Integrated non-invasive measurements reveal swallowing and respiration coordination recovery after unilateral stroke

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Key Messages

- Oropharyngeal dysphagia (OD) is common after a stroke, and OD is a potential cause of aspiration, dehydration, malnutrition, increased length of hospital stay.
- The fine coordination between oropharyngeal swallowing and respiration is essential to ensure the safety of swallowing without aspiration, and stroke insults affect swallowing and respiration coordination, but no longitudinal follow-up study of this coordination after unilateral stroke was demonstrated in a literature review.
- A non-invasive swallowing assessment method was used to detect oropharyngeal swallowing parameters and respiration coordination simultaneously during the swallowing process.
- Results show that oropharyngeal swallowing and respiration coordination in unilateral stroke patients deviate from normal controls after stroke insult and improved during the subacute phase poststroke.

Abstract

Background Oropharyngeal dysphagia is common after a stroke. Understanding the physiology of swallowing and its coordination with respiration in stroke recovery is crucially important. Methods A non-invasive swallowing assessment method was used to detect oropharyngeal swallowing and respiration coordination simultaneously during the swallowing process. This system detected movement of the larynx, submental muscle activity, and nasal airflow. Six different sizes of water boluses (maximum of 20 mL) were swallowed and assessed for each subject.

Key Results We recruited 59 healthy participants and 38 first ever unilateral stroke patients completed baseline and follow-up assessments at 3, 6, and 9 months poststroke. The results showed that oropharyngeal swallowing parameters in unilateral stroke deviate from normal patterns. For respiration coordination, the unilateral stroke group had longer swallowing apnea duration but similar frequencies of pre- and postswallowing respiratory phase patterns compared with the healthy controls. The probability of piece-meal deglutition was higher in the stroke group than in the control group. Additionally, there were gradually decreasing piece-meal deglutition probabilities among the stroke patients at follow-up, and none differed statistically from those of the controls at 6 months poststroke. Conclusions & Inferences The non-invasive swallowing and respiration assessment method applied in this study detected the changes manifested in swallowing and respiration during the subacute phase of recovery in 6 months after a unilateral stroke. The study results serve as a baseline for
INTRODUCTION

Neurogenic oropharyngeal dysphagia (OD) commonly occurs after a stroke.1 The incidence of OD in stroke patients is variable and based on the definitions used in each case series.2–5 Oropharyngeal dysphagia is a potential cause of aspiration,6 dehydration, and malnutrition. All of these complications lead to increased lengths of hospital stays and healthcare expenditures for stroke care.7 Oropharyngeal dysphagia is also associated with poor outcomes and negatively affects the quality of life after stroke.8,9 Severe cases of OD complicated by pneumonia often result in high mortality and morbidity.10 Oropharyngeal dysphagia appears acutely after the stroke insult. Many patients begin to recover in the subacute stage while others have chronic dysphagia.1,11 Nonetheless, the mechanisms of OD after stroke are not well understood.

In recent decades, the critical role of respiration coordination in the oropharyngeal swallowing process has been recognized. The fine coordination between oropharyngeal swallowing and respiration ensures the safety of swallowing without aspiration.12–17 Morton et al. demonstrated that subjects with neurological OD without adequate respiratory integration experience more aspiration episodes than those without OD.18 Stroke insults affect swallowing and respiration coordination.19–24 Currently, few studies with longitudinal follow-up of oropharyngeal swallowing function after stroke are published.25,26 Furthermore, the literature lacks longitudinal follow-up in poststroke studies of respiration coordination and oropharyngeal swallowing. We believe it is vital to understand the recovery progress of swallowing and respiration coordination during the subacute phase of stroke because stroke incidence rises with age, and most stroke patients are elderly and fragile.10 Finding a practical, quantitative, and noninvasive method to examine oropharyngeal swallowing and respiration changes in stroke recovery with little or no patient distress is necessary.

The examination of swallowing and respiration coordination required instruments to detect nasal airflow or to monitor respiration simultaneously. Such methods combined invasive and non-invasive swallowing study tools including video-fluoroscopic swallowing studies (VFSS), pharyngeal manometry,27–29 surface electromyography (sEMG),30,31 and swallowing sound studies.32,33 Video-fluoroscopic swallowing studies involves radiation exposure, and pharyngeal manometry is invasive. Thus, such follow-up studies are restricted, especially in frail, poststroke patients. Recently, a non-invasive method using piezoelectric sensors with thermistor respiration pickup sensors to monitor swallowing and respiration simultaneously was designed.34 Previously, a non-invasive instrument for oropharyngeal swallowing studies combining submental sEMG with piezoelectric sensors was used to characterize normal and neuromuscular dysphagic swallowing movements with evaluating crico-pharyngeal sphincter activities.35,36 Furthermore, respiration monitoring instrumentation was added to this instrument, which enabled the analysis of oropharyngeal swallowing impairment and respiration coordination in elderly patients37 and those with neuromuscular dysphagia.38

The purpose of this study was to understand oropharyngeal swallowing and respiration coordination after a stroke and its recovery. We used novel, non-invasive swallowing studies to characterize the physiological changes of swallowing and respiration coordination in healthy controls and patients with unilateral stroke at different follow-up time periods. We determined the longitudinal progress of swallowing and respiration coordination recovery in unilateral stroke patients.

MATERIALS AND METHODS

Hardware and software

A noninvasive electrophysiological monitoring system, the BIOPAC MP100 system (BIOPAC Systems, Goleta, CA, USA), which was designed to record biological signals for the assessment of swallowing and respiration, was used in this study.37 The simultaneous recording of swallowing and respiration signals employed sEMG for submental activity, a piezoelectric sensor for the movement of the larynx, and 16-foot length, adult sized, nasal pressure airflow cannulas (Pro-FlowTM Cannulas; Pro-Tech Services, Inc., Murrysville, PA, USA) connected to an airflow sensor pressure transducer (PTAF2; Pro-Tech Services, Inc.) for nasal airflow measurement. All of the swallowing signals with nasal airflow data were simultaneously recorded and stored on-line using the BIOPAC System and AcqKnowledge software (version 3.9.1a; BIOPAC Systems) on a personal computer. For the later off-line analysis, AcqKnowledge software (version 3.9.1a; BIOPAC Systems) showed the recorded signals and transformed them into text files for analysis and interpretation using Matlab programs (version 7.7; MathWorks, Natick, MA, USA).

Piezoelectric sensor placement

The piezoelectric sensor was used for detecting thyroid cartilage excursion. The sensor fixation method used is described
elsewhere. The thyroid cartilage level was chosen for the location of piezoelectric sensor placement.

**Healthy controls and unilateral stroke patients**

We consecutively recruited 59 healthy participants (aged 54.9 ± 8.4 years; male/female: 30/29) and 67 patients with first-ever unilateral stroke and mild dysphagia [functional oral intake scale (FOIS) ≥3] who passed bedside screening by swallowing 5 mL of water twice. The patients underwent a baseline assessment and follow-up studies.

Finally, 38 unilateral stroke patients (age 52.0 ± 6.5 years; male/female: 28/10) completed the baseline and follow-up assessments. The unilateral stroke patients who completed follow-up had an FOIS ≥4, except one who had a score of FOIS 3 in the first assessment period (T1). Twenty-nine patients dropped out of the study. They were older and had lower FOIS than the patients who completed follow-up (Table 1). Stroke patients were assessed at four different times. The assessments included time 1 (T1) within 3 months poststroke when they were admitted and transferred to the rehabilitation department, time 2 (T2) 3 months poststroke, time 3 (T3) 6 months poststroke, and time 4 (T4) 9 months poststroke. The number of stroke patients studied and drop-out information at the different follow-up time periods is shown in Fig. 1.

The exclusion criteria were a history of dysphagia, cardiopulmonary disease, neurological disease, indigestion disorder, cancer, or a disease of the head or neck. Additionally, patients taking medications with known effects on swallowing or breathing were excluded.

The ethics committee of Chang Gung Medical Foundation approved the study. Each participant understood the verbal instructions and signed an informed consent form prior to participation.

**Procedures**

The participant was shown the equipment and instructed about the study procedure. The examiner located the anatomic markers.

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**Table 1** Clinical and demographic characteristics of the unilateral stroke patients and normal controls

| Subject group | Patients with complete follow-up | Patients that dropped out | Normal | p-value<sup>1,4</sup> | p-value<sup>1,1</sup> |
|---------------|----------------------------------|---------------------------|--------|------------------------|------------------------|
| Gender (M / F) | 38 [28/10]                       | 29 [21/8]                 | 59 [30/29] | 0.025<sup>*</sup> | 0.907                  |
| Age (years)   | 52.0 ± 6.5                       | 55.8 ± 7.9                | 54.9 ± 8.4 | 0.073                  | 0.034<sup>*</sup>      |
| Laterality of stroke (L/R) | 18/20                        | 15/14                     | –       | 0.724                  | –                      |
| Type of stroke (I/H) | 27/11                         | 16/13                     | –       | 0.179                  | –                      |
| Length of stay (days) | 35.6 ± 14.2                     | 29.1 ± 14.2               | –       | 0.067                  | –                      |
| First assessment time (T1), n | 10/23/5                        | 11/15/3                   | –       | 0.594                  | –                      |
| 2-4 weeks/5-8 weeks/9-11 weeks | 1/11/9/17                     | 7/3/13/6                  | –       | 0.003<sup>*</sup>     | –                      |

<sup>*</sup>p < 0.05. <sup>†</sup>Patients with complete follow-up. <sup>‡</sup>Patients that dropped out. <sup>§</sup>Normal. <sup>¶</sup>Data are presented as means ± SD. M, Male; F, Female; L, Left; R, Right; I, Infarction; H, Hemorrhage; wk, week; FOIS, functional oral intake scale.
for swallowing and respiration signal recording, which included two electrocardiographic adhesive electrodes for the submental sEMG, piezoelectric sensor for the thyroid cartilage and the nasal cannulas for nasal airflow. Each participant was then instructed to swallow six different volumes of water as boluses sequentially, and each bolus trial was given three consecutive times and recorded individually. The participants took a 3-min recess between the three repeats of each bolus swallowing test. The participants were kept blind to the volume and temperature of each bolus. The study procedure is described elsewhere. Briefly, the amount of water was measured using identical, disposable 20 mL syringes and was given to participants in identical small disposable cups. The six bolus types include dry, saliva only [no water], 2 mL of room temperature water, 5 mL of room temperature water, 10 mL of room temperature water, 5 mL of 4 °C ice water, and 20 mL of room temperature water. The stepwise increase in bolus volume in the procedure was designed for safety considerations, especially for stroke participants with dysphagia who had an increased risk of choking. If a patient showed any sign of tracheal aspiration, such as a choking cough more than twice or shortness of breath, during water bolus swallowing, the study procedures were stopped. For each swallowing test, the participants held the water in their mouths until they received a standardized verbal cue to initiate swallowing ‘naturally’ each time. The data were recorded using the AcqKnowledge software (version 3.9.1a; BIOPAC Systems) for later off-line analysis.

Parameters of swallowing signals and respiration coordination

**Latency and duration of oropharyngeal swallowing** The temporal event analysis of oropharyngeal swallowing, including latency and duration, integrated the signals from submental sEMG and the piezoelectric sensor (Fig. 2). The onset of oral-phase swallowing was defined as the beginning of the submentalis activity. The onset latency (OL) of the laryngeal excursion was determined by measuring the time elapsed between the onset of the submentalis contraction to the onset of the laryngeal excursion signals, the duration of the laryngeal excursion time of laryngeal upward excursion was the duration of first deflection. The jitter (JIT) of the laryngeal downward excursion was defined as the duration of the second deflection. The total excursion time (TET) was the sum of excursion time [first deflection] and jitter [second deflection]. Previously, investigators demonstrated that the events of laryngeal excursion are valid definitions of the pharyngeal stages. The magnitude of thyroid cartilage excursion is indirectly reflected by the amplitude of the piezoelectric signals. The thyroid cartilage movement is synchronized with the motion of the hyoid bone while swallowing, which is an important landmark for analysis with radiological VESS studies.

**Respiratory phase patterns pre- and postswallowing** There are two respiration phase patterns each for predeglutition and postdeglutition phase. Accordingly, there are four pre- and postdeglutition respiratory phase patterns, including expiration– inspiration (EX/EX), expiration–inspiration (EX/IN), inspiration–expiration (IN/EX), and inspiration–inspiration (IN/IN). The primary pattern is the EX/EX pattern, which is the only physiologically protective respiratory phase pattern. We then grouped the remaining three minor respiratory phase patterns into one group, the non-EX/EX pattern group. The patterns in the non-EX/EX group are not protective respiratory phase patterns. This categorization has been used previously.

**Swallowing apnea duration** Deglutition apnea, a pause of respiration, is a necessary and important protective respiratory phenomenon for safe swallowing without aspiration. Swallowing apnea duration (SAD) represents the duration of airway closure while swallowing.

**Dysphagia limit and piece-meal deglutition (multiple swallows)** The dysphagia limit is the maximal bolus volume that can be swallowed. Under certain circumstances, if the amount of a bolus feeding into the mouth exceeded the dysphagia limit, then it was too large of a bolus. Patients divided these large boluses into smaller boluses and swallowed them successively by piece-meal deglutition (multiple swallows). This is a protective phenomenon for safe swallowing, and it is also a sensitive test to detect dysphagia. Under certain circumstances, it indicates an alteration in lingual control. A previous study has demonstrated that a dysphagia limit of less than 20 mL indicated inconspicuous dysphagia in neurogenic disorders. In this study, the probability of piece-meal deglutition was analyzed by swallowing 20 mL of room temperature water, which is the largest bolus swallowed by healthy controls and unilateral stroke patients. The piece-meal swallows were also observed and subjected to sEMG and laryngeal movement analysis. If piece-meal swallowing appeared, the swallowing signals recorded showed smaller volumes swallowed than the initial bolus volume given. Accordingly, these recorded swallowing signals were not analyzed any further.

**Statistical analysis**

Statistical analyses were carried out using SPSS 12.0 software (SPSS, Inc., Chicago, IL, USA). The data obtained for the three swallowing trials of the same bolus type were averaged. The un-paired t test was used for parametric testing after the Shapiro-Wilk test to examine and compare the differences between groups. For the number and frequency, the Chi-squared test was used to test the significance of differences between groups. p-values were
not adjusted for multiple comparisons. \( p < 0.05 \) was considered statistically significant.

**RESULTS**

**Oropharyngeal swallowing parameters**

The normal values for the oropharyngeal swallowing parameters and SAD in normal controls are shown in Table 2.

Onset latencies in the stroke patients were mostly negative compared to those of the healthy controls. The differences between the controls and stroke patients were statistically significant for most of the six types of boluses \( p < 0.05 \); Fig. 3A). This shows that the OL is earlier in stroke patients. There were no significant differences in onset latencies during the follow-up periods among stroke patients.

The amplitude of the thyroid cartilage excursion signal in the stroke group was larger than that in the healthy control group \( p < 0.05 \); Fig. 3B). Moreover, patients had significantly increased amplitudes of thyroid cartilage excursion during the follow-up periods for most types of boluses \( p < 0.05 \); Fig. 4B). The total duration of thyroid cartilage excursion \( TET \) was longer for the stroke patients than for the healthy controls \( p < 0.05 \). The one exception was for swallowing the 20-mL water bolus [Fig. 3E]. Similarly, the jitter of the laryngeal excursion for relocation was longer for the stroke patients than for the healthy control group for swallowing small water boluses [Fig. 3D]. Nonetheless, \( TET \) and jitter did not significantly differ among the stroke patients for the four follow-up periods \( p > 0.05 \) for both; Figs 4E and 4D).

In summary, for the temporal and excursion parameters of swallowing, the stroke group showed earlier OL, longer duration, and a larger amplitude of thyroid cartilage excursion [Fig. 2]. Oral phase impairment with early leakage of the water bolus into the pharynx activated thyro-hyoid and thyro-arytenoid muscle contraction. This caused thyroid cartilage excursion earlier than submental muscle activity. The longer duration of \( TET \) represented a delay in pharyngeal phase swallowing.

**Swallowing apnea duration**

Swallowing apnea duration differed significantly between the healthy control group and unilateral stroke group; longer SAD occurred in unilateral stroke patients for all six types of boluses and at all four follow-up time periods [Fig. 3C]. The SADs for the four different time periods of follow-up among the unilateral stroke patients did not differ statistically \( p > 0.05 \) for all; Fig. 4C).

**Pre- and postswallowing respiratory phase patterns**

For the six bolus types, the proportions of respiratory patterns in those who had unilateral stroke vs healthy control subjects did not differ, except at the 3-month T2 follow-up \( p = 0.03 \); Table 3). Fewer stroke patients experienced the non–EX-EX respiratory phase pattern. This result indicates that there is no decrease in the protective swallowing respiratory pattern in unilateral stroke in the subacute stage.

**Piece-meal deglutition**

The probability of piece-meal deglutition [multiple swallows] of the 20 mL, room-temperature water bolus differed among the stroke subjects at the four different follow-up time periods \( p < 0.05 \), McNemar test for all; Table 4). Specifically, the incidence of piece-meal deglutition was highest in the stroke patients at the baseline assessment within 3 months poststroke and lowest at the 9-month poststroke follow-up assessment. The results indicate a gradual increase in the swallowing limits during the subacute phase of swallowing recovery among unilateral stroke patients. The probability of piece-meal deglutition at T1 and T2 among stroke patients differed from that of the control subjects \( p < 0.05 \). On the other hand, the probability at T3 and T4 did not differ from that of healthy control subjects.

| Table 2 Temporal parameters of oropharyngeal swallowing signals for six different boluses in normal controls |
|---------------------------------------------------------------|
| **Onset latency (s)**       | **Total excursion time (s)** | **Jitter (s)** | **Amplitude [V]** | **SAD [s]** |
| Dry swallowing             | 0.099 ± 0.221                | 2.150 ± 0.801  | 1.238 ± 0.668     | 0.221 ± 0.160 | 1.039 ± 0.426 |
| 2 mL (RT)                  | 0.134 ± 0.236                | 2.139 ± 0.726  | 1.314 ± 0.656     | 0.213 ± 0.128 | 0.933 ± 0.409  |
| 5 mL (RT)                  | 0.073 ± 0.258                | 2.313 ± 0.913  | 1.456 ± 0.857     | 0.225 ± 0.143 | 0.915 ± 0.306  |
| 10 mL (RT)                 | 0.078 ± 0.342                | 2.532 ± 1.224  | 1.687 ± 1.039     | 0.250 ± 0.175 | 0.950 ± 0.281  |
| 5 mL (4 °C)                | 0.133 ± 0.218                | 2.571 ± 1.246  | 1.697 ± 1.118     | 0.219 ± 0.137 | 0.928 ± 0.438  |
| 20 mL (RT)                 | 0.127 ± 0.278                | 2.810 ± 1.399  | 1.976 ± 1.264     | 0.288 ± 0.236 | 0.953 ± 0.353  |

SAD, swallowing apnea duration; RT, room temperature; s, second; V, volt.
DISCUSSION

Assessment tools for swallowing and respiration coordination studies

Instrumentation for swallowing studies has its advantages and limitations. Umay et al. recommended that bedside tests should be used mainly as initial screening tests.44 Next, video-endoscopic swallowing study (VES) and electrophysiological evaluation methods should be performed in patients who are at risk for swallowing disorders.6,45 Video-fluoroscopic swallowing studies and VESS are advantageous because they can detect aspiration,46–48 which aids in the clinical management planning of tube or oral feeding. Moreover, VFSS may be combined with respiration monitoring.27,28,49 Nonetheless, the disadvantages of

Figure 3 Comparison of the oropharyngeal swallowing parameters and swallowing apnea duration (SAD) between the unilateral stroke patients and healthy controls.

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radiation exposure and non-portability are unsuitable for repeated measurements within a short period in follow-up studies or as bedside tests. VESS is a stressful procedure during endoscopy, which makes it difficult to apply for long-term monitoring. Furthermore, there are technical difficulties integrating the anatomic imaging system with respiration monitoring in VESS.

The new trend in swallowing studies is to use a non-invasive assessment method that does not cause stress to patients or pose a radiation risk. Furthermore, it should be easily carried or worn, and portable. Equally important, this non-invasive swallowing study tool should be capable of being combined with respi-

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**Table 3** Comparison of the probability of non-EX/EX respiratory phase pattern among the unilateral stroke and normal control patients

| Groups and follow-up time | Non-EX/EX trials/all trials (%) | Chi-squared | p-value |
|---------------------------|---------------------------------|-------------|---------|
| Normal                    | 555/1057 (52.3%)                |             |         |
| T1                        | 307/655 (46.9%)                 | N*T1        | 0.191   |
| T2                        | 288/664 (43.4%)                 | N*T2        | 0.030   |
| T3                        | 343/681 (50.4%)                 | N*T3        | 0.622   |
| T4                        | 306/678 (45.1%)                 | N*T4        | 0.080   |

N, normal control; T1, poststroke within 3 months; T2, poststroke 3 months; T3, poststroke 6 months; T4, poststroke 9 months.

**Table 4** Comparison of the probability of piecemeal deglutition with a 20-mL water bolus among the unilateral stroke and normal control patients

| Groups and time | Number of subjects | Piecemeal trials/all trials (%) | Chi-squared | p-value |
|-----------------|--------------------|---------------------------------|-------------|---------|
| N               | 59                 | 66/177 (37.3%)                  |             |         |
| T1              | 34                 | 73/102 (71.6%)                  | N*T1        | 0.002   |
| T2              | 37                 | 69/111 (62.2%)                  | N*T2        | 0.015   |
| T3              | 38                 | 54/114 (47.4%)                  | N*T3        | 0.275   |
| T4              | 38                 | 42/114 (36.9%)                  | N*T4        | 0.958   |

N, normal control; T1, poststroke within 3 months; T2, poststroke at 3 months; T3, poststroke at 6 months; T4, poststroke at 9 months.
swallowing, automatic breathing is suppressed by voluntary breathing. The interaction between voluntary and involuntary breathing during swallowing is well coordinated in normally functional swallowing. However, it is disrupted in the case of neurological diseases. Swallowing and respiration-related timing events are precisely coordinated subconsciously by cross-system control at the central pattern generator center in the brain stem. The entire process acts to ensure respiratory protection while swallowing. The respiration coordination with swallowing including SAD and pre- and postswallowing respiratory phase patterns are essential for safe swallowing.

**Respiratory phase pattern**

In a previous study, investigators analyzed the respiratory phase patterns of dysphagic stroke patients of whom 11 were aspirators and 15 were non-aspirators. The results showed that there was a greater frequency of the non-protective IN/IN respiratory phase pattern as dysphagia severity increased. The results of this study revealed that the stroke group and control group had similar probabilities for the non-protective respiratory phase pattern. On the other hand, the protective respiratory phase pattern did not decrease in the mildly dysphagic, unilateral stroke patients.

**Swallowing apnea duration**

Swallowing occurs in a pattern coordinated with breathing primarily in the expiratory final phase until inspiration in the next initial phase. This breath is a short expiration before a new breathing cycle. Swallowing apnea duration is a specifically preventive voluntary breathing stop that starts just before and stays present through the pharyngeal phase. Similarly, deglutition laryngeal closure duration may be measured using VFSS for comparison between controls and stroke patients, and within stroke of severity. In addition, the stroke patients with aspiration had SAD measurements twice as long as did those in the healthy control subjects. Another poststroke study of 18 patients with a wide range of neurological impairments and disabilities showed no difference in SAD between poststroke patients and control subjects. However, there was no longitudinal follow-up study. This respiratory coordination pattern demonstrated a longer duration in unilateral stroke patients with mild dysphagia compared to control subjects in our study. The prolonged SAD is necessary to compensate for the increased duration of the pharyngeal phase present with longer excursion time for thyroid cartilage movement. This is a compensatory protective response rather than a deterioration of function. Interestingly, the longer SAD persisted until the 9-month poststroke follow-up assessment.

**Piece-meal deglutition**

Previous studies demonstrated that swallowing limits can be performed as an objective, sensitive method to detect dysphagia in neurological diseases in an electromyography laboratory. Piece-meal deglutition poststroke is rarely reported and it is considered a protective mechanism. In a literature review, we found no other longitudinal follow-up of piece-meal deglutition in stroke recovery.
SAD and piece-meal deglutition

Piece-meal deglutition and longer SAD are two different protective phenomena for swallowing without aspiration. The results showed prolongation of SAD persisted until the 9-month, poststroke follow-up; nonetheless, the piece-meal swallowing probability decreased and did not differ significantly from that of the healthy controls at the 6-month, poststroke follow-up visit. Accordingly, we interpreted the results to mean that unilateral stroke patients experienced SAD prolongation that persisted longer than the piece-meal phenomenon after a stroke. Physiologically, the prolongation of SAD compensates for the delayed pharyngeal phase and longer TET to swallow the bolus in the mouth all at once. Swallowing the entire bolus is more efficient than swallowing it piece-meal in small multiple swallows. Clinically, we suggest that prolonged SAD is a more sensitive indicator to detect early subtle dysphagia than piece-meal swallowing.

Comparison with previous follow-up studies

There are few longitudinal follow-up studies of dysphagia after stroke.11,60-63 Most of these studies used the presence or absence of aspiration at the bedside evaluation61-63 or VFSS11 to determine swallowing recovery. Only one study standardized the procedures and parameters of VFSS to examine dysphagia recovery poststroke.60 Terre et al. recruited a small number of stroke patients with aspiration according to VFSS examinations from variable cerebral vascular territory of stroke insults at admission, with VFSS repeated at 1, 3, 6, and 12 months of follow-up. During follow-up, the likelihood of aspiration decreased progressively between 3 and 6 months after a stroke. The most significant decrease in aspiration occurred at the 6-month follow-up assessment.26

However, most poststroke swallowing follow-up studies had heterogeneous groups of patients and the poststroke examination period varied. Our study employed a specific and homogeneous population of patients with mild dysphagia resulting from unilateral stroke. Additionally, we applied a standardized assessment method and follow-up periods to enhance our understanding and support our conclusions. On the other hand, the main limitation of the study is that it shows swallowing and respiration coordination only the unilateral stroke patients. Thus, it does not represent stroke patients with bilateral hemispheric, brain stem, or cerebellar stroke. Additionally, large-scale, prospective follow-up studies are necessary to confirm our findings and to acquire more information about the recovery process of dysphagia after stroke in other stroke groups.

Future studies and clinical applications

The clinical application for swallowing and respiration interaction in stroke dysphagia require further investigation. Destabilization of the respiratory-swallowing coordination patterns occurred in our study and also in neurological diseases.33,64,65 The non-invasive method of monitoring swallowing and respiration parameters is valuable for future study design and research of poststroke swallowing studies. The non-invasiveness of the swallowing study makes it suitable for longitudinal follow-up study designs of outcomes and training effectiveness of poststroke swallowing. Furthermore, different foods with a variety of tastes, volumes, and consistencies for the boluses swallowed can be studied without increased radiation exposure to fragile stroke patients using such a non-invasive method. For swallowing and respiration recovery, further work is required to enable a greater understanding of the effect of stroke, and how best to facilitate treatment programs for stroke recovery. The recovery and training data could contribute to the development of stroke treatment programs and management to improve the clinical care of dysphagic stroke patients.

Because the dysphagia assessment method is non-invasive, it can be used in clinical practice at the patient’s bedside. The method may be used to monitor the dysphagia limit, time swallowing capacity, and speed in stroke or patients with neurological dysphagia.59,66 Additionally, continuous swallowing monitoring for eating behavior during meal times is important for stroke patients. This non-invasive ambulatory method is more convenient than non-ambulatory methods, and a wearable, portable or telemetering method is under development.52

CONCLUSION

The oropharyngeal parameters of swallowing and their coordination with respiration were impaired after stroke. These parameters improved gradually after the acute phase but did not return to normal during the chronic phase. These changes can be detected by the non-invasive method used in this study.

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DISCLOSURE
No competing interests declared.

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