Effects of Short Term Interferential Current Stimulation on Swallowing Reflex in Dysphagic Patients

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Abstract: We have previously shown that surface interferential current (IFC) stimulation at the sensory threshold significantly increases the number of swallows. In the present study, we evaluated the effects of IFC stimulation at the sensory threshold on the swallowing reflex of dysphagic patients (7 male and 5 female, Age, 75.8 ± 5.3 years) by videofluoroscopic (VFS) measurements. Each subject underwent three series of VFS examination, before, during, and after the IFC stimulation. We tested three food types, juice, jelly, and biscuits, however, only juice consistency resulted in significant changes in temporal measurements of VFS parameters before, during and after IFC stimulation. For juice consistency, IFC stimulation shortened the pharyngeal response duration (the duration from the hyoid bone beginning maximum elevation to its return to the resting position, before IFC: 1.37 ± 0.31(SD) s vs. during IFC: 1.17 ± 0.29 s, $p<0.001$) without changing the amount of anterior and vertical displacements of the hyoid bone. The duration from the onset of elevation of the soft palate to return to the resting position was also significantly shortened by the IFC stimulation (before IFC: 0.72 ± 0.16 s vs. during IFC: 0.64 ± 0.19 s, $p=0.035$), suggesting that pharyngeal motor activation sequence as a whole was shortened by the IFC stimulation. No painful and/or uncomfortable sensations were reported. We conclude that surface interferential current stimulation has a potential to be an alternative mode of therapeutic electrical stimulation for dysphagic patients.

Keywords: Deglutition, deglutition disorders, surface electrical stimulation, interferential current, videofluoroscopic measurements.

INTRODUCTION

Oropharyngeal dysphagia is a common complication in patients with cerebrovascular diseases and patients with Parkinson's disease [1]. In addition, dysphagia is often associated with disuse atrophy and sarcopenia. Recently, electrical stimulation techniques of various modalities have been combined with ordinary rehabilitation programs [2-4]. Modalities of therapeutic electrical stimulation may be classified into two categories; neuromuscular electrical stimulation (NMES) that contracts swallow-related muscles for improving muscle strength, and sensory afferent nerve stimulation that stimulates the central nervous system in an attempt to facilitate sensorimotor interactions within the brainstem and cerebral cortex. Among them, NMES using surface electrodes has been most widely used for the treatment of dysphagia, however its effect is controversial [5-7]. As to the effects of short term NMES, Baijens et al. [5] examined the effects of a single session of surface electrical stimulation in dysphagic patients with Parkinson's disease. They found only a few significant effects and some of them might be attributed to placebo effects. On the other hand, it has been shown that pharyngeal electrical stimulation (PES) using swallowed intraluminal electrodes can enhance the excitability and organization of human pharyngeal motor cortex [8]. Through the optimization of PES application dose, PES improved swallowing function after two weeks intervention in acute dysphagic stroke patients [9]. Whether short term afferent nerve stimulation affects the swallowing function has not been elucidated.

In the previous study [10], we have shown that surface interferential current (IFC) stimulation at the sensory threshold significantly increases the number of swallows. The result suggests that IFC stimulation activates the brainstem and/or cerebral cortex via afferent nerves, thereby facilitates the swallowing reflex. Therefore we hypothesized that short term IFC stimulation at the sensory threshold level modulates swallowing reflex in dysphagic patients as well. Specifically, we predicted that IFC stimulation would

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shorten the latency for evoking the swallowing reflex. To test this hypothesis, we evaluated changes in temporal and spatial measurements of videofluoroscopic parameters before, during, and after IFC stimulation in dysphagic patients.

METHODS

IFC Stimulation

A programmable interferential current stimulator (J Craft, Osaka, Japan) was used for IFC stimulation. The carrier frequency was set at 2000 Hz, and the beat frequency was set at 50 Hz. At this setting, the wave form of interferential current becomes 2000 Hz alternating current (AC) with 50 Hz amplitude modulation. Two independent pairs of electrodes were placed diagonally across the thyroid cartilage, targeting at the superior laryngeal nerve (Figure **1**) [10]. Rostral electrodes were placed at the submental region just beneath the mandibular angle. Caudal electrodes were placed at the level of laryngeal prominence along the anterior ridge of the sternocleidomastoid muscle. The intensity of stimulation was set at the sensory threshold level. Subjects reported a slight vibrating or ticklish sensation at this intensity level; however, they never complained of painful or tingling sensation. No muscular contraction was observed at this stimulus intensity. The current intensity was monitored using an AC leakage current clamp meter (CLAMP ON LEAK HiTESTER 3283, Hioki E.E., Nagano, Japan).

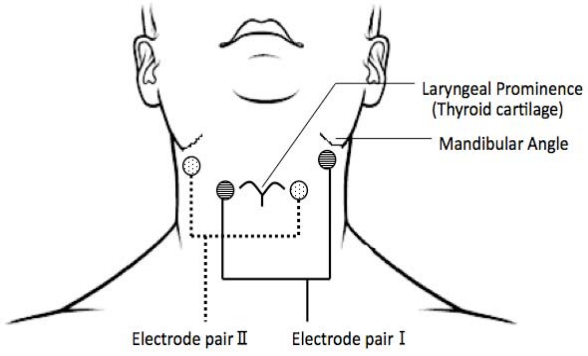

Figure 1: The placement of the electrodes is illustrated. Two pairs of electrodes were placed diagonally to induce IFC. Rostral electrodes were placed at the submental region just beneath the mandibular angle. Caudal electrodes were placed at the level of laryngeal prominence (thyroid cartilage) along the anterior ridge of the sternocleidomastoid muscle.

Videofluoroscopy (VFS)

The subject was seated upright in a chair in the fluoroscopic suite, allowing for lateral videofluoroscopic imaging of the subject during the swallow. The position of the subject was adjusted so that important structures were visible for later analyses, including the tongue, soft palate, hyoid bone, epiglottis, and upper esophageal sphincter (UES).

A single series of VFS consists of 6 trials of swallowing. Three food types, juice, jelly, and biscuits were served twice, respectively. A non-ionic contrast agent, iopamidol (Iopamiron-370, Nihon Schering, Japan), was mixed into these test foods so that it was diluted 2-fold (iodine concentration: 185 mg/mL). For juice swallowing, 3 ml of radiopaque grape juice was injected into the subject's mouth using a syringe, and immediately the command to swallow was given (command swallow). For jelly swallowing, 3g of radiopaque jelly was placed in the subject's mouth using a teaspoon, and the subject was instructed to chew and swallow naturally (chew-swallow complex). For biscuits swallowing, 1/4 portion (1.5g) of biscuits soaked with radiopaque solution was served, and the subject was instructed to chew and swallow naturally (chew-swallow complex). Videofluoroscopic images were recorded at 30 frames per second on a mini-DV camera recorder (HFG20, Canon, Tokyo, Japan). The images were off-line captured using a two-dimensional motion capture software (Move-tr/2D, Library, Tokyo, Japan), and stored on a hard disc drive for later temporal and spatial measurements.

Trial Protocol

Experimental protocols were approved by the ethical committees of Hyogo College of Medicine (No.1138), Hyogo Universities of Health Sciences (No.12007), Takasago Municipal Hospital, and Municipal Ashiya Hospital. Written informed consent was obtained from all subjects. Patients with dysphagia were recruited from inpatients in Takasago Municipal Hospital and Municipal Ashiya Hospital. Inclusion criteria were stable dysphagic patients with the dysphagia severity rating scale (DSR) [11] ranged between 2 and 4, and the age between 50 and 90 years old. Exclusion criteria were inability to a swallow following a command, a Mini-Mental State Examination (MMSE) score [12] below 21, dyskinesia or ataxia (resulting in problems with VFS quantitative measurements), and multiple histories of aspiration pneumonia or asphyxia within recent 6 months.

Each subject underwent three series of VFS examination, before, during, and after the IFC stimulation. Immediately after the first control series of

Table 1: Temporal Parameters Measured in VFS [13]

Name	Definition	
	Duration between	
OTD (Oral transit duration)	Beginning of posterior movement of the bolus	Enter head of the bolus in pharynx
STD (Stage transition duration)	Enter head of the bolus in pharynx	Hyoid beginning maximum elevation
PTD (Pharyngeal transit duration)	Enter head of the bolus in pharynx	Tail of the bolus into UES
PRD (Pharyngeal response duration)	Hyoid beginning maximum elevation	Hyoid return to rest
DTOUES (Duration to opening UES)	Beginning of posterior movement of the bolus	UES open

VFS, the IFC stimulation was applied to the patient. After ten minutes IFC stimulation, the patient underwent the second VFS series while receiving the IFC stimulation. The stimulation was discontinued at the end of the second VFS series. The total duration of IFC stimulation did not exceed 15 minutes. The patient took a rest for 15-20 minutes, and underwent the third VFS series.

Temporal and Spatial Measurements

Temporal parameters measured for VFS include the oral transit duration (OTD), the stage transition duration (STD), the pharyngeal transit duration (PTD), the pharyngeal response duration (PTD), and the duration to opening the upper esophageal sphincter (DTOUES). Each duration is defined as previously described [13] (Table **1**).

For spatial measurements, we defined the X-Y coordinate as follows: First the Y-axis was defined as the line connecting the anterior borders of C3 and C5, and the X-axis was defined as the line perpendicular to the Y-axis (Figure **2**).

The trajectory of the anterior-inferior edge of the hyoid bone was traced to measure the anterior and vertical displacements of the hyoid bone. To compensate the movement of the body, the X-Y coordinates of the anterior-inferior edge of C4 vertebral body were also measured, which was served as the anchor point. Then the anterior and vertical displacements of the hyoid bone were calculated according to the method described by Kim and McCullough [14]. The amount of displacement was normalized by defining the thickness of C5 vertebral body (arrow) as 1.0. Two expert speech therapists conducted these temporal and spatial measurements independently, and values were averaged.

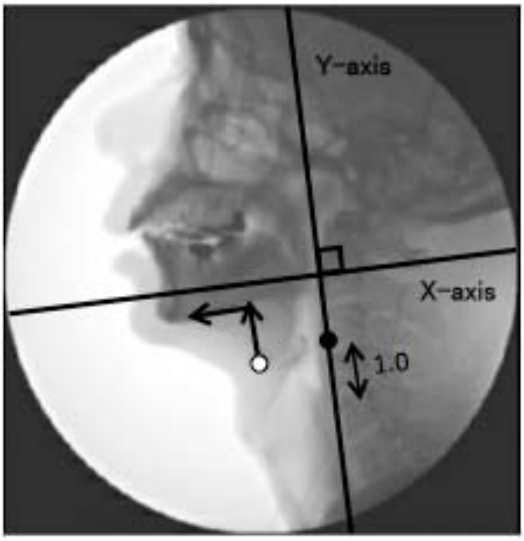

Figure 2: A representative videofluoroscopic movie frame showing landmarks used for spatial measurements. The Y-axis is defined as the line connecting the anterior borders of C3 and C5, and the X-axis is defined as the line perpendicular to the Y-axis. The X-Y coordinates of the following two landmarks were measured for each movie frame: (1) the anterior-inferior edge of C4 vertebral body (closed circle), served as the anchor point, and (2) the anterior-inferior edge of the hyoid bone (open circle). See text.

Statistical Analysis

Data are summarized as mean ± standard deviation (SD). Paired data were compared using dependent t-test. Changes in temporal VFS parameters' measurements and hyoid bone displacements before, during and after IFC stimulation were analyzed with the use of a linear mixed-effects model. The model included an unstructured covariance as a covariance structure among measurements. Three series of VFS examination were treated as a categorical factor. The linear mixed effects model analysis was followed by post-hoc dependent t-tests. The multiplicity of testing was corrected by Bonferroni's method. All p values were two-sided, and $p < 0.05$ was considered

Table 2: Patient Profiles

Patient ID	Age	Sex	Underlying disease	DSR	Cranial nerve involvement				
					V	VII	IX	X	XII
1	73	M	PD (Yahr 2)	2	-	-	-	-	-
2	68	M	CVD	4	-	+	-	-	-
3	78	F	CVD	3	-	+	-	-	-
4	78	M	Unknown	2	-	-	-	-	-
5	69	F	CVD	3	-	+	-	-	-
6	81	F	CVD	2	-	-	-	-	-
7	80	M	Unknown	4	-	-	-	-	-
8	81	F	CVD	3	-	+	+	+	+
9	83	F	PD (Yahr 3)	2	-	-	-	-	-
10	86	M	PD (Yahr 3)	4	-	-	-	-	-
11	72	M	CVD	3	-	+	-	-	+
12	83	M	PD (Yahr 2)	2	-	-	-	-	-

M; male, F; female, PD; Parkinson's disease, CVD; cerebrovascular disease, DSR; dysphagia severity rating score [11].

statistically significant. Statistical analyses were performed using IBM SPSS Statistics (version 22) for fitting the linear mixed-effects model analysis and SYSTAT (version 13) for others.

RESULTS

Twelve subjects (7 male and 5 female, Age, 75.8 ± 5.3 years) were enrolled in the study. The profiles of these subjects are given in Table **2**. Dysphagia was associated with Parkinson's disease in 4 subjects, and associated with cerebrovascular diseases in 6 subjects. In two subjects, the cause of dysphagia was not specified. The involvement of cranial nerves was seen in 5 subjects. All patients with Parkinson's disease conducted VFS series when they were at "on periods". Their Yahr's stages ranged between 2 and 3. All patients completed the control VFS before IFC stimulation and the second VFS during IFC stimulation. Three of twelve patients did not undergo the third VFS after IFC because of the time limitation of the use of the VFS facility. The current intensity of IFC stimulation ranged between 2-4 mA. No adverse side effects were observed during IFC stimulation.

Changes in temporal measurements of VFS parameters before, during and after IFC stimulation for different food consistencies are shown in Tables **3-5**. The only temporal parameter significantly changed among the three VFS series was PRD for juice consistency ($p<0.001$, linear mixed-effects model analysis). Post-hoc dependent t-tests revealed that PRD significantly shortened during IFC stimulation ($p<0.001$) and after IFC stimulation ($p=0.010$). Figure **3** shows changes in pharyngeal response duration (PRD) and stage transition duration (STD) before, during and after IFC stimulation for juice consistency. PRD shortened during IFC stimulation in all patients. Although STD shortened in three patients whose

Table 3: Changes in Temporal Measurements of VFS Parameters (Mean ± SD) before, during and after the Interferential Current Stimulation. Juice Consistency

VFS parameters	Before IFC	During IFC	After IFC
OTD	0.69 ± 0.38	0.70 ± 0.38	0.58 ± 0.34
STD	0.47 ± 1.31	0.24 ± 0.64	0.36 ± 0.63
PTD	1.30 ± 1.44	1.09 ± 0.69	1.15 ± 0.63
PRD	1.37 ± 0.31	1.17 ± 0.29**	1.15 ± 0.33*
DTOUES	1.43 ± 1.57	1.28 ± 0.90	1.54 ± 1.70

**$p < 0.001$, *$p=0.010$ after Bonferroni's correction.

Table 4: Changes in Temporal Measurements of VFS Parameters (Mean ± SD) before, during and after the Interferential Current Stimulation. Jelly Consistency

VFS parameters	Before IFC	During IFC	After IFC
OTD	0.95± 0.63	0.71 ± 0.41	0.88 ± 0.51
STD	2.20 ± 2.94	1.33 ± 1.47	1.29 ± 1.63
PTD	2.97 ± 3.00	2.11 ± 1.47	2.21 ± 1.80
PRD	1.24 ± 0.37	1.18 ± 0.28	1.20 ± 0.35
DTOUES	3.50 ± 3.51	2.43 ± 1.67	2.54 ± 1.69

Table 5: Changes in Temporal Measurements of VFS Parameters (Mean ± SD) before, during and after the Interferential Current Stimulation. Biscuits Consistency

VFS parameters	Before IFC	During IFC	After IFC
OTD	1.14 ± 0.81	1.31 ± 0.78	1.17 ± 0.65
STD	2.21 ± 3.94	1.75 ± 2.09	0.97 ± 1.35
PTD	3.15 ± 3.98	2.75 ± 2.14	1.96 ± 1.30
PRD	1.25 ± 0.28	1.29 ± 0.40	1.33 ± 0.39
DTOUES	3.78 ± 4.69	3.48 ± 2.36	2.72 ± 1.72

control STD was > 0.4 seconds, it did not show any consistent tendency in patients whose STD ranged between -0.21 and 0.21 seconds. Incidences of aspiration and pooling were not significantly altered.

To further characterize the temporal changes in swallowing reflex, timings and activity durations of swallowing-related organs for juice consistency were compared before and during IFC stimulation (Figure **4**). Activation timings were indicated relative to the onset of the hyoid elevation. Besides the duration from the onset of elevation of the hyoid bone to return to the resting position (PRD), the duration from the onset of elevation of the soft palate to return to the resting position was also significantly shortened by the IFC stimulation (before IFC: 0.72 ± 0.16 s vs. during IFC:

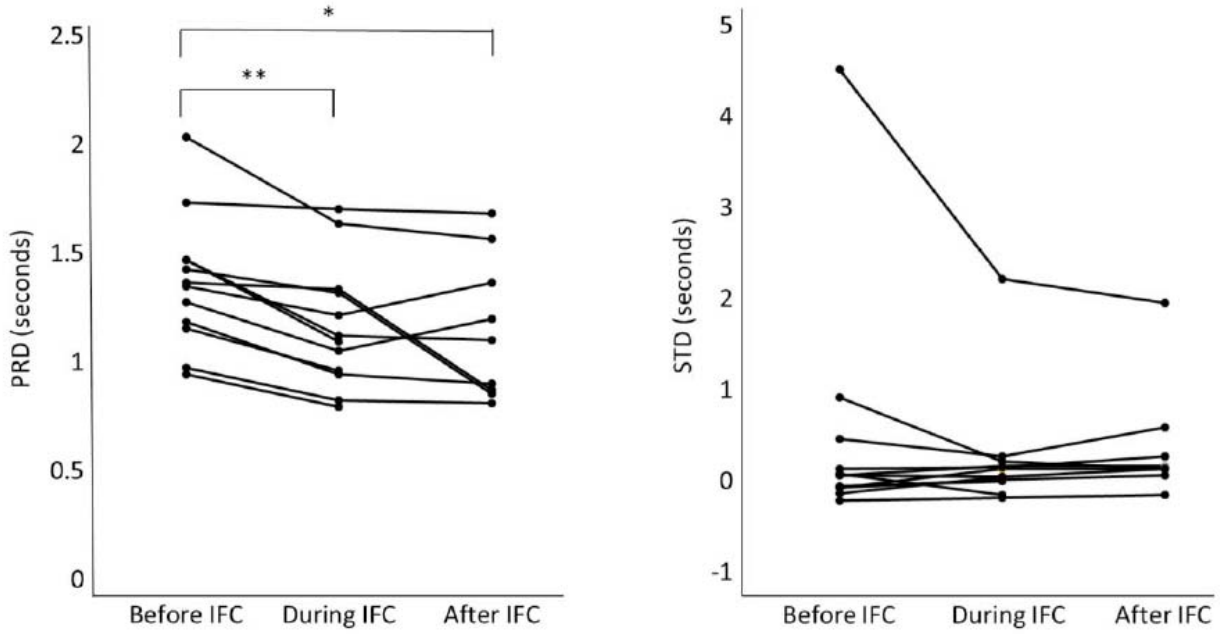

Figure 3: Changes in pharyngeal response duration (PRD) and stage transition duration (STD) before, during and after IFC stimulation. Juice consistency. **p < 0.001, *p=0.010 after Bonferroni's correction.

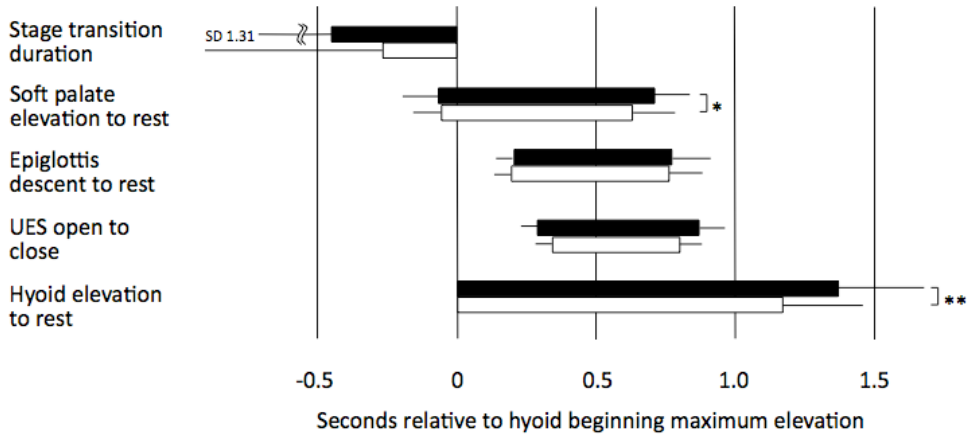

Figure 4: Timings and activity durations of swallowing-related organs before and after IFC stimulation. Juice consistency. Black bars represent durations before IFC stimulation and white bars represent durations during IFC stimulation. Each bar is drawn from the mean of the onset to the mean of the offset of activity. Whiskers before and after each bar represent SD of the onset and offset of activity, respectively. **p < 0.001, *p=0.035 by paired t-tests.

Table 6: Hyoid Displacements (Mean ± SD) before, during, and after the Interferential Current Stimulation

Test food	Before IFC		During IFC		After IFC	
	Anterior	Vertical	Anterior	Vertical	Anterior	Vertical
Juice	0.73 ± 0.24	0.69 ± 0.32	0.66 ± 0.30	0.64 ± 0.48	0.73 ± 0.25	0.75 ± 0.39
Jelly	0.75 ± 0.30	0.79 ± 0.24	0.68 ± 0.24	0.70 ± 0.33	0.73 ± 0.30	0.84 ± 0.45
Biscuits	0.82 ± 0.22	0.95 ± 0.36	0.82 ± 0.18	0.88 ± 0.47	0.83 ± 0.15	0.80 ± 0.41

0.64 ± 0.19 s, p=0.035). The results suggest that pharyngeal motor activation sequence as a whole was shortened by the IFC stimulation.

The anterior and vertical displacements of the hyoid bone before, during and after IFC stimulation for each food consistencies are shown in Table **6**. The linear mixed effects model analysis indicated no significant stimulation effects on the displacements of the hyoid bone.

DISCUSSION

We evaluated the effects of surface interferential current stimulation at the sensory threshold on the swallowing reflex of dysphagic patients by videofluoroscopic measurements. Although the latency for evoking swallow assessed by STD was shortened during IFC stimulation in patients with prolonged STD for juice consistency, it did not reach a statistically significant level. Considering that STD is the most varying measure among temporal parameters [13], further studies are needed to clarify whether short term IFC stimulation shortens the latency for evoking the swallowing reflex. Unexpected finding was that PRD for juice consistency was shortened during IFC stimulation for all patients. As shown in Figure **4**, it seems that the entire process of coordinated movements of pharyngeal and laryngeal organs during swallowing became compact. An increased total duration of the swallowing reflex may be seen in dysphagic patients [1], and thus the shortening of the swallowing reflex may be beneficial to a subset of dysphagic patients. It should be noted that the shortening of PRD was not the consequence of the reduction of displacements of swallowing-related organs, because the anterior and vertical displacements of the hyoid bone were not changed by IFC stimulation. PRD values during IFC stimulation are comparable to the normative data of PRD for juice consistency, which was reported to be 1.14 ± 0.24 [13]. The PRD shortening effect persisted after the electrical stimulation was discontinued. Whether the compactness of the swallowing reflex reflects improvement of swallowing function, and whether repeated stimulation further modifies swallowing function should to be elucidated in future.

We did not find any significant changes in temporal parameters for jelly and biscuits consistencies by IFC stimulation. We think that it is related to the instruction we gave to the patients upon test food swallowing. For jelly and biscuits swallowing, we instructed the patients

to chew and swallow naturally. The instruction might have added variability in properties of the bolus when it was swallowed, thereby increased the variability in parameter values, and eventually masked changes in temporal parameters caused by IFC stimulation, if any. In addition, the method we used for temporal analysis might be suitable only for the evaluation of command swallow, but not for the evaluation of chew-swallow complex that involves stage II transport [15]. Indeed, observing Tables **3-5**, it looks like with exception of PRD, baseline values of all other variables markedly increased from juice to higher consistencies, while PRD remained essentially unchanged. This is conceivably because other variables are associated with the movement of the bolus, which would be highly influenced by chew-swallow activity.

We do not know the exact mechanisms how IFC stimulation affects coordinated motor activity during swallowing. However, it is known that sensory input not only triggers reflex responses and modifies the threshold of the central pathway to be triggered, but also continually modulates motor activity during swallowing [16]. Although the swallowing motor sequence is centrally organized, it can change as the result of peripheral afferent information [17]. For example, it has been established that the amplitude and duration of the electromyographic activity of oropharyngeal muscles partly depends on the consistency of the bolus [18]. The superior laryngeal nerve (SLN) not only plays a major role in triggering the swallowing reflex, but also seems to relay such peripheral afferent information to the central pattern generator (CPG) in the brainstem to modulate the swallowing motor sequence. A subset of medullary swallowing interneurons, activated orthodromically by electrical stimulation of SLN, projects to the hypoglossal nucleus and the nucleus ambiguus, which are major motoneuron pools related to swallowing [19]. These swallowing interneurons may modulate coordinated swallowing motor activity.

Besides direct activation of swallowing interneurons in the medulla, supramedullary structures may be important for modulating swallowing motor sequence. Stimulation of the ipsilateral SLN or the glossopharyngeal nerve can induce evoked potentials in the fronto-orbital cortex in rabbits [20], and short-term (30 minutes) pharyngeal stimulation changes pharyngeal motor cortex excitability in humans [8]. These findings suggest that pharyngeal sensory afferent ascends to the cortex to possibly modulate swallowing function.

CONCLUSION

Short-term surface IFC stimulation modulated swallowing motor sequence to cause the shortening of the pharyngeal response duration without changing the amount of anterior and vertical displacements of the hyoid bone in patients with dysphagia. No painful and/or uncomfortable sensations were reported. We conclude that surface IFC stimulation has a potential to be an alternative mode of therapeutic electrical stimulation for dysphagic patients. Therefore, more intensive studies are needed.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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