Published in final edited form as:
Dysphagia. 2011 September ; 26(3): 218–224. doi:10.1007/s00455-010-9289-x.

Respiratory-Swallowing Coordination and Swallowing Safety in Patients with Parkinson's Disease

Michelle S. Troche, PhD, CCC-SLP,
University of Florida, P.O. Box 117420, Gainesville, FL 32611, USA. Brain Rehabilitation Research Center, Malcom Randall VAMC, 1601 S.W. Archer Road, Gainesville, FL 32608, USA

Irene Huebner, MA, CCC-SLP,
Brain Rehabilitation Research Center, Malcom Randall VAMC, 1601 S.W. Archer Road, Gainesville, FL 32608, USA

John C. Rosenbek, PhD, CCC-SLP,
Brain Rehabilitation Research Center, Malcom Randall VAMC, 1601 S.W. Archer Road, Gainesville, FL 32608, USA. University of Florida, Box 100174, Gainesville, FL 32610, USA

Michael S. Okun, MD, and
University of Florida, P.O. Box 100236, Gainesville, FL 32610, USA

Christine M. Sapienza, PhD, CCC-SLP
University of Florida, P.O. Box 117420, Gainesville, FL 32611, USA. Brain Rehabilitation Research Center, Malcom Randall VAMC, 1601 S.W. Archer Road, Gainesville, FL 32608, USA

Michelle S. Troche: michi81@ufl.edu

Abstract

The purpose of this study was to determine if individuals with Parkinson's disease (PD) demonstrate abnormal respiratory events when swallowing thin liquids. In addition, this study sought to define associations between respiratory events, swallowing apnea duration, and penetration–aspiration (P–A) scale scores. Thirty-nine individuals with PD were administered ten trials of a 5-ml thin liquid bolus. P–A scale score quantified the presence of penetration and aspiration during the swallowing of a 3-oz sequential bolus. Participants were divided into two groups based on swallowing safety judged during the 3-oz sequential swallowing: Group 1 = P–A ≤ 2; Group 2 = P–A ≥ 3. Swallows were examined using videofluoroscopy coupled with a nasal cannula to record respiratory signals during the event(s). Findings indicated that expiration was the predominant respiratory event before and after swallowing apnea. The data revealed no differences in our cohort versus the percentages of post-swallowing events reported in the literature for healthy adults. In addition, individuals with decreased swallowing safety, as measured by the P–A scale, were more likely to inspire after swallows and to have shorter swallowing apnea duration. Individuals who inspired before swallow also had longer swallowing apnea duration. The occurrence of inspiratory events after a swallow and the occurrence of shorter swallowing apnea durations may serve as important indicators during clinical swallowing assessments in patients at risk for penetration or aspiration with PD.

Correspondence to: Michelle S. Troche, michi81@ufl.edu.

Keywords

Dysphagia; Penetration–aspiration; Inspiration; Expiration; Parkinson's disease; Deglutition; Deglutition disorders

Respiration and swallowing are centrally controlled acts, mediated by central pattern generators (CPGs) [1] thought to reside within proximal regions of the brainstem [2–4]. In addition to these shared neuronal pathways, respiratory and swallowing functions also share an array of common pharyngeal structures. Close coordination of respiration and swallowing functions is evidenced by apnea that normally occurs during a swallow as a means of lower airway protection. Under brainstem control, swallowing apnea [1] can occur in the absence of glottal closure [5]. The onset of swallowing apnea varies among healthy adults and can occur before or upon the onset of laryngeal vestibule and glottal closure [6, 7]; however, the offset of swallowing apnea is more consistent among healthy individuals and generally occurs when the hyoid bone returns to rest [7]. The duration of swallowing apnea is relatively unchanged across boluses less than 20 ml [6–11] but may increase with larger boluses (100–200 ml), directly relating to the increased duration of laryngeal elevation [8, 12].

The dominant respiratory-swallowing pattern is expiratory preceding and following 72–100% of swallows [6, 7, 9–14]. Potentially serving as a protective mechanism, expiration serves to expel penetrant(s) that may enter the airway as the laryngeal vestibule descends to its rest position. In healthy adults, this pattern is stable across bolus consistencies [11, 13] and with thin liquid boluses that range in size from 3 to 20 ml [6–8, 10–12]. As bolus size increases, the respiratory pattern changes, with an increased amount of inspiratory events [11, 12, 14]. Swallowing impairment is a common sequela of Parkinson's disease (PD), likely resulting from disruption of both volitional and autonomic control of the quality and timing of oral and pharyngeal movements across all swallowing phases. In addition, respiratory impairment (be it obstructive or restrictive) can be evidenced in 28–85% of individuals with PD [15–20]. This combination of respiratory and swallowing impairment associated with PD may manifest as a disrupted respiratory-swallowing pattern [21–23].

Pinnington et al. [22] examined the respiratory patterns associated with swallowing a 5-ml thin liquid bolus in 12 persons with PD (H&Y II–V) and 14 healthy controls using the Exeter Dysphagia Assessment Technique (EDAT) [24–26] and found a significant difference in the percent of swallows that were followed by expiration, with 99% of swallows followed by expiration in healthy subjects and 80% of swallows followed by expiration in those with PD. For those with PD, 18% of swallows were followed by inspiration and 2% of swallows were followed by a brief period of apnea [21, 22]. More recently, Gross et al. [23] studied swallowing patterns using a nasal cannula, respiratory inductance plethysmography, and surface electromyography (sEMG). These authors tested swallowing of pudding and cookie boluses in 25 individuals with PD and 25 healthy controls. Participants with PD had more occurrences of inspiration than healthy controls, both before and after swallows and regardless of bolus type. Moreover, unlike the healthy controls, individuals with PD did not demonstrate an increase in swallowing apnea duration during swallows initiated on inspiration, possibly because of respiratory compromise or a disruption in the signal from the brainstem (which modifies respiratory pattern based on sensory input) [27]. To date, no studies have used videofluoroscopy, coupled with a respiratory signal from a nasal cannula, to describe respiratory-swallowing events in those with PD. Videofluoroscopy defines temporal measures of swallowing [6, 28–32] and describes the coordination of these temporal events with respiration [6, 7, 14, 33–38]. Videofluoroscopic studies of healthy individuals provide a foundation for comparison of

swallowing abnormalities associated with PD, including disturbances of movement and timing within the oral and pharyngeal phases of swallowing as well as the occurrence of penetration and/or aspiration [21, 39–47]. The increased risk of penetration or aspiration during post-swallow inspiration supports the use of videofluoroscopy [28] because this technology allows for real-time observations of oral and pharyngeal dysfunction, penetration or aspiration, and associated respiratory events.

The current study compared the respiratory events accompanying a 5-ml thin-bolus swallow by individuals with PD with that of healthy older adults. It was hypothesized that individuals with PD would demonstrate more inspiratory than expiratory events before and after the swallow. This study also sought to determine the relationship between these observed respiratory events and penetration–aspiration (P–A) scores as well as duration of apnea for the 5-ml thin bolus. It was hypothesized that swallows followed by expiration would be significantly and positively correlated with P–A scores that reflect a “safe” swallow (P–A score ≤ 2) and would be related to longer durations of apnea. Furthermore, swallows followed by inspiration would be significantly and positively correlated with “unsafe” swallow (P–A score ≥ 3) and shorter durations of apnea in persons with PD.

Methods

Thirty-nine participants (29 males and 10 females; mean age = 67.8 years, SD = 9.28 years) with idiopathic Parkinson’s disease (IPD), referred from the University of Florida (UF) and Malcom Randall Veteran’s Affairs (VA) Movement Disorders Center in Gainesville, FL, were included in this study. Participants were recruited as part of a larger randomized clinical trial testing the effects of expiratory muscle strength training on swallowing function in PD. All participants signed an informed consent form approved by the UF and VA Institutional Review Boards (154–2003 and 195–2005) prior to enrollment. Following informed consent, a UF Movement Disorders neurologist completed a clinical assessment of each individual’s PD disease severity, making the diagnosis of PD based on UK Brain Bank Criteria [48]. Participants with Hoehn and Yahr (H&Y) [49] scores of II–IV in the “on dopaminergic” state were included. All participants were receiving benefit from an antiparkinsonian medication (i.e., Carbidopa/Levodopa, a dopamine agonist, an MAO-B inhibitor, and/or Amantadine) and verbally reported swallowing disturbances (i.e., reports of coughing/choking with meals, increased eating duration) prior to enrollment.

Additional inclusion criteria for participation included being 35–85 years old and having a score of at least 24 on the Mini-Mental State Examination [50]. Exclusion criteria were a history of other neurologic disorders, head and neck cancer, gastrointestinal disease, previous gastroesophageal surgery, chronic and acute cardiac disease, untreated hypertension, heart disease, smoking in the past 5 years, history of breathing disorder or disease, failure to pass a screening test of pulmonary functioning (e.g., $FEV_1/FVC < 75\%$), or other neuropsychological disturbance such as severe depression or dementia.

Instrumentation

Videofluoroscopy was used to examine swallowing function. The recordings were conducted in a standard fluoroscopic suite. Participants sat upright and were recorded in the lateral plane using a properly collimated Phillips Radiographic/Fluoroscopic unit a 63-kV, 1.2-mA output with a full field-of-view mode. The field of view included the lips and teeth anteriorly, nasal spine superiorly, cervical spine posteriorly, and upper esophageal sphincter inferiorly. Fluoroscopic images were digitally recorded at 29.97 frames per second using a scan converter (Kay Elemetrics Swallowing Signals Lab, Kay Elemetrics, Lincoln Park, NJ). Videofluoroscopic recordings were made with a resolution of 60 fields (30 frames) per second. Therefore, the resolution for determining measurements using digital video

recordings was approximately 17 ms per digital field. Nasal respiratory flow was captured using a standard, 7-ft nasal cannula coupled to the Swallow Signals Lab. A respiratory tracing at 250 Hz was used to generate a digital display of both the respiratory phase and duration of the apneic pause during swallowing. Participants completed ten 5-ml trials of thin liquid (Liquid E-Z Paque Barium Sulfate Suspension; 60% w/v, 41% w/w; from E-Z-EM) and one 3-oz sequential thin liquid barium swallow by cup. All participants self-fed in order to closely replicate "natural" feeding conditions. Participants were prompted by the investigator to "place the liquid in [your] mouth and swallow when ready."

Outcome Measures

A licensed and certified speech pathologist with expertise in the evaluation of patients with PD and blinded to participant identity generated P–A scores for each participant and analyzed all data for expiratory and inspiratory events related to a swallowing cycle, swallowing apnea duration, and P–A score. A second rater with similar credentials completed reliability on 20% of the data set.

Physiologic Measures

Respiratory events occurring before and after swallowing apnea were interpreted from the Kay Elemetrics Signal Lab output and completed for each of the 5-ml thin liquid swallows. The polarity of the respiratory signal determined airflow. Positive polarity represented expiratory events and negative polarity represented inspiratory events. Swallowing apnea was represented by a plateau of the airflow signal along the x axis with duration measured in milliseconds. An examiner placed measurement tags at swallowing events and later the tags for calculation of oral transit time, pharyngeal transit time, and total swallowing duration.

Functional Measures of Swallowing

P–A scale score [51, 52] was used to quantify the presence of penetration and aspiration during the swallowing of the 3-oz sequential bolus. The P–A scale (Table 1) is a validated ordinal scale, where 1 indicates the safest swallow and 8 indicates the least safe swallow, or silent aspiration. The scale measures whether material entered the airway and if it did, whether the residue remained or was expelled. Participants were divided into two groups based on swallowing safety: Group 1 = P–A ≤ 2 and Group 2 = P–A ≥ 3.

Rater Reliability

To test the inter- and intrarater reliability of the primary respiratory-swallow outcomes, 20% of the waveform data was reanalyzed.

Statistical Analysis

Descriptive statistics were used to define the type of respiratory events (inspiratory versus expiratory) that occurred before and after swallowing apnea. Pearson r correlations assessed the relationships between these respiratory events before and after swallowing apnea and swallowing apnea duration. Initially, the data were analyzed without averaging across events (all ten swallowing trials of 5-ml thin liquid were analyzed individually) and then averaged across trials. Pearson r correlations were conducted with the collapsed trial data to determine relationships between respiratory events before and after swallowing, swallowing apnea duration, and P–A score (which as stated previously was determined from the 3-oz thin liquid sequential swallowing). A t test with aggregates was used to compare measures between Group 1 and Group 2 ($p < 0.05$).

Results

Interrater and intrarater reliabilities were calculated, yielding intraclass coefficients of 0.84 (95% CI = 0.77, 0.88) and 0.85 (95% CI = 0.79, 0.89).

Table 2 summarizes the frequencies of respiratory events associated with swallows for all patients. In brief, expiration preceded swallowing apnea 70.1% of the time and followed apnea 86.4% of the time. Inspiration preceded swallowing apnea 29.9% of the time and followed apnea 13.6% of the time.

Respiratory events, swallowing apnea duration, oral transit times, and total swallowing duration were then averaged across trials. A significant positive correlation was found between swallowing apnea duration and preswallowing respiratory events ($r = 0.357$, $p < 0.001$). In addition, a significant positive correlation existed between oral transit time and both preswallowing respiratory events ($r = 0.171$, $p = 0.001$) and post-swallowing respiratory events ($r = 0.177$, $p < 0.001$). P–A score and respiratory events were averaged across trials and collapsed across groups. There was significant correlation between P–A score and a post-swallowing respiratory event ($r = 0.590$, $p < 0.001$). Group 2 (those with less safe swallows and higher P–A scores) had significantly more inspiratory events post-swallowing ($t = -2.253$, df = 36, $p = 0.03$; Table 3).

Discussion

The data from this study suggest that expiration is the predominant respiratory event that occurs both before and after swallowing apnea in patients with PD when swallowing 5-ml thin boluses. In addition, significant positive relationships were uncovered between respiratory events, swallowing apnea duration, and P–A scores. Preswallowing inspiratory events were positively related to longer durations of swallowing apnea. Post-swallowing inspiratory events were positively related to shorter swallowing apnea durations and higher P–A scores. Inspiratory events, both before and after the swallow, were positively related to longer oral transit times. To further investigate the relationship of swallowing safety with swallowing apnea, individuals were divided into two groups based on P–A score. Individuals with P–A scores of 1–2 (Group 1) were designated as *non-penetrator–aspirators* and those with P–A scores of 3–8 (Group 2) were designated as *penetrator–aspirators*. The penetrator–aspirators demonstrated significantly shorter swallowing apnea durations compared to the non-penetrator–aspirator group.

The initial analysis of the swallows of the 39 individuals with PD revealed that 70.1% (232/331) of swallows were preceded by expiration and 86.4% (293/339) of swallows were followed by expiration. It was hypothesized that in participants with PD there would be an increased percentage of swallows followed by inspiration. Although the present study did not include a healthy control group, individuals in the current study generated about 6–7% fewer swallows followed by expiration compared to a similar study conducted by Martin-Harris et al. [7], which described the respiratory swallowing events associated with a 5-ml thin bolus in 76 healthy individuals. Additional studies using comparable methodology have generated similar results [8, 9]. Previous investigations of breathing and swallowing coordination in individuals with PD compared with healthy controls have observed significant differences in respiratory events surrounding a swallow [22, 23]. Caution should be used when comparing results of these studies with those of the present study because the different bolus types utilized could potentially impact the swallowing and respiratory events.

The present investigation also sought to determine the relationship between respiratory events, swallowing apnea duration, and P–A scale scores. Swallows initiated during inspiratory events were positively related to longer swallowing apnea durations. It is

possible that participants who inspired before the swallow had a disordered oral phase with decreased bolus control [21, 40–42], resulting in longer swallowing apnea duration. This finding, however, is supported by an earlier investigation [23]. In that study, healthy adults produced significantly longer swallowing apnea durations with cookie and pudding boluses when swallows were initiated in inspiration; this pattern was not observed in PD. The type of bolus may account for the different findings between the Gross et al. [23] study and the present study, which used a 5-ml thin liquid bolus. Therefore, we cannot conclude that the presence of PD alone gives rise to longer swallowing apnea durations.

Post-swallowing inspiratory events were positively related to shorter swallowing apnea durations as well as higher P–A scores. Shorter swallowing apnea duration followed by inspiration supports a possible relationship between respiratory events and swallowing severity in PD. Poor bolus containment, premature spillage of liquid into the valleculae and pyriform sinuses, and delayed swallowing reflex [39, 40, 42, 45] have been reported in PD. Participants who demonstrated penetration or aspiration (P–A score = 3–8) were also likely to have shorter durations of swallowing apnea. Morton et al. [53] studied the relationship of pharyngeal dwell time and aspiration in individuals with dysphagia of varied etiologies. They found that among those who aspirated, a greater percentage of the pharyngeal dwell time occurred in inspiration. Inspiratory events coupled with the presence of residue in the pharynx leave the airway more susceptible to aspiration events. Shortened swallowing apnea duration may be related to the delay in triggering the swallowing reflex. Individuals with greater impairment of the swallowing function, resulting in shortened swallowing apnea duration, may also experience poor integration of the swallowing and respiratory signals, thereby increasing aspiration risk.

Continued investigation into the relationship between post-swallowing inspiration and swallowing severity, including objective temporal measures, hyoid displacement, and qualitative observations or oral bolus manipulations, is warranted. It may be that swallowing severity is also related to higher P–A scores or less safe swallows. The finding that inspiratory events after swallowing were positively related to higher P–A scores supports past observations that post-swallowing inspiration is associated with decreased swallowing safety [1, 6–14, 54].

Limitations

The current study did not include a healthy age-matched control group. Inclusion of such a group would allow further discussion of the effects of neurodegeneration on respiratory-swallowing events. This limitation was addressed in part by comparing the current results to those of the Martin-Harris et al. study [7], which employed similar methodology and investigated respiratory events surrounding the swallowing of a 5-ml thin bolus in healthy adults. In addition, whereas respiratory-swallowing patterns and swallowing apnea measures were determined from the multiple 5-ml thin bolus presentations, P–A scores were determined from a 3-oz sequential thin liquid trial. This allowed for the identification of participants who were at risk for penetration–aspiration but restricted the direct comparison of swallowing pattern and swallowing safety. This study used a nasal cannula signal as the single source of respiratory data. The validity of these measures would be enhanced by supplementation with respiratory plesthymography.

Conclusion

This study contributes to the growing literature of respiratory-swallowing coordination in impaired populations, specifically patients with PD. To our knowledge, this is the first study in PD patients to examine respiratory events associated with swallowing utilizing videofluoroscopy and the P–A scale. In individuals with mild to moderate PD severity

(H&Y II–IV), expiration is the predominant event, occurring after approximately 70% of swallows. Comparison of the present results with those of prior investigations of healthy adults suggests that individuals with PD follow a greater percentage of swallows with an inspiratory event. When considering post-swallowing inspiration and swallowing safety, individuals with P–A scores of 3–8 showed a greater predominance of inspiratory events occurring after a swallow. In addition, those with decreased swallowing safety also showed shorter swallowing apnea durations. The occurrences of (1) inspiratory events after a swallow and (2) shorter swallowing apnea durations may serve as important indicators during clinical swallowing assessments in patients at risk for penetration or aspiration.

Acknowledgments

This work was supported by VA Merit Grant RR & D B3721R to Christine Sapienza, PhD.

References

1. Nishino T, Hiraga K. Coordination of swallowing and respiration in unconscious subjects. J Appl Physiol. 1991; 70:988–93. [PubMed: 2033013]
2. Zald DH, Pardo JV. The functional neuroanatomy of voluntary swallowing. Ann Neurol. 1999; 46:281–6. [PubMed: 10482257]
3. Broussard DL, Altschuler SM. Central integration of swallow and airway-protective reflexes. Am J Med. 2000; 108(Suppl 4a):62S–7S. [PubMed: 10718454]
4. Saito Y, Ezure K, Tanaka I. Swallowing-related activities of respiratory and non-respiratory neurons in the nucleus of solitary tract in the rat. J Physiol. 2002; 540:1047–60. [PubMed: 11986389]
5. Hiss SG, Strauss M, Treole K, Stuart A, Boutilier S. Swallowing apnea as a function of airway closure. Dysphagia. 2003; 18:293–300. [PubMed: 14571335]
6. Martin-Harris B, Brodsky MB, Price CC, Michel Y, Walters B. Temporal coordination of pharyngeal and laryngeal dynamics with breathing during swallowing: single liquid swallows. J Appl Physiol. 2003; 94:1735–43. [PubMed: 12506044]
7. Martin-Harris B, Brodsky MB, Michel Y, Ford CL, Walters B, Heffner J. Breathing and swallowing dynamics across the adult lifespan. Arch Otolaryngol Head Neck Surg. 2005; 131:762–70. [PubMed: 16172351]
8. Hirst LJ, Ford GA, Gibson GJ, Wilson JA. Swallow-induced alterations in breathing in normal older people. Dysphagia. 2002; 17:152–61. [PubMed: 11956841]
9. Klahn MS, Perlman AL. Temporal and durational patterns associating respiration and swallowing. Dysphagia. 1999; 14:131–8. [PubMed: 10341108]
10. Preiksaitis HG, Mayrand S, Robins K, Diamant NE. Coordination of respiration and swallowing: effect of bolus volume in normal adults. Am J Physiol. 1992; 263:R624–30. [PubMed: 1415651]
11. Preiksaitis HG, Mills CA. Coordination of breathing and swallowing: effects of bolus consistency and presentation in normal adults. J Appl Physiol. 1996; 81:1707–14. [PubMed: 8904590]
12. Martin BJ, Logemann JA, Shaker R, Dodds WJ. Coordination between respiration and swallowing: respiratory phase relationships and temporal integration. J Appl Physiol. 1994; 76:714–23. [PubMed: 8175582]
13. Smith J, Wolkove N, Colacone A, Kreisman H. Coordination of eating, drinking and breathing in adults. Chest. 1989; 96:578–82. [PubMed: 2766816]
14. Dozier TS, Brodsky MB, Michel Y, Walters BC Jr, Martin-Harris B. Coordination of swallowing and respiration in normal sequential cup swallows. Laryngoscope. 2006; 116:1489–93. [PubMed: 16885759]
15. Weiner P, Inzelberg R, Davidovich A, Nisipeanu P, Magadle R, Berar-Yanay N, Carasso RL. Respiratory muscle performance and the perception of dyspnea in Parkinson's disease. Can J Neurol Sci. 2002; 29:68–72. [PubMed: 11858539]
16. Izquierdo-Alonso JL, Jimenez-Jimenez FJ, Cabrera-Valdivia F, Mansilla-Lesmes M. Airway dysfunction in patients with Parkinson's disease. Lung. 1994; 172:47–55. [PubMed: 8295432]

17. Sabate M, Rodriguez M, Mendez E, Enriquez E, Gonzalez I. Obstructive and restrictive pulmonary dysfunction increases disability in Parkinson disease. Arch Phys Med Rehabil. 1996; 77:29–34. [PubMed: 8554470]
18. Vercueil L, Linard JP, Wuyam B, Pollak P, Benchetrit G. Breathing pattern in patients with Parkinson's disease. Respir Physiol. 1999; 118:163–72. [PubMed: 10647860]
19. Polatli M, Akyol A, Cildag O, Bayulkem K. Pulmonary function tests in Parkinson's disease. Eur J Neurol. 2001; 8:341–5. [PubMed: 11422431]
20. Pal PK, Sathyaprabha TN, Tuhina P, Thennarasu K. Pattern of subclinical pulmonary dysfunctions in Parkinson's disease and the effect of levodopa. Mov Disord. 2007; 22:420–4. [PubMed: 17230476]
21. Troche MS, Sapienza CM, Rosenbek JC. Effects of bolus consistency on timing and safety of swallow in patients with Parkinson's disease. Dysphagia. 2008; 23:26–32. [PubMed: 17551793]
22. Pinnington LL, Muhiddin KA, Ellis RE, Playford ED. Non-invasive assessment of swallowing and respiration in Parkinson's disease. J Neurol. 2000; 247:773–7. [PubMed: 11127532]
23. Gross RD, Atwood CW Jr, Ross SB, Eichhorn KA, Olszewski JW, Doyle PJ. The coordination of breathing and swallowing in Parkinson's disease. Dysphagia. 2008; 23:136–45. [PubMed: 18027027]
24. Pinnington LL, Muhiddin KA, Lobeck M, Pearce VR. Interrater and intrarrater reliability of the Exeter dysphagia assessment technique applied to healthy elderly adults. Dysphagia. 2000; 15:6–9. [PubMed: 10594252]
25. Selley WG, Ellis RE, Flack FC, Bayliss CR, Pearce VR. The synchronization of respiration and swallow sounds with video-fluoroscopy during swallowing. Dysphagia. 1994; 9:162–7. [PubMed: 8082324]
26. Selley WG, Flack FC, Ellis RE, Brooks WA. The Exeter Dysphagia Assessment Technique. Dysphagia. 1990; 4:227–35. [PubMed: 2209098]
27. Kelly BN, Huckabee ML, Jones RD, Carroll GJ. The influence of volition on breathing-swallowing coordination in healthy adults. Behav Neurosci. 2007; 121:1174–9. [PubMed: 18085871]
28. Martin-Harris B, Logemann JA, McMahon S, Schleicher M, Sandidge J. Clinical utility of the modified barium swallow. Dysphagia. 2000; 15:136–41. [PubMed: 10839826]
29. Mendell DA, Logemann JA. Temporal sequence of swallow events during the oropharyngeal swallow. J Speech Lang Hear Res. 2007; 50:1256–71. [PubMed: 17905910]
30. Logemann JA, Rademaker AW, Pauloski BR, Ohmae Y, Kahrilas PJ. Normal swallowing physiology as viewed by videofluoroscopy and videoendoscopy. Folia Phoniatr Logop. 1998; 50:311–9. [PubMed: 9925954]
31. Dodds WJ, Stewart ET, Logemann JA. Physiology and radiology of the normal oral and pharyngeal phases of swallowing. AJR Am J Roentgenol. 1990; 154:953–63. [PubMed: 2108569]
32. Dantas RO, Kern MK, Massey BT, Dodds WJ, Kahrilas PJ, Brasseur JG, Cook IJ, Lang IM. Effect of swallowed bolus variables on oral and pharyngeal phases of swallowing. Am J Physiol. 1990; 258:G675–81. [PubMed: 2333995]
33. Martin-Harris B, Michel Y, Castell DO. Physiologic model of oropharyngeal swallowing revisited. Otolaryngol Head Neck Surg. 2005; 133:234–40. [PubMed: 16087021]
34. Gross RD, Atwood CW Jr, Grayhack JP, Shaiman S. Lung volume effects on pharyngeal swallowing physiology. J Appl Physiol. 2003; 95:2211–7. [PubMed: 12909607]
35. McCool FD. Global physiology and pathophysiology of cough: ACCP evidence-based clinical practice guidelines. Chest. 2006; 129:48S–53S. [PubMed: 16428691]
36. Smith Hammond C. Cough and aspiration of food and liquids due to oral pharyngeal dysphagia. Lung. 2008; 186(Suppl 1):S35–40. [PubMed: 18196338]
37. Smith Hammond CA, Goldstein LB, Zajac DJ, Gray L, Davenport PW, Bolser DC. Assessment of aspiration risk in stroke patients with quantification of voluntary cough. Neurology. 2001; 56:502–6. [PubMed: 11222795]
38. Martin-Harris B, Brodsky MB, Michel Y, Lee FS, Walters B. Delayed initiation of the pharyngeal swallow: normal variability in adult swallows. J Speech Lang Hear Res. 2007; 50:585–94. [PubMed: 17538102]

39. Potulska A, Friedman A, Krolicki L, Spychala A. Swallowing disorders in Parkinson's disease. Parkinsonism Relat Disord. 2003; 9:349–53. [PubMed: 12853234]
40. Ali GN, Wallace KL, Schwartz R, DeCarle DJ, Zagami AS, Cook IJ. Mechanisms of oral-pharyngeal dysphagia in patients with Parkinson's disease. Gastroenterology. 1996; 110:383–92. [PubMed: 8566584]
41. Fuh JL, Lee RC, Wang SJ, Lin CH, Wang PN, Chiang JH, Liu HC. Swallowing difficulty in Parkinson's disease. Clin Neurol Neurosurg. 1997; 99:106–12. [PubMed: 9213054]
42. Nagaya M, Kachi T, Yamada T, Igata A. Videofluorographic study of swallowing in Parkinson's disease. Dysphagia. 1998; 13:95–100. [PubMed: 9513304]
43. Monte FS, da Silva-Junior FP, Braga-Neto P, Nobre e Souza MA, Sales de Bruin VM. Swallowing abnormalities and dyskinesia in Parkinson's disease. Mov Disord. 2005; 20:457–62. [PubMed: 15625689]
44. Hunter PC, Crameri J, Austin S, Woodward MC, Hughes AJ. Response of parkinsonian swallowing dysfunction to dopaminergic stimulation. J Neurol Neurosurg Psychiatry. 1997; 63:579–83. [PubMed: 9408096]
45. Robbins JA, Logemann JA, Kirshner HS. Swallowing and speech production in Parkinson's disease. Ann Neurol. 1986; 19:283–7. [PubMed: 3963773]
46. Fernandez HH, Lapane KL. Predictors of mortality among nursing home residents with a diagnosis of Parkinson's disease. Med Sci Monit. 2002; 8:CR241–6. [PubMed: 11951064]
47. Bird MR, Woodward MC, Gibson EM, Phyland DJ, Fonda D. Asymptomatic swallowing disorders in elderly patients with Parkinson's disease: a description of findings on clinical examination and videofluoroscopy in sixteen patients. Age Ageing. 1994; 23:251–4. [PubMed: 8085513]
48. Hughes AJ, Daniel SE, Kilford L, Lees AJ. Accuracy of clinical diagnosis of idiopathic Parkinson's disease: a clinico-pathological study of 100 cases. J Neurol Neurosurg Psychiatry. 1992; 55:181–4. [PubMed: 1564476]
49. Hoehn MM, Yahr MD. Parkinsonism: onset, progression, and mortality. Neurology. 1967; 17:427–42. [PubMed: 6067254]
50. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975; 12:189–98. [PubMed: 1202204]
51. Robbins JM, Coyle J, Rosenbek J, Roecker E, Wood J. Differentiation of normal and abnormal airway protection during swallowing using the penetration-aspiration scale. Dysphagia. 1999; 14(4):228–32. [PubMed: 10467048]
52. Rosenbek JC, Robbins JA, Roecker EB, Coyle JL, Wood JL. A penetration-aspiration scale. Dysphagia. 1996; 11:93–8. [PubMed: 8721066]
53. Morton R, Minford J, Ellis R, Pinnington L. Aspiration with dysphagia: the interaction between oropharyngeal and respiratory impairments. Dysphagia. 2002; 17:192–6. [PubMed: 12140644]
54. Butler SG, Stuart A, Pressman H, Poage G, Roche WJ. Preliminary investigation of swallowing apnea duration and swallow/respiratory phase relationships in individuals with cerebral vascular accident. Dysphagia. 2007; 22(3):215–24. [PubMed: 17440776]

Table 1

Penetration–aspiration scale (from [52])

1	Contrast does not enter the airway: No penetration–aspiration
2	Contrast enters the airway, remains above the vocal folds: Penetration
3	Contrast remains above the vocal folds with visible residue: Penetration
4	Contrast contacts vocal folds, no residue: Penetration
5	Contrast contacts vocal folds, visible residue: Penetration
6	Contrast passes glottis, no subglottic residue: Aspiration
7	Contrast passes glottis, visible subglottic residue despite patient response: Aspiration
8	Contrast passes glottis, visible subglottic residue, absence of patient response: Aspiration

Table 2

Respiratory events preceding and following 5-ml thin bolus

	Expiration	Inspiration
Preswallowing respiratory event	70.1% (232/331)	29.9% (99/331)
Post-swallowing respiratory event	86.4% (293/339)	13.6% (46/339)

A total of 670 swallowing events were measured

Table 3

Results of the pairwise comparisons (*t* tests) using aggregates for equality of means for the nonpenetrators versus penetrators

		t	df	Sig. (2-tailed)	Non-P–A mean	P–A mean	Mean difference	Standard error
Preswallowing respiratory event	Equal variances assumed	0.579	36	0.566	1.3420	1.2750	0.0669	0.1156
Post-swallowing respiratory event	Equal variances assumed	−2.253	36	**0.030**	1.0629	1.2306	−0.1677	0.0744
Swallowing apnea	Equal variances assumed	1.963	33	0.058	1.4553	1.7565	0.3991	0.2033