or post-surgery

Authors	Total N =	Lead location	Method of swallowing evaluation	Medication conditions	Measurement points	Summary of DBS-specific results	Main limitations
Wolz et al. (2012)	34	Bilateral STN	One question, VAS	Off meds	Post-DBS on/off stim	Significant improvement in dysphagia severity per VAS "on" stim	No objective measure of swallowing, no rater blinding, use of a single question from a non-validated instrument
Zibetti et al. (2007)	36	Bilateral STN	UPDRS Items 6 & 7	On/off meds (Pre-DBS) On meds (Post-DBS)	Pre-DBS Post-DBS on/off stim	UPDRS items were significantly better in post-DBS on stim/on med to pre-DBS off med	No comparisons pre-DBS on med to post-DBS on med, UPDRS as measure of swallowing function

Deep brain stimulation (DBS); Subthalamic nucleus (STN); Caudal zona incerta (cZI); Stimulation (stim); Videofluoroscopic evaluation (VFS); Fiberoptic endoscopic evaluation of swallowing (FEES); Unified Parkinson's disease rating scale (UPDRS); Oculo-pharyngeal muscular dystrophy (OPMD); Percutaneous endoscopy gastrostomy (PEG); decreased (dec); months (mos); visual analog scale (VAS); medications (meds).