Published in final edited form as:

Physiol Behav. 2018 October 01; 194: 144–152. doi:10.1016/j.physbeh.2018.05.010.

Differences in swallow physiology in patients with left and right hemispheric strokes

Janina Wilmskoetter[a,b,*], **Bonnie Martin-Harris**[c,d], **William G. Pearson Jr.**[e], **Leonardo Bonilha**[b], **Jordan J. Elm**[f], **Janet Horn**[a], and **Heather S. Bonilha**[a,g]

[a]Department of Health Sciences and Research, College of Health Professions, Medical University of South Carolina, 77 President St, MSC 700, Charleston, SC 29425, USA

[b]Department of Neurology, College of Medicine, Medical University of South Carolina, 96 Jonathan Lucas St, MSC 606, Charleston, SC 29425, USA

[c]Roxelyn and Richard Pepper Department of Communication Sciences and Disorders, School of Communication, Northwestern University, IL/USA

[d]Otolaryngology Head and Neck Surgery, Radiation Oncology, Feinberg School of Medicine, Northwestern University, IL/USA

[e]Department of Cellular Biology and Anatomy, Augusta University, 1120 15th Street, Augusta, GA 30912, USA

[f]Department of Public Health Sciences, College of Medicine, Medical University of South Carolina, 135 Cannon St, MSC 835, Charleston, SC 29425, USA

[g]Department of Otolaryngology – Head and Neck Surgery, Medical University of South Carolina, 135 Rutledge Ave, MSC 550, Charleston, SC 29425, USA

Abstract

Background—We sought to determine the impact of lesion lateralization and lesion volume on swallow impairment on group-level by comparing patients with left and right hemisphere strokes and on patient-level by analyzing patients individually.

Methods—We performed a retrospective, observational, cross-sectional study of 46 patients with unilateral (22 left, 24 right), acute, first-ever, ischemic strokes who received a diffusion weighted MRI (DW-MRI) and modified barium swallow study (MBSS) during their acute hospital stay. We

[*]**Corresponding author at:** Postdoctoral Scholar, Dept of Health Sciences & Research, College of Health Professions, Medical University of South Carolina, 77 President St. MSC 700, Charleston, SC 29425.

Institution where the study was performed

Medical University of South Carolina, Department of Health Sciences and Research, College of Health Professions

Declaration of interest

Dr. Wilmskoetter has nothing to disclose. Dr. Martin-Harris reports grants from NIH/NIDCD, grants from Bracco Diagnostics, during the conduct of the study; and Copyright royalties from Northern Speech Services and Medical University of South Carolina. Dr. Pearson has nothing to disclose. Dr. L. Bonilha has nothing to disclose. Dr. Elm has nothing disclose. Ms. Cucciare has nothing to disclose. Dr. H. Bonilha has nothing to disclose.

determined lesion side on the DW-MRI and measured swallow physiology using the Modified Barium Swallow Impairment Profile (MBSImP™©), Penetration-Aspiration scale (PAS), swallow timing, distance, area, and speed measures. We performed Pearson's Chi- and Wilcoxon rank-sum tests to compare patients with left and right hemisphere strokes, and Pearson or Spearman correlation, simple logistic regression, linear, and logistic multivariable regression modeling to assess the relationship between variables.

Results—At the group-level, there were no differences in MBSImP oral swallow impairment scores between patients with left and right hemisphere stroke. In adjusted analyses, patients with right hemisphere strokes showed significantly worse MBSImP pharyngeal total scores ($p=0.02$), worse MBSImP component specific scores for laryngeal vestibular closure (Bonferroni adjusted alpha $p\leq0.0029$), and worse PAS scores ($p=0.03$). Patients with right hemisphere strokes showed worse timing, distance, area, and speed measures. Lesion volume was significantly associated with MBSImP pharyngeal residue ($p=0.03$) and pharyngeal total scores ($p=0.04$). At the patient-level, 24% of patients (4 left, 7 right) showed opposite patterns of MBSImP oral and pharyngeal swallow impairment than seen at group-level.

Conclusion—Our study showed differences in swallow physiology between patients with right and left unilateral strokes with patients with right hemisphere strokes showing worse pharyngeal impairment. Lesion lateralization seems to be a valuable marker for the severity of swallowing impairment at the group-level but less informative at the patient-level.

Keywords

deglutition; deglutition disorders; stroke; cerebral hemispheres

1. Introduction

Swallowing is a vital and complex body function that enables nutrition and hydration, control of saliva, and has a great impact on quality of life. On average, an adult human swallows about 600 times per day [1] and only takes 1–2 seconds to transport a bolus from the lips through the upper esophageal sphincter [2]. This process involves five cranial nerves, more than 30 muscles and muscles pairs [3], and is controlled by a broad neural brain network [4]. If disrupted, swallowing can be treated but requires a careful diagnosis of the underlying causes and physiology because these will dictate the type of dysphagia rehabilitation, recommendations for rehabilitative exercises, compensatory strategies, diet modifications, or alternative means of nutrition.

One of the most common causes of dysphagia is a stroke with up to 78% of all stroke survivors experiencing swallow difficulties [5, 6]. Dysphagia can occur after strokes to various brain locations; however, dysphagia following lesions to the cerebral hemispheres is of high clinical interest because anterior circulation infarcts that result in hemispheric lesions reflect the majority of all strokes [7]. Further, cerebral hemispheric strokes are often coupled with cognitive or perceptual deficits that impose additional challenges on the diagnosis and rehabilitation of patients' swallowing function. Therefore, a thorough understanding of the potentially underlying swallow physiological impairments in patients with left or right hemisphere strokes is crucial. Since swallowing is a midline function and at least, to some extent, bilaterally controlled [8–11], it is not surprising that unilateral strokes to either hemisphere can result in dysphagia [12–14].

Interestingly, right and left hemisphere lesions may differently impact dysphagia occurrence after a stroke; however, there is a discrepancy regarding how the side of the lesion affects swallow physiology after stroke. Some studies suggest that dysphagia after stroke mainly occurs after lesions to the left hemisphere [15, 16], while other studies suggest lesions to the right hemisphere are mainly responsible [17, 18]. Alternative studies suggest there is no difference between the hemispheres [5, 19, 20]. Moreover, some studies claim that each hemisphere has a different role in swallowing and that left hemisphere lesions are more often associated with oral-stage dysfunction while right hemisphere lesions are more often associated with pharyngeal-stage dysfunction, i.e., severe and prolonged dysphagia involving aspiration [13–17, 21, 22]. Some studies have reported cases that seem to be an exception to the rule [15]. Furthermore, other studies could not confirm any differences between the hemispheres, e.g., for lingual discoordination [20], aspiration occurrence [5, 23–25], swallow physiology [24], and overall oral or pharyngeal impairment [25].

There are various reasons why study findings show this large degree of variability. First, methodological differences between the studies, such as patient selection, swallow measures and definitions, and statistical power, may impact study results. For example, studies included patients with various times since their stroke, assessed only very few and selected swallow measures, or applied functional brain imaging that does not necessarily converge on the same results as lesion symptom mapping. Second, it has been suggested that lateralization is dependent on age [26], brain regions, aspects of swallow physiology, muscles involved in swallowing, or swallow tasks [10, 19]. Consequently, it is speculated that commonly applied group level analyses may average out any effects that are present at the level of individual brain regions, muscles, or swallow tasks (e.g. Lowell et al., 2012).

The goal of our study was to systematically compare the swallow physiology of patients with left and right unilateral strokes at the group- and the patient-level by using a broad array of swallow physiology measures to provide detailed insights into differences in swallow impairment. Further, we assessed associations between lesion volume and swallow impairment in specific aspects of swallow physiology, which we believe to be a novel investigation. Lesion volume has been shown to be a significant predictor for stroke outcome in general [27–29], but it is not known how it relates to swallow impairment after stroke.

2. Methods

We conducted a retrospective, cross-sectional, observational study on patients with first-ever unilateral ischemic strokes. This study was reviewed and approved by our Institutional Review Board.

2.1. Participants

We selected patients from a larger study of 68 patients with first-ever acute ischemic strokes admitted to the Medical University of South Carolina. Selection criteria were unilateral stroke and brain MRI followed by MBSS during the acute hospital stay. We excluded patients with a history of diseases with a high risk to affect swallow physiology, patients with documented neurological worsening between the MRI and MBSS, and patients younger than 21 years. We collected demographic and medical information from electronic medical records. We estimated the severity of comorbidities at hospital admission with the validated Charlson comorbidity index (CCI) [30] using its updated algorithm [31, 32].

2.2. Determination of lesion side and volume

All enrolled patients received a diffusion weighted MRI (DW-MRI) during their hospital stay on a Siemens 1.5T Intera scanner using a 12-channel head coil located at the Medical University of South Carolina. One rater (JW), trained in reading DW-MRIs of patients with strokes, manually drew all lesions using the software MRIcron and determined lesion locations and sides for all patients. A second rater (LB), a neurologist with special expertise in lesion symptom mapping analyses, checked all lesion maps for accuracy. The lesion maps were normalized into standard space and co-registered to the MNI 152 1 mm atlas to allow for comparisons of lesion locations across patients by creating a lesion overlay. We calculated the volume of the stroke lesion based on the number of voxels being outlined. Each voxel had a size of 1 mm × 1mm × 1mm and, therefore, the lesion volume was the number of lesioned voxels in cubic mm.

2.3. Modified Barium Swallow Study Measures

All patients received a MBSS during their hospital stay as standard of care. MBSSs were performed at 30 pulses per second and digitally recorded at 30 frames per second. All MBSSs followed the Modified Barium Swallow Impairment Profile (MBSImP™©) protocol that includes up to 11 different swallow tasks across up to 5 different bolus consistencies (thin liquid, nectar thick liquid, honey thick liquid, pudding, cookie) [33]. Barium sulfate suspensions were used as contrast agents in standardized preparations for different viscosities (VARIBAR®, E-Z-EM Canada Inc, Bracco Diagnostics Inc.).

The primary dependent variables were the 17 swallow components of the MBSImP; secondary dependent variables were MBSImP oral and pharyngeal total scores, aspiration/penetration events measured with the Penetration-Aspiration Scale (PAS) [34], 17 timing, 10 distance and area, and 2 hyoid speed measures (supplementary material 1). For all MBSImP components, oral and pharyngeal total scores, as well as for the PAS, higher scores indicate more severe impairment, and lower scores indicate less severe impairment. All measures were obtained during the first swallow in case of multiple swallows per bolus. We scored all MBSImP components and the PAS for each swallow separately and calculated an overall impression (OI) score that was the worst score across all swallow tasks for each of the 17 swallow components as well as for the PAS. Because timing, distance, area, and hyoid measures are known to vary by bolus volume [35, 36], we obtained those measures separately per bolus and only for the first and second teaspoons thin liquid, teaspoon nectar thick liquid and teaspoon pudding, because they were presented in standardized volumes (5ml bolus applications via a spoon). We controlled for the actual bolus volume “attempted” to be swallowed, and excluded swallows where the majority of the bolus remained in the oral cavity (scores of >2 for the MBSImP component 5 “oral residue”).

2.4. Reliability

Inter- and intra-rater reliability was established for all MBSS measures from 25% of all eligible patients. One rater (JW) rated all studies and re-rated 25% with at least two weeks in between to limit the chance of recall. A second rater (JH) rated the same 25% of MBSSs. For the PAS, inter-rater reliability was established for 100% of the patients. Reliability was estimated with two-way mixed intraclass coefficients (ICC), and for all ordinal measures with percent agreements and weighted Kappa coefficients. Following previous publications in dysphagia research [37, 38], we interpreted ICCs and Kappa coefficients as follows: <0.4 = poor, 0.4–0.75 = good, >0.75 excellent [39].

2.5. Statistical Analysis

Patients with left and right hemisphere strokes were compared using Pearson's Chi-Square tests for categorical variables and Wilcoxon rank-sum tests for ordinal or linear variables. Pearson or spearman correlation analyses were used to assess associations between variables. We interpreted the size of the correlation with $|r| < 0.3$ as weak, $0.3 \leq |r| < 0.5$ as moderate, and $|r| \geq 0.5$ as strong [40]. Simple logistic regression, linear, and logistic multivariable regression modeling were used to assess the relationship between variables. Control variables were age (known to affect swallow physiology [41–43]), lesion volume (known to affect stroke outcome in general [27–29]), and race (patients with left and right hemisphere strokes in our study showed nearing significant different distributions for race). P-values ≤0.05 were considered statistically significant. We corrected for multiple comparisons in our primary analysis of the 17 MBSImP components with Bonferroni corrections (alpha of 0.05/17 comparisons = 0.0029). Ordinal dependent variables (MBSImP components, PAS) were dichotomized for use in adjusted logistic regression models. MBSImP components were dichotomized based on MBSImP recommendations (score of "0" represents "not impaired" scores of >0 represent "impaired"; except for components 1, 5, 15 and 16 where scores of "0" or "1" represent "not impaired", and scores of >1 represent "impaired") [33, 44]. PAS scores of 1–2 represented normal and scores of >2 not normal [45].

For the MBSImP scores that were our primary dependent variables, we additionally performed patient-by-patient analyses to report individual scores.

We used SAS statistical software (version 9.4, released 2016, SAS Institute, Inc., Cary, N.C., USA) or IBM SPSS Statistics for Windows (version 24, released 2016, IBM Corp., Armonk, N.Y., USA) to conduct the analyses.

3. Results

3.1. Participants

We included in total 46 patients with unilateral strokes (22 left, 24 right) (Table 1). Patients with left and right unilateral brain lesions showed very similar demographic and medical characteristics. There were no statistically significant differences between patients with left and right hemisphere strokes for the tested variables.

Average lesion volume was 97ml for patients with left and 114ml for patients with right hemisphere strokes. Overall, brain regions that were most commonly lesioned were regions supplied by the middle cerebral artery with the highest number of patients showing lesions in the insula region and its adjacent areas of both hemispheres (Figure 1). In particular, the left external capsule, right external capsule, and right posterior insula, were most commonly lesioned across patients, thus had the highest number of patients showing a lesion in these areas.

3.2. Reliability

Reliability was established for 12 of the 46 patients (26%). Intra- and inter-rater reliability ranged from excellent to good across all measures for Kappa as well as ICC coefficients.

3.3. MBSImP oral total scores

3.3.1. Group-level analysis—There were no statistically significant differences between patients with left and right hemisphere strokes in their MBSImP oral total scores in unadjusted or adjusted comparisons (Table 2).

We compared the MBSImP oral total and pharyngeal total scores for each swallow type between patients with left and right hemisphere lesions to determine whether there are differences in impairment depending on the swallow type. In unadjusted analyses, patients with left and right hemisphere strokes had statistically significantly different oral total scores for pudding swallows but not for any other bolus consitencies. Patients with right hemisphere strokes had significantly higher mean oral total scores for pudding than patients with left hemisphere strokes (Wilcoxon-rank-sum test: p=0.05). After adjusting for age, race, and lesion volume in multivariable linear regression models, no significant differences were found in oral total scores for any swallow type.

3.3.2. Patient-level analysis—Each patient with a left and each patient with a right hemisphere stroke had, at least to some degree, oral impairment (supplementary material 2). Every patient with a left or right hemisphere stroke showed impairment for the majority of the six oral components, except for one left hemisphere stroke patient who only showed impairment for half of the components.

3.4. MBSImP pharyngeal total scores

3.4.1. Group-level analysis—In unadjusted analyses, patients with right hemisphere strokes showed significantly higher (worse) MBSImP pharyngeal total scores (Table 2). After controlling for age, race, and lesion volume in multivariable linear regression, the side of the lesion was significantly predictive for the MBSImP pharyngeal total score (p=0.02).

When analyzing differences related to bolus consistencies, patients with right hemisphere strokes had significantly higher pharyngeal total scores for the overall impression scores of thin liquid swallows (p=0.02) and for overall impression scores of nectar thick liquid swallows (p=0.008), but not for honey thick liquid or pudding swallows. The comparisons for thin and nectar thick liquid swallows remained significant after adjusting for age, race, and lesion volume.

3.4.2. Patient-level analysis—The group-level analysis suggested that patients with right hemisphere strokes show overall worse pharyngeal impairment than patients with left hemisphere strokes. The patient-level analysis showed a few patients with an opposite pattern of pharyngeal impairment scores: four of 22 patients with left hemisphere strokes showed higher (worse) pharyngeal total scores than the median pharyngeal total score of all patients with right hemisphere strokes (Figure 2). Seven of 24 patients with right hemisphere strokes showed lower (better) pharyngeal total scores than the median pharyngeal total score of all patients with left hemisphere strokes (Figure 2).

3.5. MBSImP component scores

In unadjusted analyses, three components showed significant differences between patients with left- and right-hemisphere lesions: component 8 (laryngeal elevation): p=0.0084; component 11 (laryngeal vestibular closure): p=0.0025; and component 16 (pharyngeal residue): p= 0.0252 (Figure 3). For all three components, patients with lesions in the right hemisphere had higher, thus, worse scores than patients with lesions in the left hemisphere. However, only component 11 (laryngeal vestibular closure) remained significant at the Bonferroni adjusted alpha of p≤0.0029.

After controlling for age, lesion volume, and race in multivariable regression modeling, patients with right hemisphere unilateral strokes showed 11-fold higher risks for reduced (partial, minimal, or no) laryngeal elevation, 6-fold higher risks for reduced (incomplete or none) laryngeal vestibular closure, and 11-fold higher risks for more than just trace pharyngeal residue (Figure 4).

3.6. Association between lesion volume and MBSImP scores

MBSImP oral total scores did not correlate with lesion volume, but MBSImP pharyngeal total scores showed a weak to moderate negative correlation (Spearman: correlation coefficient: −0.302, p=0.041; Pearson: correlation coefficient: −0.314, p=0.033). Only one of the 17 MBSImP components correlated with total lesion volume, component 16 “pharyngeal residue” that showed a weak to moderate negative correlation (Spearman: correlation coefficient: −0.319, p=0.031; Pearson: correlation coefficient: −0.319, p=0.031).

3.7. Penetration-Aspiration Scale

In unadjusted analyses, patients with right hemisphere strokes showed significantly higher PAS scores (median 5, range 1–8) compared to patients with left hemisphere strokes (median 2, range 1–8) (p=0.03). No significant differences in PAS scores were present after controlling for age, lesion volume, and race. Total lesion volume did not correlate with PAS scores.

3.8. Timing measures

When we excluded swallows where the majority of the bolus remained in the oral cavity (scores of >2 for the MBSImP component 5 “oral residue”), only velopharyngeal closure duration for teaspoon nectar (p=0.03) was statistically significant with patients with right hemisphere strokes showing longer velopharyngeal closure duration than patients with left hemisphere strokes. When we included all swallows – independent of the bolus amount that remained in the oral cavity – pharyngeal transit time and hyopharyngeal transit time for the teaspoon pudding swallow were significantly longer in patients with right hemispheric strokse compared to patients with left hemispheric strokes (p=0.04, for both) (supplementary material 3). After controlling for age, race, and lesion volume in a liner multivariable regression model, pharyngeal transit time, hypopharyngeal transit time, pharyngeal delay time, and stage transition duration were significantly longer (p≤0.05) in patients with right compared to left hemispheric strokes for swallowing one teaspoon of pudding.

3.9. Distance and area measures

When we excluded swallows where the majority of the bolus remained in the oral cavity, only hyoid excursion (in reference to the mandible) for a pudding swallow was significant in adjusted and unadjusted modeling, with patients with right hemisphere strokes showed significantly less hyoid excursion than patients with left hemisphere strokes (p=0.01 in unadjusted and adjusted analyses). When we included all swallows – independent of the bolus amount remaining in the oral cavity – there were no additional measures that showed significant differences between patients with left and right hemisphere strokes (supplementary material 4).

3.10. Hyoid speed measures

In unadjusted analyses, hyoid speed (in reference to mandible) for one teaspoon pudding swallow was significantly slower for patients with right hemisphere strokes compared to patients with left hemisphere strokes (p=0.03). This was also the case after controlling for confounders (p=0.01).

4. Discussion

We aimed to compare the swallow physiology of patients with left and right unilateral stroke lesions with the objective to determine differences in swallow impairment. We employed a broad array of swallow physiology measures to determine differences related to stroke lateralization.

4.1. MBSImP oral total scores

Both patients with left and right hemisphere strokes showed impaired oral swallow physiology with no significant differences in severity for overall impression calculated across all swallows. However, looking at separate bolus consistencies, we found that patients with right compared to left hemisphere strokes showed significantly worse oral total scores for pudding swallows in unadjusted analyses. The observation of no difference in oral swallowing impairment between patients with left and right hemisphere strokes, is in line with some [20] and contradictory to other studies that suggest more severe oral impairment in patients with left hemisphere strokes [13–17, 21, 22]. Our finding of worse oral swallow impairment in pudding swallows underlines the importance of detailed evaluations of swallowing physiology of different types of boluses in clinical practice and research, because pooling or averaging across swallow types may mask differences. It remains speculative why patients with right hemisphere strokes had worse oral swallow impairment scores for pudding swallows but not for other consistencies when compared to patients with left hemisphere strokes. Perhaps, patients with right hemisphere strokes are less capable of producing the necessary strength to transport and clear a pudding bolus out of the oral cavity.

4.2. MBSImP pharyngeal total scores

Both patients with left and right hemisphere strokes showed pharyngeal impairment, but patients with right hemisphere strokes showed worse pharyngeal impairment than patients with left hemisphere strokes. This is in line with results from previous [12–14, 46] and contradictory to other studies [15, 24, 25]. The observed differences occurred especially in thin and nectar thick liquid swallows, where patients with right hemisphere strokes showed worse pharyngeal impairment than patients with left hemisphere strokes. Thin and nectar thick liquid consistencies are fast flowing and require a rapid pharyngeal response to achieve a safe and efficient transport into the esophagus. This suggests that patients with right hemisphere strokes might be especially challenged with fast pharyngeal adaptions. This finding may be helpful for clinicians determining oral diet recommendations.

When we compared these group-level results with patient-level data, we found that some patients showed an opposite pattern. About 20% of patients with left hemisphere strokes showed notable pharyngeal impairment that was worse than the average of patients with right hemisphere strokes, and about 30% of patients with right hemisphere strokes showed only little pharyngeal impairment with less severity than the average of patients with left hemisphere strokes. It could be speculated that the observed differences in pharyngeal impairment are a function of stroke severity instead of lesion side. Thus, we assessed the predictive ability of NIHSS scores for pharyngeal impairment using regression modeling and found no significant association. Therefore, in our patient cohort a minority of patients were exceptions to the observation that patients with right hemisphere strokes have worse pharyngeal impairment than patients with left hemisphere strokes. Hereby, our study highlights that differences in swallow impairment between patients with left and right hemisphere strokes seem consistent at the group-level but might not hold true at the patient-level.

4.3. MBSImP component scores

On a component-level, patients with left hemisphere strokes showed, on average, normal swallow physiology (scores of “0”) for the MBSImP components 7 (soft palate elevation), 10 (epiglottis movement), 11 (laryngeal vestibular closure), 12 (pharyngeal stripping wave), and 13 (pharyngeal contraction), whereas patients with right hemisphere strokes only showed, on average, normal swallow physiology for components 7 (soft palate elevation) and 13 (pharyngeal contraction). It needs to be noted that component 13 (pharyngeal contraction) was not assessable for 18 of 46 patients (39%), because of limited patient compliance that hindered the evaluation of swallows in the posterior-anterior projection. Thus, it is likely that patients with more severe clinical presentations were not included in the assessment of pharyngeal contraction. Lesions in both hemispheres were associated with oral and pharyngeal swallow impairment, but patients with right hemisphere strokes showed impairment in notably more pharyngeal swallow components, which is in line with previous research.

When comparing the component scores of patients with left and right hemisphere strokes in adjusted analyses, we found that patients with right hemisphere strokes had substantially, 6- to 11-fold, higher risks than patients with left hemisphere strokes for reduced laryngeal elevation, reduced laryngeal vestibular closure and more than just trace pharyngeal residue. These findings underline the clinically important impact of stroke lateralization on swallowing safety as well as efficacy.

4.4. Association between lesion volume and MBSImP

In our study, total lesion volume was not associated with any individual physiological swallow impairments. The only associations found for lesion volume were with pharyngeal residue and pharyngeal total scores. Interestingly, the associations were negative, meaning that smaller lesions were associated with more pharyngeal residue and worse pharyngeal total scores. These findings emphasize that clinicians should be cautious to draw inferences from the size of a lesion to the presence of swallow impairment or dysphagia in general. Several patients in our study had small lesions with a size of less than 5ml and presented with profound oral and/or pharyngeal impairment. Previous research has shown that lesion site is a crucial factor for the occurrence of post-stroke dysphagia [47, 48] and, further, our ongoing research has shown that the lesion site is a significant predictor for impairment in swallow physiology independently of the lesion volume [49].

4.5. Penetration-Aspiration Scale

In unadjusted, univariate analyses, patients with right hemisphere strokes showed worse penetration-aspiration scores than patients with left hemisphere strokes. However, differences were not statistically significant after controlling for confounders. This seems to be reflective of previous evidence stating higher risks of penetration/aspiration in patients with right hemisphere strokes [13, 14, 17, 21] as well as equal risks between patients with left and right hemisphere strokes [5, 23–25]. Thus, our study underlines that – in general – patients with right hemisphere strokes seem to be at higher risk for airway invasion of bolus material, however, if group differences beyond lesion side (e.g. age, lesion volume, race) are taken into account, differences might be negligible. Moreover, our results emphasize the importance of looking beyond airway invasion measures (PAS) to profile patterns of impairment in stroke patients.

4.6. Timing, distance and area measures

Only very few timing, distance, area, and speed measures showed differences between patients with left and right hemisphere strokes. For those that were different, we found a similar pattern as seen with the MBSImP scores: patients with right hemisphere strokes showed more severely impaired swallow physiology than patients with left hemisphere strokes. The asymmetry in the severity of swallow impairment as measured by timing, distance, area, and speed measures was overall very consistent between patients with left and right hemisphere strokes. Patients with left hemisphere strokes rarely showed more severely impaired swallow physiology than patients with right hemisphere strokes.

When combining the results from the MBSImP, PAS, timing, distance, area, and speed measures, we found differences between patients with left and right unilateral strokes predominantly for hyoid and laryngeal swallow movements. Interestingly, May et al. (2016) compared swallow mechanics of patients with left and right hemisphere strokes and also found differences especially for the larynx position and movement [46]. Findings from studies like May et al. and ours may explain the higher penetration and aspiration scores in patients with right hemisphere strokes. Further, a lateralization of hyo-laryngeal impairment in conjunction with higher risks for penetration and aspiration might also explain observations of studies reporting increased risks for pneumonia in patients with right hemisphere lesions compared to other lesion locations [50, 51].

4.7. Limitations

The limited sample size of 46 patients may have only let us reveal the most robust relationships and obscured other relationships. Also, not all patients received all boluses during the MBSS what potentially further decreased the statistical power. Thus, the detected differences in swallow physiology between patients with left and right hemisphere strokes can be interpreted as robust, whereas lack of statistical significance should be interpreted cautiously and require further investigations with a larger sample size. Further, the majority of our swallow measures describe pharyngeal swallow physiology (e.g., only 1 out of 17 timing measures captured oral swallow physiology). Thus, the key findings in regard to pharyngeal impairments and lack of findings in regard to oral impairments might be biased by the imbalance of available/applied measures of oral impairment. Moreover, the interpretation of our results needs to account for a possible selection bias because we only included patients with a MBSS and, thus, our study cohort is not representative of patients with strokes in general.

5. Clinical Implications

Clinicians should anticipate more severe pharyngeal swallow impairment in patients with right compared to left hemisphere strokes with higher risks for penetration, aspiration, and pharyngeal residue. Further, patients with right hemisphere strokes might especially benefit from early swallow rehabilitation focusing on hyo-laryngeal movement during swallowing.

6. Conclusions

Our study confirms that both patients with left and right, unilateral strokes may exhibit oral and/or pharyngeal swallow impairment, but patients with right hemisphere strokes showed worse pharyngeal impairment, especially in terms of hyo-laryngeal physiology. Differences were limited to a few aspects of swallow physiology measures and group results (left vs right) did not hold true for all individual patients. Results from the study presented here, suggest that simply using lesion size or pooling lesion locations within hemispheres, might assist in predicting overall pharyngeal impairment but might not provide sufficient information to predict detailed impairment of swallow physiology after stroke. Future studies should address the information yield of precise lesion and residual brain information, (e.g. detailed lesion locations), remaining neural networks outside the lesion), as well as other factors that particularly contribute to swallow physiology in stroke survivors.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Acknowledgement/Funding / Grants

The project described was supported in part by the NIH National Center for Advancing Translational Sciences (NCATS) through Grant Number UL1 TR001450, SCTR Pilot Project 17254, and the NIH/NIDCD through Grant Number 1K24DC12801. We would like to thank the Center for Biomedical Research Excellence (COBRE) in Stroke Recovery at the Medical University of South Carolina (MUSC) in Charleston, South Carolina who provided resources for patient identification and recruitment (Grant Number 5P20GM109040).

References

1. Lear CS, Flanagan JB Jr, Moorrees CF. THE FREQUENCY OF DEGLUTITION IN MAN. Archives of oral biology. 1965; 10:83–100. [PubMed: 14262163]
2. 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]
3. Shaw SM, Martino R. The normal swallow: muscular and neurophysiological control. Otolaryngologic clinics of North America. 2013; 46:937–56. [PubMed: 24262952]
4. Leopold NA, Daniels SK. Supranuclear control of swallowing. Dysphagia. 2010; 25:250–7. [PubMed: 19730940]
5. Daniels SK, Foundas AL. Lesion localization in acute stroke patients with risk of aspiration. J Neuroimaging. 1999; 9(2):91–8. [PubMed: 10208106]
6. Martino R, Foley N, Bhogal S, Diamant N, Speechley M, Teasell R. Dysphagia after stroke: incidence, diagnosis, and pulmonary complications. Stroke. 2005; 36:2756–63. [PubMed: 16269630]
7. Tao WD, Liu M, Fisher M, Wang DR, Li J, Furie KL, et al. Posterior versus anterior circulation infarction: how different are the neurological deficits? Stroke. 2012; 43:2060–5. [PubMed: 22678088]
8. Hamdy S. The cortical topography of human swallowing musculature in health and disease. Nature Med. 1996; 2(11):1217–24. [PubMed: 8898748]
9. Teismann IK, Dziewas R, Steinstraeter O, Pantev C. Time-dependent hemispheric shift of the cortical control of volitional swallowing. Human brain mapping. 2009; 30:92–100. [PubMed: 17979116]
10. Mosier KM, Liu WC, Maldjian JA, Shah R, Modi B. Lateralization of cortical function in swallowing: a functional MR imaging study. AJNR. American journal of neuroradiology. 1999; 20:1520–6. [PubMed: 10512240]
11. Daniels SK, Corey DM, Barnes CL, Faucheaux NM, Priestly DH, Foundas AL. Cortical representation of swallowing: a modified dual task paradigm. Percept Mot Skills. 2002; 94:1029–40. [PubMed: 12081263]
12. Daniels SK, Foundas AL, Iglesia GC. Lesion site in unilateral stroke patients with dysphagia. J Stroke Cerebrovasc Dis. 1996; 6:30–4. [PubMed: 17894962]
13. Robbins J. Swallowing after unilateral stroke of the cerebral cortex. Arch Phys Med Rehabil. 1993; 74(12):1295–300. [PubMed: 8259895]
14. Robbins J, Levin RL. Swallowing after unilateral stroke of the cerebral cortex: preliminary experience. Dysphagia. 1988; 3(1):11–7. [PubMed: 3248391]
15. Li S, Luo C, Yu B, Yan B, Gong Q, He C, et al. Functional magnetic resonance imaging study on dysphagia after unilateral hemispheric stroke: a preliminary study. Journal of neurology, neurosurgery, and psychiatry. 2009; 80:1320–9.

16. Cola MG, Daniels SK, Corey DM, Lemen LC, Romero M, Foundas AL. Relevance of subcortical stroke in dysphagia. Stroke. 2010; 41:482–6. [PubMed: 20093638]
17. Suntrup S, Kemmling A, Warnecke T, Hamacher C, Oelenberg S, Niederstadt T, et al. The impact of lesion location on dysphagia incidence, pattern and complications in acute stroke. Part 1: Dysphagia incidence, severity and aspiration. European journal of neurology. 2015
18. Daniels SK, Foundas AL, Iglesia GC, Sullivan MA. Lesion site in unilateral stroke patients with dysphagia. J Stroke Cerebrovasc Dis. 1996; 6:30–4. [PubMed: 17894962]
19. Martin R. Cerebral cortical representation of automatic and volitional swallowing in humans. J Neurophysiol. 2001; 85(2):938–50. [PubMed: 11160524]
20. Daniels SK, Brailey K, Foundas AL. Lingual discoordination and dysphagia following acute stroke: analyses of lesion localization. Dysphagia. 1999; 14:85–92. [PubMed: 10028038]
21. Smithard DG, O'Neill PA, Martin DF, England R. Aspiration following stroke: is it related to the side of the stroke? Clin Rehabil. 1997; 11:73–6. [PubMed: 9065363]
22. Saito T, Hayashi K, Nakazawa H, Ota T. Clinical Characteristics and Lesions Responsible for Swallowing Hesitation After Acute Cerebral Infarction. Dysphagia. 2016
23. Galovic M, Leisi N, Muller M, Weber J, Abela E, Kagi G, et al. Lesion location predicts transient and extended risk of aspiration after supratentorial ischemic stroke. Stroke. 2013; 44:2760–7. [PubMed: 23887840]
24. Jeon WH, Park GW, Lee JH, Jeong HJ, Sim YJ. Association between Location of Brain Lesion and Clinical Factors and Findings of Videofluoroscopic Swallowing Study in Subacute Stroke Patients. Brain & Neurorehabilitation. 2014; 7:54.
25. Daniels SK, Pathak S, Mukhi SV, Stach CB, Morgan RO, Anderson JA. The Relationship Between Lesion Localization and Dysphagia in Acute Stroke. Dysphagia. 2017
26. Malandraki GA, Sutton BP, Perlman AL, Karampinos DC. Age-related differences in laterality of cortical activations in swallowing. Dysphagia. 2010; 25:238–49. [PubMed: 19760457]
27. Wu O, Cloonan L, Mocking SJ, Bouts MJ, Copen WA, Cougo-Pinto PT, et al. Role of Acute Lesion Topography in Initial Ischemic Stroke Severity and Long-Term Functional Outcomes. Stroke. 2015; 46:2438–44. [PubMed: 26199314]
28. Yassi N, Churilov L, Campbell BC, Sharma G, Bammer R, Desmond PM, et al. The association between lesion location and functional outcome after ischemic stroke. Int J Stroke. 2015; 10:1270–6. [PubMed: 26045301]
29. Hope TM, Seghier ML, Leff AP, Price CJ. Predicting outcome and recovery after stroke with lesions extracted from MRI images. NeuroImage. Clinical. 2013; 2:424–33. [PubMed: 24179796]
30. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis. 1987; 40:373–83. [PubMed: 3558716]
31. Quan H, Li B, Couris CM, Fushimi K, Graham P, Hider P, et al. Updating and validating the Charlson comorbidity index and score for risk adjustment in hospital discharge abstracts using data from 6 countries. Am J Epidemiol. 2011; 173:676–82. [PubMed: 21330339]
32. Quan H, Sundararajan V, Halfon P, Fong A, Burnand B, Luthi JC, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. Med Care. 2005; 43:1130–9. [PubMed: 16224307]
33. Martin-Harris B, Brodsky MB, Michel Y, Castell DO, Schleicher M, Sandidge J, et al. MBS measurement tool for swallow impairment--MBSImp: establishing a standard. Dysphagia. 2008; 23:392–405. [PubMed: 18855050]
34. Rosenbek JC, Robbins JA, Roecker EB, Coyle JL, Wood JL. A penetration-aspiration scale. Dysphagia. 1996; 11:93–8. [PubMed: 8721066]
35. Molfenter SM, Steele CM. Temporal variability in the deglutition literature. Dysphagia. 2012; 27:162–77. [PubMed: 22366761]
36. Molfenter SM, Steele CM. Physiological Variability in the Deglutition Literature: Hyoid and Laryngeal Kinematics. Dysphagia. 2011; 26:67–74. [PubMed: 20927634]
37. Molfenter SM, Amin MR, Branski RC, Brumm JD, Hagiwara M, Roof SA, et al. Age-Related Changes in Pharyngeal Lumen Size: A Retrospective MRI Analysis. Dysphagia. 2015; 30:321–7. [PubMed: 25750039]

38. Muss L, Wilmskoetter J, Richter K, Fix C, Stanschus S, Pitzen T, et al. Changes in Swallowing After Anterior Cervical Discectomy and Fusion With Instrumentation: A Presurgical Versus Postsurgical Videofluoroscopic Comparison. Journal of speech, language, and hearing research : JSLHR. 2017:1–9.
39. FleissJL. The design and analysis of clinical experimentsNew York, NY: Wikey; 1986
40. CohenJ. Statistical power analysis for the behavioral sciences2. Hillsdale, NJ: Lawrence Erlbaum; 1988
41. Humbert IA, Fitzgerald ME, McLaren DG, Johnson S, Porcaro E, Kosmatka K, et al. Neurophysiology of swallowing: effects of age and bolus type. Neuroimage. 2009; 44:982–91. [PubMed: 19010424]
42. Logemann JA, Pauloski BR, Rademaker AW, Colangelo LA, Kahrilas PJ, Smith CH. Temporal and biomechanical characteristics of oropharyngeal swallow in younger and older men. Journal of speech, language, and hearing research : JSLHR. 2000; 43:1264–74.
43. Rademaker AW, Pauloski BR, Colangelo LA, Logemann JA. Age and volume effects on liquid swallowing function in normal women. Journal of speech, language, and hearing research : JSLHR. 1998; 41:275–84.
44. Northern Speech Services. Modified Barium Swallow Impairment Profile. 2010
45. Steele CM, Grace-Martin K. Reflections on Clinical and Statistical Use of the Penetration-Aspiration Scale. Dysphagia. 2017
46. May NH, Pisegna JM, Marchina S, Langmore SE, Kumar S, Pearson WG Jr. Pharyngeal Swallowing Mechanics Secondary to Hemispheric Stroke. J Stroke Cerebrovasc Dis. 2016
47. Gonzalez-Fernandez M, Kleinman JT, Ky PK, Palmer JB, Hillis AE. Supratentorial regions of acute ischemia associated with clinically important swallowing disorders: a pilot study. Stroke. 2008; 39:3022–8. [PubMed: 18688014]
48. Flowers HL, AlHarbi MA, Mikulis D, Silver FL, Rochon E, Streiner D, et al. MRI-Based Neuroanatomical Predictors of Dysphagia, Dysarthria, and Aphasia in Patients with First Acute Ischemic Stroke. Cerebrovasc Dis Extra. 2017; 7:21–34. [PubMed: 28208139]
49. WilmskoetterJ, , Martin-HarrisB, , BonilhaL, , ElmJ, , CucciareJ, , BonilhaH. 26th Annual Meeting Dysphagia Research SocietyBaltimore (MD): 2018Mapping acute lesion locations to physiological swallow impairments after stroke.
50. Kemmling A, Lev MH, Payabvash S, Betensky RA, Qian J, Masrur S, et al. Hospital acquired pneumonia is linked to right hemispheric peri-insular stroke. PloS one. 2013; 8:e71141. [PubMed: 23951094]
51. Teasell RW, McRae M, Marchuk Y, Finestone HM. Pneumonia associated with aspiration following stroke. Archives of Physical Medicine and Rehabilitation. 1996; 77:707–9. [PubMed: 8669999]

Author Manuscript
Author Manuscript
Author Manuscript

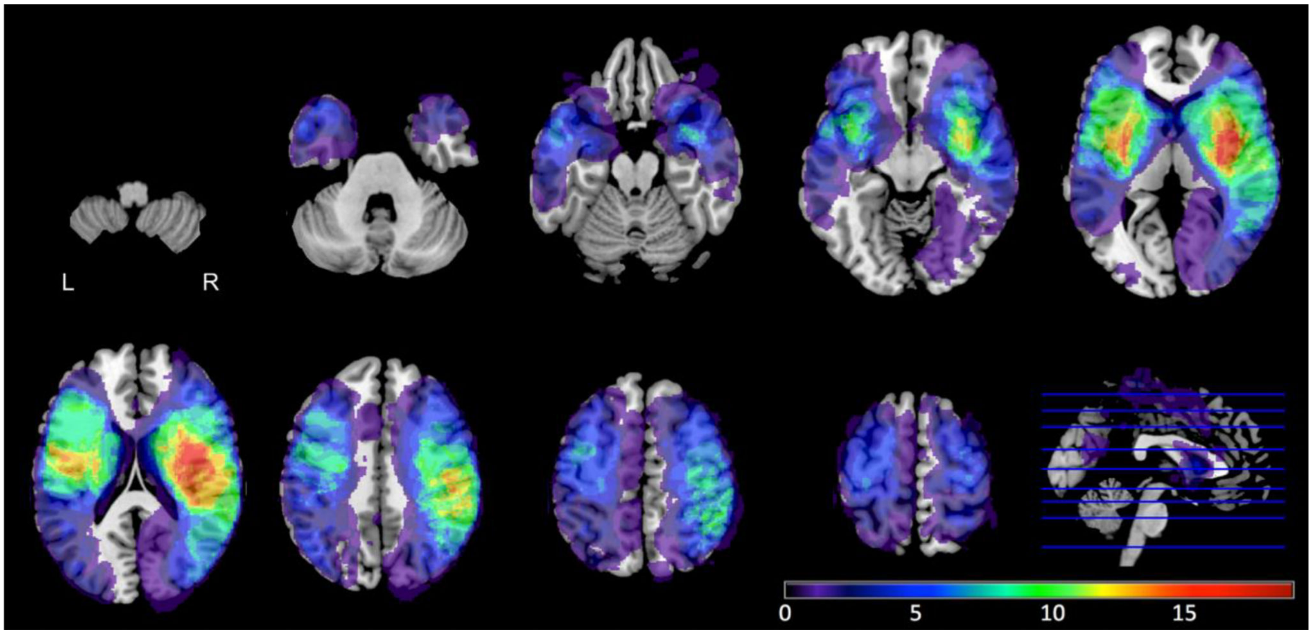

Figure 1.

Lesion overlap of all included patients with unilateral hemisphere strokes (N=46). Colors represent numbers of patients with lesions in that area. For example, 18 of 24 patients with left and 20 of 22 patients with right hemisphere strokes had a lesion in the putamen. L=left hemisphere, R=right hemisphere.

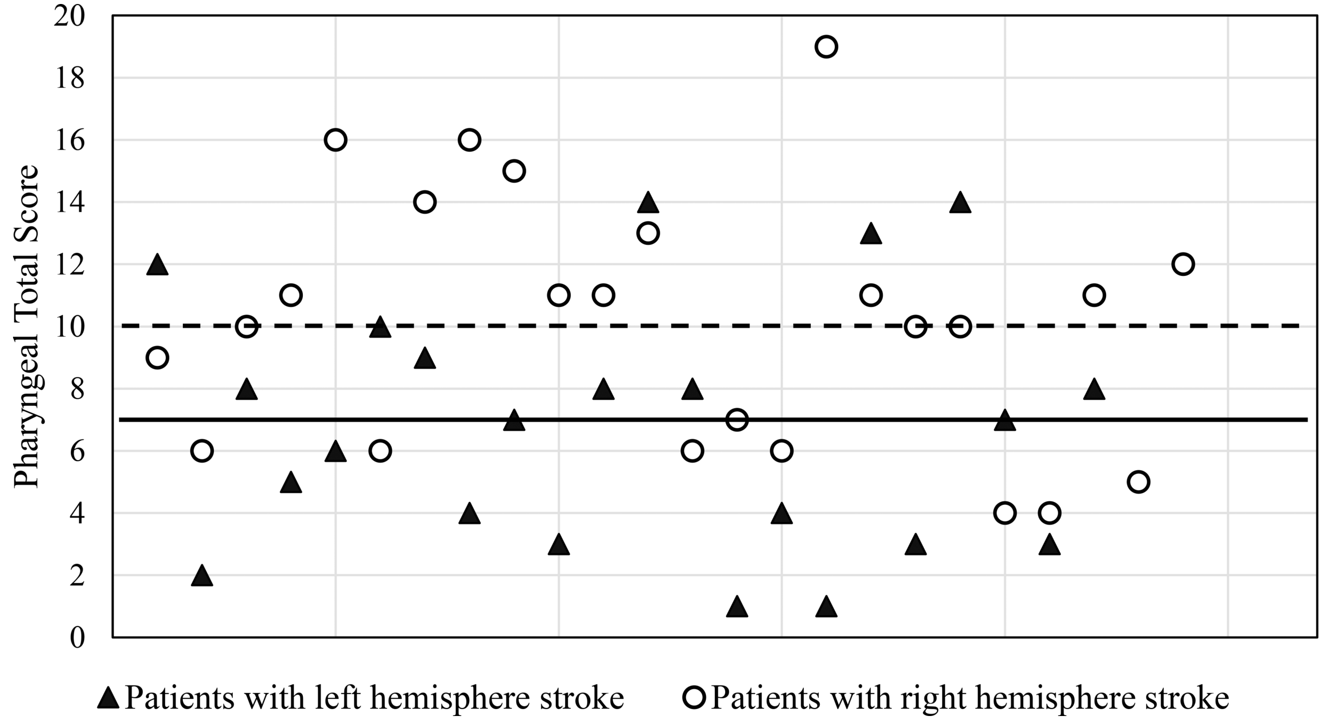

Figure 2.

Pharyngeal total scores of all patients with left and right hemisphere strokes (triangles and circles represent one patient; full line = median pharyngeal total score (=7) of all patients with left hemisphere strokes; dashed line = median pharyngeal total score (=10) of all patients with right hemisphere strokes).

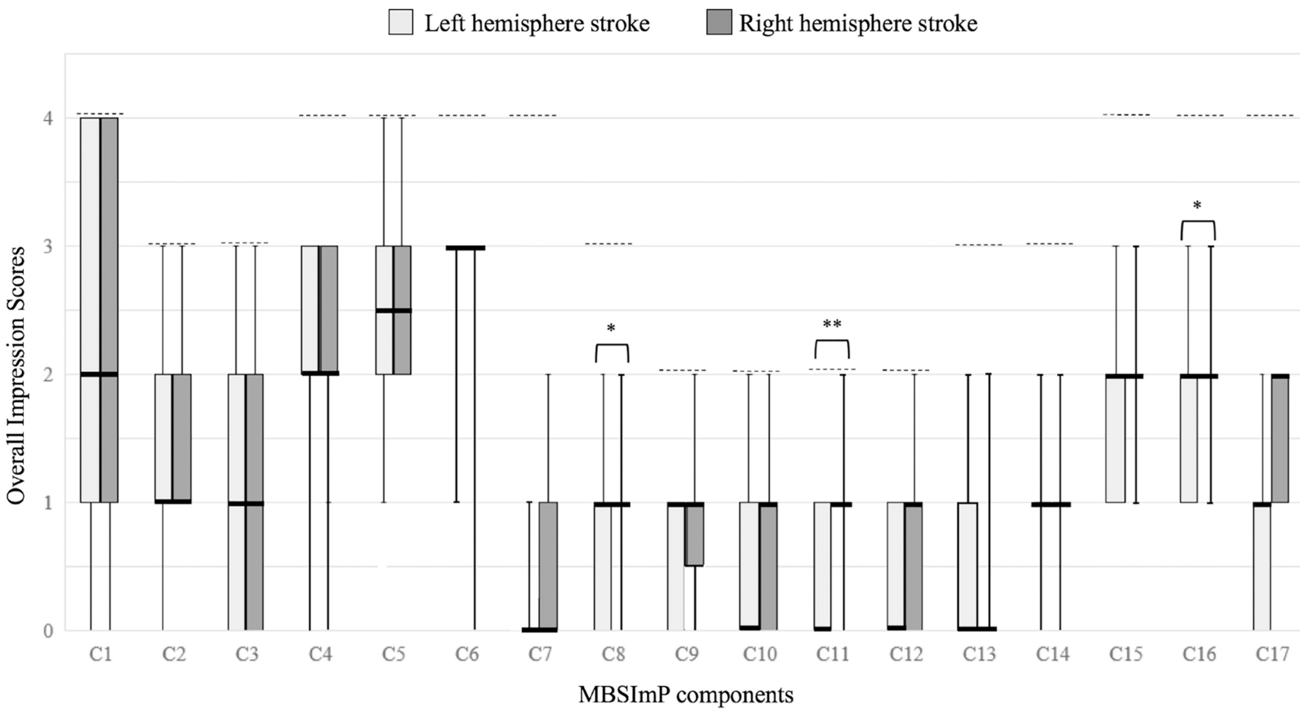

Figure 3.

Box plots for each MBSImP component comparing patients with left (light grey) and right (dark grey) unilateral hemisphere lesions (fat horizontal lines: median, box borders: 1st and 3rd quartile, end of whiskers: minimum and maximum value, dashed lines: maximum possible component value, ** : Bonferroni adjusted alpha of p≤0.0029, * : unadjusted alpha of p≤0.05 (two-sided Wilcoxon test)

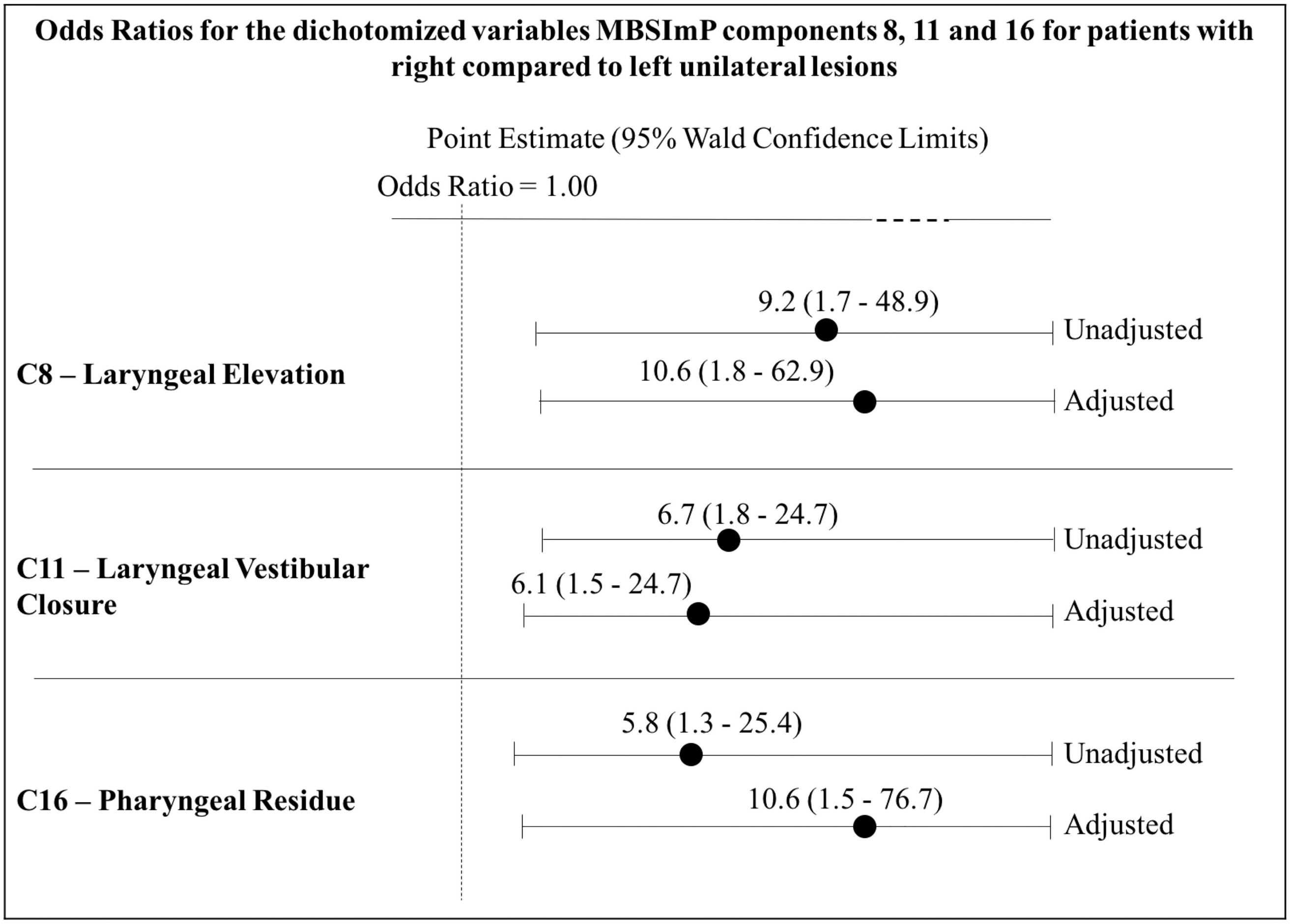

Figure 4.

Unadjusted and adjusted odds ratios for MBSImP components 8, 11, and 16 for patients with right compared to left unilateral lesions. Unadjusted: simple logistic regression with lesion side as primary predictor; adjusted: multivariable logistic regression with lesion side as primary predictor and race, age, and lesion volume as control variables.

Table 1

Demographic and medical characteristics for patients with left and right unilateral brain lesions.

		Left (N=22)	Right (N=24)	Statistical difference p-value
Demographical information				
Age, mean (SD; range)		68.18 (14.98; 44–93)	66.83 (16.55; 28–95)	0.89†
Gender, N (%)	Female	12 (55)	11 (46)	0.56*
	Male	10 (45)	13 (54)	
Race, N (%)	White or Caucasian	12 (55)	19 (79)	0.08*
	Black or African-American	10 (45)	5 (21)	
Ethnicity, N (%)	Not Hispanic or Latino	22 (100)	24 (100)	NA
	Hispanic or Latino	0 (0)	0 (0)	
Status at hospital admission and stroke characteristics				
National Institute of Health Stroke Scale, N, mean (SD; range)		N=22, 15.14 (6.59; 1–26)	N=22, 11.55 (6.01; 0–21)	0.07†
Modified Rankin Scale, N, median (range)		N=18, 0 (0–4)	N=15, 0 (0–1)	0.97†
Charlson Comorbidity Index, mean (SD; range)		0.95 (1.36; 0–6)	0.95 (1.36; 0–6)	0.97†
Lesion volume (in ml / cc), mean (SD; range)		96.99 (89.77; 1.22–360.72)	113.88 (119.64; 0.21–337.29)	0.94†
Hospital course				
Length of hospital stay, mean (SD; range)		12.64 (18.72; 2–90)	12.50 (8.90; 3–36)	0.24†
Tissue plasminogen activator N(%)		9 (41)	13 (54)	0.66*
Thrombectomy, N(%)		6 (28)	8 (33)	0.66*
Intubation, N(%)		3 (14)	4 (17)	0.78*
	Days of intubation, mean (SD; range)	4.33 (2.52; 2–7)	7.5 (1.73; 6–9)	0.10†
Tracheotomy, N (%)		1 (5)	2 (8)	0.60*
Percutaneous endoscopic gastrostomy, N (%)		4 (18)	6 (25)	0.58*
Functional oral intake scale (FOIS) during hospital stay				
FOIS at 1st SLP encounter, N, median (range)		N=20, 1 (1–5)	N=22, 1 (1–7)	0.29†
FOIS at last SLP encounter, N, median (range)		N=19, 5 (1–5)	N=20, 5 (1–7)	0.17†
Time line of MRI and MBSS				
Days between hospital admission and MRI, mean (SD; range)		2.00 (3.13; 0–14)	2.38 (3.65; 0–17)	0.75†
Days between hospital admission and MBSS, mean (SD; range)		4.14 (3.31; 0–16)	6.42 (6.78; 0–23)	0.71†
Days between MRI and MBSS, mean (SD; range)		2.09 (2.16; 0–9)	3.89 (5.58; 0–20)	0.84†

*Chi-Square Test;

†two-tailed Wilcoxon-Rank-Sum-Test, NA=not applicable, SLP=Speech and Language Pathologist

Table 2

MBSImP total scores and PAS scores for patients with left and right hemisphere strokes.

Variable	Left (N=22) Median (range)	Right (N=24) Median (range)	Statistical difference	
			Unadjusted p-value	Adjusted p-value
MBSImP Oral Total	12 (6–17)	11.5 (7–18)	0.94*	0.64†
MBSImP Pharyngeal Total	7 (1–14)	10 (0–19)	0.02*	0.02†

*two-tailed Wilcoxon-Rank-Sum-Test;

†Linear Regression (adjusted for age, race, and lesion volume)