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ORIGINAL ARTICLE

The Relationship Between Leukoaraiosis Involving Contralateral Corticobulbar Tract and Dysphagia in Patients with Acute Unilateral Corona Radiata Infarction with Corticobulbar Tract Involvement

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Abstract

This study investigated the impact of leukoaraiosis (LA) involving the contralateral corticobulbar tract (CBT) on dysphagia in patients with unilateral corona radiata (CR) infarction with CBT involvement. Patients admitted to the Department of Neurology (September 2011–August 2014) were evaluated; those with a first episode of acute unilateral CR infarction involving the CBT and with LA were included. The 'Case' group comprised patients with LA involving the contralateral CBT; the 'Control' group comprised patients with LA not involving the contralateral CBT. The primary outcome was the feeding method at discharge; secondary outcomes were the feeding method at admission and results of the bedside swallowing test, videofluoroscopic swallowing study (VFSS), videofluoroscopic dysphagia scale, penetration–aspiration scale, American Speech–Language–Hearing Association National Outcome Measurement System Swallowing Scale (ASHA NOMS), oral transit time, and pharyngeal transit time. Infarct size was measured using brain magnetic resonance imaging; LA severity was rated using the Fazekas scale. Eighty-one patients were included (mean age 64.6 ± 11.5 years; 64% male; Case group: 20, 5 underwent VFSS; Control group: 67, 11 underwent VFSS). The Case group was older and had higher total Fazekas scale score than the Control group. The feeding method at discharge and ASHA NOMS score were significantly worse in the Case group than in the Control group. Multivariate analysis revealed that LA involving the contralateral CBT independently predicted the feeding method at discharge and ASHA NOMS score. In conclusion, LA involving the contralateral CBT is associated with dysphagia in patients with unilateral CR infarction involving the CBT.

Keywords Pyramidal tracts · Leukoaraiosis · Deglutition disorders · Infarction · Neuroimaging

Introduction

Dysphagia is a common functional impairment associated with acute stroke, affecting up to 50% of patients [1]. Although the condition resolves within 7 days in approximately half of all patients with stroke, 11–13% have persistent swallowing dysfunction after 6 months [2]. Dysphagia is associated with pulmonary aspiration and pneumonia, as well as with malnutrition and dehydration [3].

The corticobulbar tract (CBT) plays an important role in swallowing. It passes the precentral gyrus at the lower quarter of the motor cortex, corona radiata (CR) just anterior to corticospinal tract (CST) fibers, posterior limb of the internal capsule just anterior and medial to the CST fibers, cerebral peduncles just medial to the CST fibers, and motor nuclei of cranial nerves in the midbrain, pons, and medulla. The CBT from one side of the brain projects to the motor nuclei on both sides of the brainstem; therefore, it is considered that CBT impairment in only one side could preserve swallowing function due to the presence of the unimpaired contralateral tract.

Some patients already have leukoaraiosis (LA) before they develop stroke. On T2-weighted magnetic resonance imaging (MRI), LA appears as hyperintense lesions in the

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cerebral white matter [4]. Advancing age and hypertension are the greatest risk factors for the development of LA [5]. Previous studies have suggested that LA is also related to post-stroke dysphagia [6] and that it is an independent predictor of stroke-associated pneumonia [7]. However, these studies did not consider the involvement of the CBT in LA, which is a crucial tract involved in swallowing. Therefore, the aim of the present study was to investigate the relationship between the presence of LA involving the contralateral CBT and dysphagia in patients with unilateral CR infarction with CBT involvement.

Methods

Study Design and Participants

The study involved a retrospective evaluation of data from patients admitted to the Department of Neurology, Asan Medical Center, from September 2011 to August 2014. Patients were included if they met the following criteria: (1) first unilateral ischemic stroke within 7 days of onset, (2) objective lesions in the CR identified on brain MRI, (3) brain lesions involving the CBT identified on brain MRI, and (4) LA identified on brain MRI. The exclusion criteria were as follows: (1) prior cerebrovascular disease, (2) preexisting dysphagia, (3) preexisting neurological or psychiatric disorders (including seizures, global cognitive impairments, aphasia, neglect, substantial sensory disturbances, and severe depression), (4) multiple brain lesions, and (5) age $<$ 18 years.

The patients were divided into two groups: the 'Case' group consisted of patients with LA involving the contralateral CBT (Fig. 1a) and the 'Control' group consisted of patients with LA not involving the contralateral CBT (Fig. 1b). Two experienced radiologists determined the involvement of the CBT based on the change in signal intensity at the anatomical location of the CBT at the CR, approximately halfway between the most anterior and the most posterior points of the lateral ventricle, approximately one-third between the midline and the most lateral point of the brain, and anterior and medial compared with the CST at the CR [8]. The radiologists who judged the MRI images were blinded to the results of the dysphagia assessments. Patients with ambiguous lesions were included in the Control group.

Bedside Swallowing Test

All patients underwent the bedside swallowing test (BST), which consists of five steps, and the feeding method at admission was determined according to the results of the BST. Step 1, fasting was considered necessary if patients: (1) were in state of coma or semi-coma, (2) were very ill (e.g., were intubated or in shock), (3) had comorbid conditions preventing enteral feeding (e.g., paralytic ileus, pancreatitis, or post-abdominal surgery), (4) had severe recurrent vomiting, (5) refused L-tube feeding or it was not possible to place an L-tube, and (6) were at high risk of neurological aggravation or emergency surgery. In these cases, total parenteral nutrition was prescribed. Step 2, patients were assessed for drowsiness and ability to open their mouth or attempt to swallow. If they could not, L-tube feeding was prescribed. Step 3, patients were assessed for dysarthria, facial palsy, impairment of the tongue, and dysphonia. Step 4, the dry swallow test was performed. If patients were unable to complete this test, L-tube feeding was prescribed. Step 5, the wet swallow test with 3 or 10 cc of water was performed. If patients were unable to complete this test, a limited diet was prescribed. Patients who had none of the above conditions received a regular diet. The BST results were considered abnormal if the patient failed any of the five testing stages and normal if all five steps were successfully completed.

Videofluoroscopic Swallowing Study

After the BST, the clinicians proceeded to videofluoroscopic swallowing study (VFSS) for objective examination when the feeding method could not definitively judged. The VFSS was conducted by two experts, and the oral, pharyngeal, and esophageal stages of swallowing were examined using the EasyDiagnost Eleva (Philips, Amsterdam, The Netherlands). The patients were seated on a chair and turned 90° away from the fluoroscope to achieve a lateral projection position. The protocol was conducted in a stepwise manner, with patients receiving 3 and 5 ml of a thick barium fluid mixture using a syringe, 3 and 5 ml of a pureed diet, mechanically altered, and regularly textured food using a spoon; 3 and 5 ml of a thin barium fluid mixture using a syringe, and two drinks of a thin barium fluid mixture using a cup. In the case of significant aspiration or excessive residues in the vallecular or pyriform sinus, which could lead to aspiration, the test was discontinued. The results of the VFSS were considered abnormal if any abnormality in the oral, pharyngeal, or esophageal phases was detected and normal in the case of no specific abnormality.

Outcome Measurements

The primary outcome was the feeding method at discharge; secondary outcomes were the feeding method at admission and the results of the BST, VFSS, videofluoroscopic dysphagia scale (VDS) [9], penetration–aspiration scale (PAS) [10, 11], American Speech–Language–Hearing

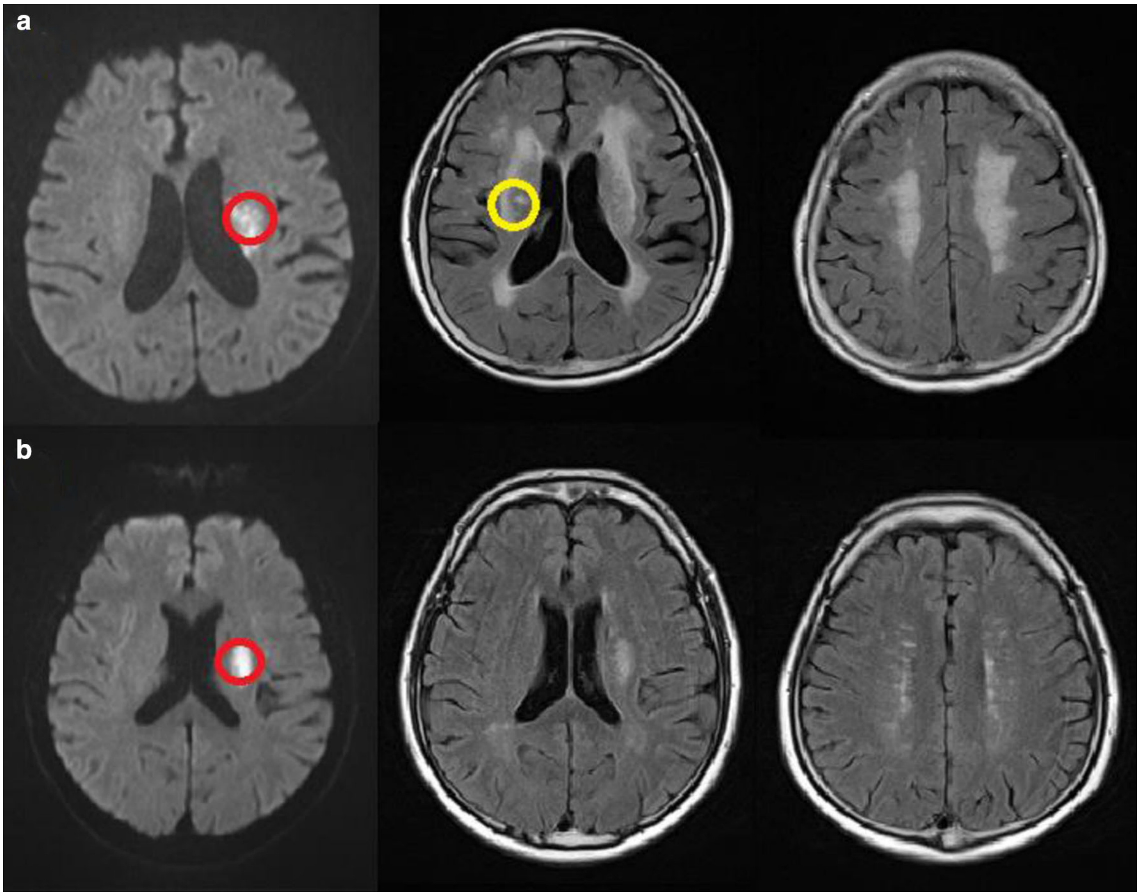

Fig. 1 **a** Diffusion weighted image (DWI) and fluid attenuated inversion recovery (FLAIR) image of a brain MRI showing left corona radiata (CR) infarction with corticobulbar tract (CBT) involvement (red color) and leukoaraiosis (LA) involving the contralateral CBT (yellow color) in a 73-year-old female patient. **b** DWI and FLAIR images of a brain MRI showing left CR infarction with CBT involvement (red color) and mild LA without CBT involvement in a 66-year-old male patient

Association National Outcome Measurement System Swallowing Scale (ASHA NOMS) [12, 13], oral transit time (OTT), and pharyngeal transit time (PTT). The feeding methods at admission and discharge were classified as non-oral diet, limited diet, and regular diet. The results of the BST and VFSS were marked as normal or abnormal. The VDS (0–100) is measured based on the findings of the VFSS and comprises 14 items with weighted values, which include oral function (lip closure, bolus formation, mastication, apraxia, premature bolus loss, and oral transit time) and pharyngeal function (pharyngeal triggering, vallecular and pyriform sinus residues, laryngeal elevation and epiglottic closure, pharyngeal coating, pharyngeal transit time, and aspiration) [9]. The PAS (0–8) is a clinical scale for rating penetration and aspiration that depends on the perceived depth of entry of food or fluid material into the airway and clearance of material from the airway, judged using videofluoroscopy and fiberoptic endoscopic evaluation of swallowing [10, 11]. The ASHA NOMS (0–7) is a simple, easy-to use scale developed to systematically rate the functional severity of dysphagia based on objective assessments. It is used to make recommendations for diet level, independence level, and type of nutrition, with a higher score indicating a better swallowing ability [12, 13]. Furthermore, the duration of the following movements during swallowing was measured: tongue tip at incisors to passage of the bolus tail through the fauces (OTT) and bolus tail at fauces to offset of UES opening (PTT).

For analysis of the infarct size on brain MRI, the formula shown by Sims et al. to be the most accurate was used [14]. The largest lesion slice was selected, and the longest lesion axis on this slice was measured with the ruler tool, comprising the x-axis (A). A second line was drawn perpendicular to the first at the widest dimension, comprising the y-axis (B). A third axis, the z-axis (C), was computed by multiplying the number of slices by slice thickness (3 or 5 mm depending on the case). The final infarct size was measured as ABC/2.

The degree of LA severity on fluid attenuated inversion recovery MRI was rated using the Fazekas scale [15, 16] which separately rates periventricular hyperintensities and deep white matter hyperintense signals. The scores for periventricular hyperintensities are as follows: 0 = absence, 1 = “caps” or pencil-thin lining, 2 = smooth “halo,” and 3 = irregular periventricular hyperintensities extending into the deep white matter. The scores for deep white matter hyperintense signals are as follows: 0 = absence, 1 = punctuate foci, 2 = beginning confluence of foci, and 3 = large confluent areas. A total score (0–6) was obtained by summing the two partial scores.

Information on sex, age, time since stroke, side of lesion, history of recanalization therapies including intravenous thrombolysis and intra-arterial treatment, history of intubation, Modified National Institute for Health Stroke Scale (mNIHSS) score [17], Korean version of the Mini-mental status examination (K-MMSE) score [18], motricity index [19] of the upper and lower limbs, and history of swallowing therapy during the hospitalization period, which included oral-motor facilitation, chin-down posture, laryngeal elevation, effortful swallow, Mendelsohn maneuver, and supraglottic swallow, was obtained from the medical records.

Statistical Analyses

Data collected were analyzed using SPSS for Windows version 20.0 (IBM Corp, Armonk, NY), and the threshold for statistical significance was set at $p < 0.05$. The mean and standard deviation of the data were obtained. Comparisons between the two groups were conducted using the Chi-square test, Fisher’s exact test, or linear-by-linear association for categorical variables and the Mann–Whitney U test for continuous variables. To evaluate independent predictors of the feeding method at discharge, which was a two-level variables (limited diet and regular diet), a multiple logistic regression model with the enter method was used. Multivariate linear regression analysis with a stepwise method was used to evaluate independent predictors of ASHA NOMS. In these models, age, time since stroke, side of lesion, infarct size, mNIHSS score, total Fazekas scale score, and LA with contralateral CBT involvement were entered as covariates, each of which could be associated with swallowing function. To evaluate collinearity, data of tolerance and variance inflation factors were used.

Results

Patient Enrollment

Between September 2011 and August 2014, 759 patients with infarction were admitted and screened, of whom 81 were eligible for inclusion (Fig. 2). The Case group included 20 patients who had LA with contralateral CBT involvement, five of whom underwent VFSS. The Control group included 61 patients who had LA without contralateral CBT involvement, 11 of whom underwent VFSS.

Baseline Characteristics

When comparing the baseline characteristics between the two groups, there were no significant differences in sex, time since stroke, total hospital days, side of lesion, infarct size, presence of hypertension and diabetes mellitus, mNIHSS and K-MMSE scores, motricity index, and history of swallowing therapy during the hospitalization period (mean number of 5.9 ± 3.9 therapies in 12 patients who underwent swallowing therapy) (Table 1). However, the age in the Case group was significantly higher than that in the Control group ($p < 0.01$), and the total Fazekas scale score in the Case group (3.8 ± 1.1) was significantly higher than that in the Control group (2.0 ± 1.1) ($p < 0.01$). None of the patients in either group had history of recanalization therapy or intubation.

Comparison of the Outcome Measurements Between the Two Groups

No significant difference in the BST results was seen between the two groups (Table 2). The feeding method at admission and discharge included non-oral, limited, and regular diets. More patients in the Control group (54.1%) than in the Case group (30.0%) had a regular diet at admission, although this did not reach statistical significance. However, significantly more patients in the Control group (90.2%) than in the Case group (50.0%) had a regular diet at discharge ($p < 0.01$).

Of the patients who underwent VFSS, 100% of those in the Case group ($n = 5$) but only 45.5% of those in the Control group ($n = 5$) showed an abnormal result, although this difference did not reach statistical significance (Table 3). However, the Case group had significantly lower ASHA NOMS score than the Control group ($p = 0.03$). The Case group had higher VDS score (15.8 ± 6.2) than the Control group (10.3 ± 9.7); however, the difference was not statistically significant ($p = 0.06$). Furthermore, when comparing PAS scores, the number of patients in whom the material did not enter the airway in the VFSS (PAS 1) was six (54.5%) in the Control group compared to zero (0.0%) in the Case group, but the difference was not statistically significant. OTT and PTT were longer in the Case group than in the Control group; however, the difference was not statistically significant.

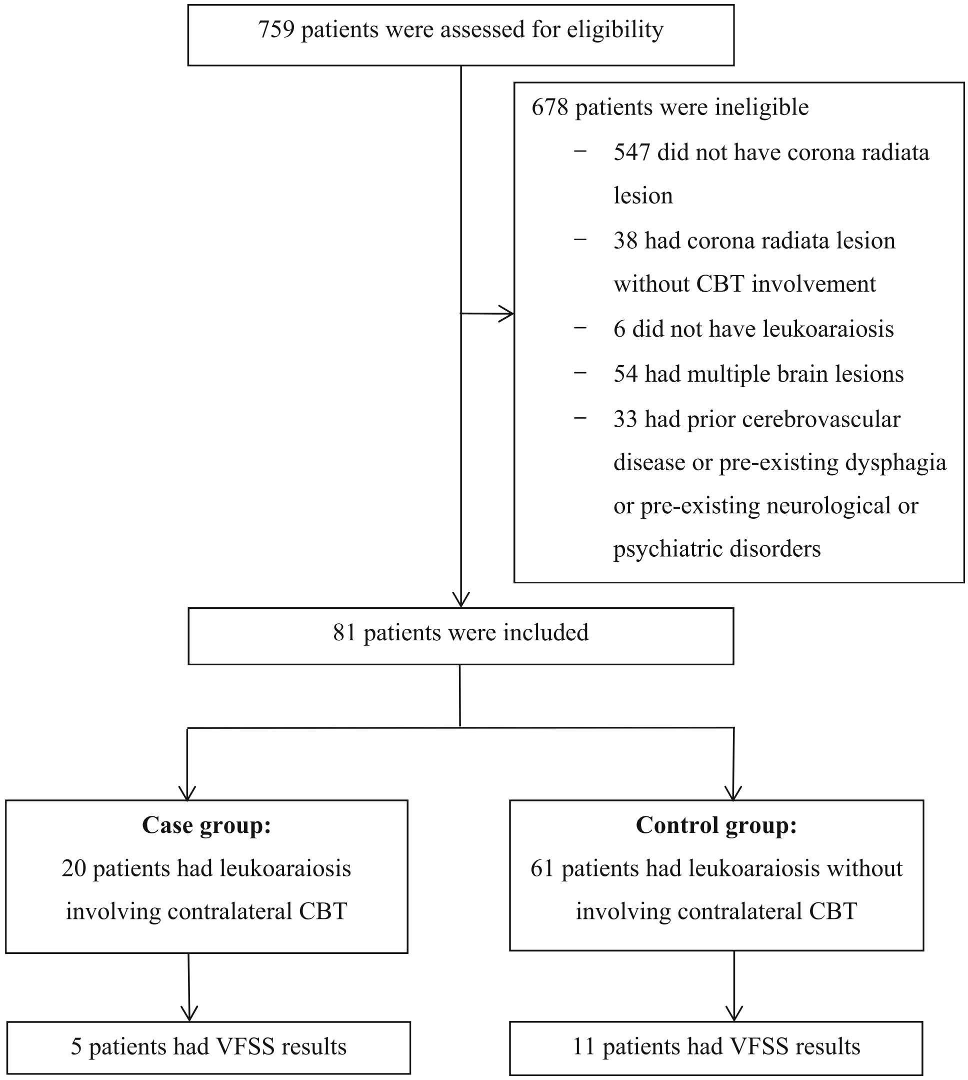

Fig. 2 Flowchart of patient enrollment

Independent Predictors of Dysphagia

In the multivariate logistic regression analysis with the enter method, LA with contralateral CBT involvement was a significant predictor of feeding method at discharge (B = − 3.95; odds ratio 0.02; $p < 0.01$, Table 4). Furthermore, multivariate linear regression analysis with the stepwise method revealed that LA with contralateral CBT involvement was a significant factor associated with the ASHA NOMS score (B = 1.56, $p = 0.03$, Table 5), and no relevant collinearity was observed. However, age, time since stroke, side of lesion, infarct size, mNIHSS score, and total Fazekas scale score were not the associated with feeding method at discharge and the ASHA NOMS score.

Discussion

This is the first study to discuss the association between LA involving the contralateral CBT and dysphagia in patients with unilateral CR infarction with CBT involvement. Patients with LA involving the contralateral CBT had a greater degree of dysphagia than the Control patients, as determined by the feeding method at discharge ($p < 0.01$) and the ASHA NOMS score ($p = 0.03$). Although age and total Fazekas scale score differences were seen between the two groups, these were not independent predictors of dysphagia. However, LA involving the contralateral CBT was the significant predictor of dysphagia.

A number of previous studies have assessed prognostic factors of dysphagia in patients with stroke, including stroke type (hemorrhagic stroke being worse than ischemic stroke) [6], stroke severity (NIHSS score) [6, 20], aspiration during VFSS [20, 21], cognitive impairment [6, 22, 23], dysarthria [20], intubation [20], and bilateral

Table 1 Baseline patient characteristics

	Case group (n = 20)	Control group (n = 61)	p value
Sex (male/female)	12 (60.0):8 (40.0)	40 (65.6):21 (34.4)	0.65
Age (years)			
Age < 60	1 (5.0)	25 (41.0)	< 0.01*
60 ≤ age < 70	5 (25.0)	20 (32.8)	
70 ≤ age	14 (70.0)	16 (26.2)	
Time since stroke (days)	1.7 ± 1.1	1.3 ± 0.8	0.09
Total hospital days	9.1 ± 9.5	14.4 ± 13.7	0.20
Side of lesion (right:left)	8 (40.0):12 (60.0)	29 (47.5):32 (52.5)	0.56
Infarct size (mm^3)	742.6 ± 1022.0	786.6 ± 741.2	0.26
Hypertension	9 (45.0)	34 (55.7)	0.40
Diabetes mellitus	4 (20.0)	15 (24.6)	0.77
mNIHSS score (0–31)	4.0 ± 3.2	3.7 ± 2.7	0.85
History of recanalization therapy	0 (0)	0 (0)	–
History of intubation	0 (0)	0 (0)	–
K-MMSE (0–30)	21.8 ± 6.4	24.5 ± 5.4	0.30
Motricity index			
Upper limb (0–100)	70.5 ± 14.4	65.1 ± 16.6	0.14
Lower limb (0–100)	70.8 ± 9.6	65.8 ± 15.1	0.22
Total Fazekas scale (0–6)	3.8 ± 1.1	2.0 ± 1.1	< 0.01*
Swallowing therapy	2 (10.0)	10 (16.4)	0.72

Data are presented as mean ± standard deviation or N (%)

For categorical variables, data were evaluated using the Chi-square or Fisher's exact test. For continuous variables, the Mann–Whitney U test was used

mNIHSS Modified National Institute for Health Stroke Scale, *K-MMSE* Korean version of the Mini-mental status examination

*p < 0.05, Mann–Whitney U test

Table 2 Comparison of BST results and feeding method at admission and discharge between the two groups

	Case group (n = 20)	Control group (n = 61)	p value
BST result			
Normal	5 (25.0)	24 (39.3)	0.25
Abnormal	15 (75.0)	37 (60.7)	
Feeding method at admission			
Non-oral diet	1 (5.0)	1 (1.6)	0.15
Limited diet	13 (65.0)	27 (44.3)	
Regular diet	6 (30.0)	33 (54.1)	
Feeding method at discharge			
Non-oral diet	0 (0.0)	0 (0.0)	< 0.01*
Limited diet	10 (50.0)	6 (9.8)	
Regular diet	10 (50.0)	55 (90.2)	

Data are presented as N (%)

Data were evaluated using the Chi-square or Fisher's exact test

BST bedside swallowing test

*p < 0.05, Fisher's exact test

stroke [20, 21]. Some studies have discussed whether the right or left hemisphere is more important for swallowing. Some have shown that stroke location in the right hemisphere was associated with a higher rate of dysphagia [24, 25]. In another study, cortical stroke on the non-dominant side (generally right) was associated with

Table 3 Comparison of VFSS, VDS, PAS, ASHA NOMS, OTT, and PTT results between the two groups

	Case group (n = 5)	Control group (n = 11)	p value
VFSS results			
Normal	0 (0.0)	6 (54.5)	0.09
Abnormal	5 (100.0)	5 (45.5)	
VDS	15.8 ± 6.2	10.3 ± 9.7	0.06
PAS			
1	0 (0.0)	6 (54.5)	0.25
2	3 (60.0)	4 (36.4)	
3	1 (20.0)	0 (0.0)	
8	1 (20.0)	1 (9.0)	
ASHA NOMS	3.8 ± 0.5	5.4 ± 1.4	0.03*
OTT (s)	5.0 ± 1.8	2.8 ± 1.8	0.19
PTT (s)	2.0 ± 0.9	1.0 ± 0.6	0.19

Data are presented as mean ± standard deviation or N (%)

For categorical variables, data were evaluated using Fisher's exact test or linear-by-linear association

For continuous variables, the Mann–Whitney U test was used

VFSS videofluoroscopic swallowing study, *VDS* videofluoroscopic dysphagia scale, *PAS* penetration–aspiration scale, *ASHA NOMS* American Speech–Language–Hearing Association National Outcome Measurement System Swallowing Scale, *OTT* oral transit time, *PTT* pharyngeal transit time

*$p < 0.05$, Mann–Whitney U test

Table 4 Independent factors of feeding method at discharge in patients with unilateral corona radiata infarction involving the corticobulbar tract

	B	p value	Odds ratio
Leukoaraiosis with contralateral CBT involvement			
No	Reference		
Yes	− 3.95	< 0.01*	0.02
Age (years)			
Age < 60	Reference		
60 ≤ age < 70	− 1.39	0.19	0.25
70 ≤ age	− 1.38	0.23	0.25
Time since stroke	0.47	0.33	1.60
Side of lesion			
Right	Reference		
Left	0.53	0.47	1.69
Infarct size	− 0.001	0.11	1.00
mNIHSS score	− 0.16	0.20	0.86
Total Fazekas scale	0.77	0.09	2.16

Data analyzed with multivariate logistic regression analysis, enter method

CBT corticobulbar tract, *mNIHSS* Modified National Institute for Health Stroke Scale

*$p < 0.05$

dysphagia and subcortical non-dominant (generally right) stroke showed a reduced frequency of dysphagia [22]. However, one study found that there was no significant association between dysphagia and hemisphere in stroke [26]. In this study, side of lesion was not the associated factors of dysphagia in patients with unilateral CR infarction involving the CBT. Other studies have examined the association between lesion location and dysphagia. Galovic et al. [27] suggested that lesions of the insular cortex and the internal capsule were significantly related to acute risk of aspiration after stroke, and Suntrup et al. [25] demonstrated that the opercular region, supramarginal gyrus, and respective subcortical white matter tracts were related to dysphagia. Furthermore, Moon et al. [23] suggested that lesions predominantly distributed in the left frontal lobe tend to associate with delayed OTT, and Cola et al. [28] proposed that lesions at the left periventricular white matter (PVWM) may be more disruptive to swallowing behavior

Table 5 Selected factors of American Speech–Language–Hearing Association National Outcome Measurement System Swallowing Scale in the stepwise linear regression analysis in patients with unilateral corona radiata infarction involving the corticobulbar tract

	B	*p* value	R^2
Leukoaraiosis with contralateral CBT involvement	1.56	0.03*	0.253
Age	Eliminated in step 1 (p = 0.41)		
Time since stroke	Eliminated in step 1 (p = 0.22)		
Side of lesion	Eliminated in step 1 (p = 0.23)		
Infarct size	Eliminated in step 1 (p = 0.91)		
mNIHSS score	Eliminated in step 1 (p = 0.38)		
Total Fazekas scale	Eliminated in step 1 (p = 0.38)		

Data analyzed with multivariate linear regression analysis, stepwise method

CBT corticobulbar tract, *mNIHSS* Modified National Institute for Health Stroke Scale

*$p < 0.05$

than similar lesions at the right PVWM, especially in oral control and transfer.

LA is associated with age, sex, hypertension, diabetes mellitus, smoking, alcohol consumption, and abnormal homocysteine and low-density lipoprotein cholesterol levels [29]. It is pathologically correlated with myelin pallor, tissue rarefaction related to loss of myelin axons, and mild gliosis [30]. However, the pathogenesis of LA is not completely understood. A vascular origin, related to deep cerebral small vessel diseases caused by aging and arterial hypertension, is considered likely [30]. In the LADIS study, based on a multicenter and multinational collection and follow-up of non-disabled elders, severe LA was associated with pseudobulbar sign; however, the exact location of LA was not considered. Furthermore, it was also associated with the occurrence of neurological signs including gait and stance abnormalities, upper motor signs, primitive reflexes, and FingerTap slowing, independently of other vascular brain lesions, confirming that these lesions have clinical relevance [31, 32].

Few studies have considered the location of LA. One study [33] showed an association between the location of LA and falls; LA at the deep frontal and periventricular regions, but not in the basal ganglia or infratentorial region, was associated with falls. However, no study has thus far considered the association between the location of LA and dysphagia.

The association between LA and dysphagia in patients with stroke has been discussed in previous studies. Levine et al. [34] demonstrated that the degree of LA severity was associated with the duration of oropharyngeal swallowing in normal individuals. Toscano et al. [6] evaluated the neuroanatomical, clinical, and cognitive factors correlated with post-stroke dysphagia, demonstrating that the degree of LA was an independent predictor of the occurrence and persistence of dysphagia after stroke and suggesting the importance of the subcortical white matter connections in the process of swallowing. The severity of LA, rated with the total Fazekas scale, was a confounding factor in this current study; however, the multivariate analysis showed that LA involving the contralateral CBT, not total Fazekas scale score, was the independent predictor of dysphagia in unilateral CR infarct with CBT involvement. There are some differences between this study and the previous [6] one; the previous study [6] included patients with both ischemic and hemorrhagic strokes involving various locations and did not consider the involvement of CBT, whereas this study included only patients with CR infarction with consideration of LA with CBT involvement. Furthermore, considering that LA is related to loss of myelin axons and mild gliosis [30], it may also be associated with delayed nerve conduction time. When the time required for swallowing was examined in this study, OTT (5.0 ± 1.8 vs. 2.8 ± 1.8) and PTT (2.0 ± 0.9 vs. 1.0 ± 0.6) were longer in the Case group than in the Control group, but the differences were not statistically significant, probably due to the small number of patients included.

When discussing dysphagia in patients with stroke, the CBT is a crucial tract to consider. It is involved in the motor function of the non-oculomotor cranial nuclei and therefore involved in bulbar function [35]. The CBT innervates the nuclei of cranial nerves V, VII, XI, and XII and also contributes to cranial nerves IX and X [35]. The CBT is associated with the muscles of the face, head, and neck; therefore, injury often results in bulbar symptoms, including dysphagia, dysarthria, and facial palsy [35]. The anatomical location of the CBT at the CR was shown with diffusion tensor tractography (DTT) [8]. This is the most accurate description of the CBT pathway to date and was, therefore, used as reference for this study. In addition, an anatomical location of the CBT in the internal capsule has been reported, with pathways for the tongue and face located anteromedial to the face and hand, respectively [36]. A recent study showed that early swallowing recovery after stroke was influenced by lesions disrupting CBT fibers [37]. Another study investigated patients with dysarthria following cerebral infarction, reconstructing the

CBT using DTT and showed that the reconstructed CBTs in the affected hemisphere of the patient group were thinner than those in the unaffected hemisphere of the patient group and the control group [38]. Therefore, involvement of the CBT should be considered when discussing the effect of LA on dysphagia, but no relevant study has so far been conducted. This study was the first to associate dysphagia and LA involving the CBT.

The results of this study revealed that the patients who had LA involving the contralateral CBT had a higher degree of dysphagia than the ones who had LA without CBT involvement. However, the age difference between the two groups was significant, which is a confounding factor in interpreting the results of this study. Age is known to be related to LA [5] and is associated with poor prognosis in patients with stroke with dysphagia [21]. Ickenstein et al. [21] demonstrated that patient age > 52 years was a negative predictor of dysphagia measured by the gastrostomy/jejunostomy tube removal rate ($p < 0.001$). However, there was no consideration of LA or involvement of the CBT in that study [21]. By comparison, this present study considered age, LA, and the CBT in evaluating the prognosis of dysphagia in patients with stroke, concluding that LA involving the contralateral CBT, rather than age, was an independent predictor of dysphagia in patients with unilateral CR infarction with CBT involvement.

Numerous studies have been conducted on CR infarction and they usually focus on the involvement of the CST and motor symptoms using DTT [39, 40]. However, there is limited information on dysphagia in patients with CR infarction. Dysphagia is an independent predictor of morbidity and mortality, and early detection of dysphagia can reduce post-stroke mortality and the length of hospitalization. Therefore, dysphagia should be a major concern in patients with stroke and proper diet prescription is necessary. This current study was the first to discuss dysphagia in patients with CR infarction.

The present study has several strengths. First, it was the first to discuss dysphagia in patients with unilateral CR infarction, which is considerably a specific group. Second, it was also the first study to consider CBT involvement using brain MRI with anatomical references, which logically explains the corresponding symptom of dysphagia. Third, this was the first study to emphasize the importance of the location of LA regarding dysphagia in patients with stroke. The limitations of this study include the fact that the integrity of the CBT was not confirmed by DTT reconstruction, as it was a retrospective study and no such data were available. Instead, high signal intensity lesions along the CBT in the CR defined CBT involvement. Second, the anatomical location of the CBT used does not include the entire CBT. The reference used for the anatomical location of the CBT [8] reconstructed only the dorsal CBT, which corresponds to the lips and larynx, but not the ventral CBT, which corresponds to the tongue. The authors explained that this approach was employed to avoid the fiber crossing effect and stiff angle of the ventral CBT in DTT. Therefore, the involvement of ventral CBT was not considered in this study. Third, since this study included patients with acute stroke, the effect of natural recovery on dysphagia cannot be excluded. Finally, this was a single-center retrospective study with no long-term follow-up, and only a few patients underwent VFSS.

Conclusions

This study presents the importance of the location of LA in patients with stroke. The presence of LA involving the contralateral CBT is associated with dysphagia in patients with unilateral CR infarctions involving the CBT. In clinical practice, careful interpretation of the location of LA on brain MRI in these high-risk patients may assist in the identification and explanation of the severity and prognosis of dysphagia. Further evaluation of our observations is required in larger, prospective studies.

Compliance with Ethical Standard

Conflict of interest The authors declare that they have no conflict of interest.

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