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Electromyographic study assessing swallowing function in subacute stroke patients with respiratory muscle weakness

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Abstract

Background: Dysphagia has been reported to be associated with the descent of the hyolaryngeal complex. Further, suprahyoid muscles play a greater role than infrahyoid muscles in elevation of the hyolarngeal complex. Respiratory muscle training (RMT) can improve lung function, and expiratory muscle strength training can facilitate elevation of the hyoid bone and increase the motor unit recruitment of submental muscles during normal swallowing. This study aimed to investigate the surface electromyography (sEMG) of the swallowing muscles, bilaterally, and the effect of RMT on swallowing muscles in stroke patients with respiratory muscle weakness.

Methods: Forty patients with first episode of unilateral stroke were included in this retrospective controlled trial. After exclusion of 11 patients with respiratory muscle strength stronger than 70% of the predicted value, 15 were allocated to the RMT group and 14 to the control group. However, eventually, 11 patients in RMT group and 11 patients in control group completed the study. The sEMG of the orbicularis oris, masseter, submental, and infrahyoid muscles were recorded during dry swallowing, water swallowing (2 mL), and forced exhalation against a threshold breathing trainer set at different intensities, at baseline and after 6-week RMT.

Results: Regarding the sEMG of submental muscles, there were significant between-group differences on the latency of the unaffected side ($P=.048$), significant change from baseline force on the unaffected side ($P=.035$), and significant between-side difference ($P=.011$) in the RMT group during dry swallowing. Significant change in the duration from baseline was observed on the affected side of the RMT group when blowing was set at 50% maximal expiratory pressure (MEP; $P=.015$), and on the unaffected side of the control group when blowing set at 15% MEP ($P=.005$). Significant difference was observed in the duration between 50% MEP and 15% MEP after 6-week program in the control group ($P=.049$).

Conclusions: A 6-week RMT can improve the electric signal of the affected swallowing muscles with more effect on the unaffected side than on the affected side during dry swallowing. Furthermore, RMT with 50% MEP rather than 15% MEP can facilitate greater submental muscle activity on the affected side in stroke patients with respiratory muscle weakness.

Abbreviations: EMST = expiratory muscle strengthening training, MEP = maximal expiratory pressure, MIP = maximal inspiratory pressure, RMT = respiratory muscle training, sEMG = surface electromyography.

Keywords: dysphagia, respiratory muscle training, stroke, surface electromyography

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1. Introduction

Dysphagia is common in stroke patients. It is often followed by aspiration pneumonia, dehydration, and malnutrition.[1–3] It is reported to occur after a stroke in up to 51% to 55% of cases confirmed by clinical tests and 64% to 78% of cases by instrumental tests.[4]

Dysphagia has also been reported to be associated with the descent of the hyolaryngeal complex,[5] which is more elevated by the suprahyoid muscles than by both long pharyngeal muscles and the thyrohyoid.[6] Ding et al[7] demonstrated that the onset of submental muscle activity most often occurred before laryngeal elevation, and the initiation of laryngeal descent typically occurred before the termination of submental muscle activity, using surface electromyography (sEMG) and electroglottography techniques.

Respiratory muscle training (RMT) can improve pulmonary function, and expiratory muscle strength training (EMST) can increase motor unit recruitment of the submental muscle complex.[8] During EMST, the high expiratory pressure generated against a pressure threshold breathing device can cause epiglottis and laryngeal closure, trigger the opening of the upper esophageal sphincter, and facilitate vertical and anterior movements of the hyoid bone during normal swallowing.[9]

In healthy adults, the close temporal correlation between sEMG signals and laryngeal elevation during swallowing has been reported.[10] The signals from the orbicularis oris and masseters represent the oral phase. Those of the submental muscles including the geniohyoid and anterior belly of the digastric muscles represent the pharyngeal phase, and those of the infrahyoid muscles including the laryngeal strap muscles and the thyrohyoid muscles indicate the pharyngeal and initial esophageal phases.[11]

RMT has been reported to have a small effect on the swallowing function of patients with Huntington disease.[12] However, EMST has been reported to improve hyolaryngeal complex movement in patients with Parkinson disease. In subacute stroke patients, EMST with 70% of maximal expiratory pressure (MEP) can influence the activity of the suprahyoid muscles with the increase in motor unit recruitment of submental muscles recorded by sEMG.[3] Our recent study revealed that 6-week combined inspiratory and expiratory RMT could improve fatigue level, respiratory muscle strength, lung volume, respiratory flow, and dysarthria in stroke patients with respiratory muscle weakness.[13] However, the effect of RMT on the swallowing function of poststroke patients with respiratory muscle weakness remains unclear.

To our knowledge, no study has compared and reported sEMG data related to the swallowing muscles of the affected side and the unaffected side of stroke patients. This study aimed to assess the activation patterns of sEMG during swallowing and expiratory tasks and the effect of RMT on oral, masseter, submental and infra-hyoid muscles, and compare the differences between the sEMG signals from the 4 swallowing muscles of the unaffected side and the affected side, at baseline and after RMT in subacute stroke patients with respiratory muscle weakness.

We hypothesized that the afferent sensory stimulation through the oral, pharyngeal, and laryngeal regions, and the motor stimulation of the RMT could facilitate central and peripheral adaptation, organization, and reorganization of the swallowing motor cortex.[14] sEMG can provide information on the differences in electrical activity of swallowing muscles between the unaffected side and the affected side and between a control group and an RMT group.

2. Methods

2.1. Setting

This was a retrospective, nonrandomized, controlled trial. The study was approved by the Institutional Review Board of the Chang Gung Memorial Hospital, Kaohsiung Medical Board (IRB number: 202002163B0). Each patient or their family signed the informed consent form.

2.2. Participants

Poststroke patients (onset <6 months), aged 35 to 80 years, with inspiratory muscles weaker than 70% maximal inspiratory pressure (MIP) and expiratory muscles weaker than 70% MEP, admitted to a tertiary hospital, from April, 2016 to June, 2019 were selected from 2 clinical trials, funded by the Chang Gung Memorial Hospital, Taiwan (grant number: CMRPG8E0911; 2016-5-1 to 2018-4-30, and CMRPG8F0961, 2017-7-1 to 2019-6-30). The registration numbers for these clinical trials were NCT03491111 and NCT03767998.

Patients with increased intracranial pressure, uncontrolled hypertension, complicated arrhythmia, myocardial infarction, unstable angina, acute heart failure and pneumothorax, bullae/blebs in the preceding 3 months, and severe cognitive function or emotional disturbance, or infection were excluded.

Each patient's baseline characteristics: sex, age, body mass index, stroke duration, stroke type, Brunnstrom stage, Barthel index, functional oral intake scale,[15] modified Rankin scale, hand grip strength of the affected side, fatigue assessment scale,[16] heart rate at rest, peak cough flow, oxyhemoglobin saturation at rest, Borg scale,[17] MIP, MEP, and pulmonary function were recorded before and after the 6-week RMT program.

The inspiratory RMT started from 30% to 60% of MIP, and expiratory RMT started from 15% to 75% of MEP for 5 days per week for 6 weeks.[13]

2.3. sEMG study

After cleansing the skin with alcohol, a disposable, self-adhesive surface ground electrode was positioned on the skin overlying the clavicle, and another 4 pairs of recording and reference electrodes were placed on the ipsilateral orbicularis oris muscles (one over the upper lip and the other over the lower lip), masseters, submental muscles (one below the chin and the other lateral to the midline), and along the infrahyoid muscles lateral to the thyroid cartilage.[18–20] The electrodes were fixed with tape. sEMG signals were recorded using multiple channels of the VikingQuest Systems (VikingQuest EMG and Master Software V8.1 or newer, 2005; Nicolet VIASYS Healthcare, Madison, WI). The inter-electrical distance of the electrodes was not less than 10 mm,[11,19,21] and placed by a senior experienced physician.

While sitting, each patient performed 4 tasks: 3 trials of voluntary swallowing of saliva (dry swallowing task), 3 trials of swallowing 2 mL of water (water swallowing task; participants were asked to hold water in the mouth and remain still until instructed), and forced exhalation to generate sufficient expiratory pressure against the threshold breathing trainer after maximal inhalation to the total lung capacity. The resistance

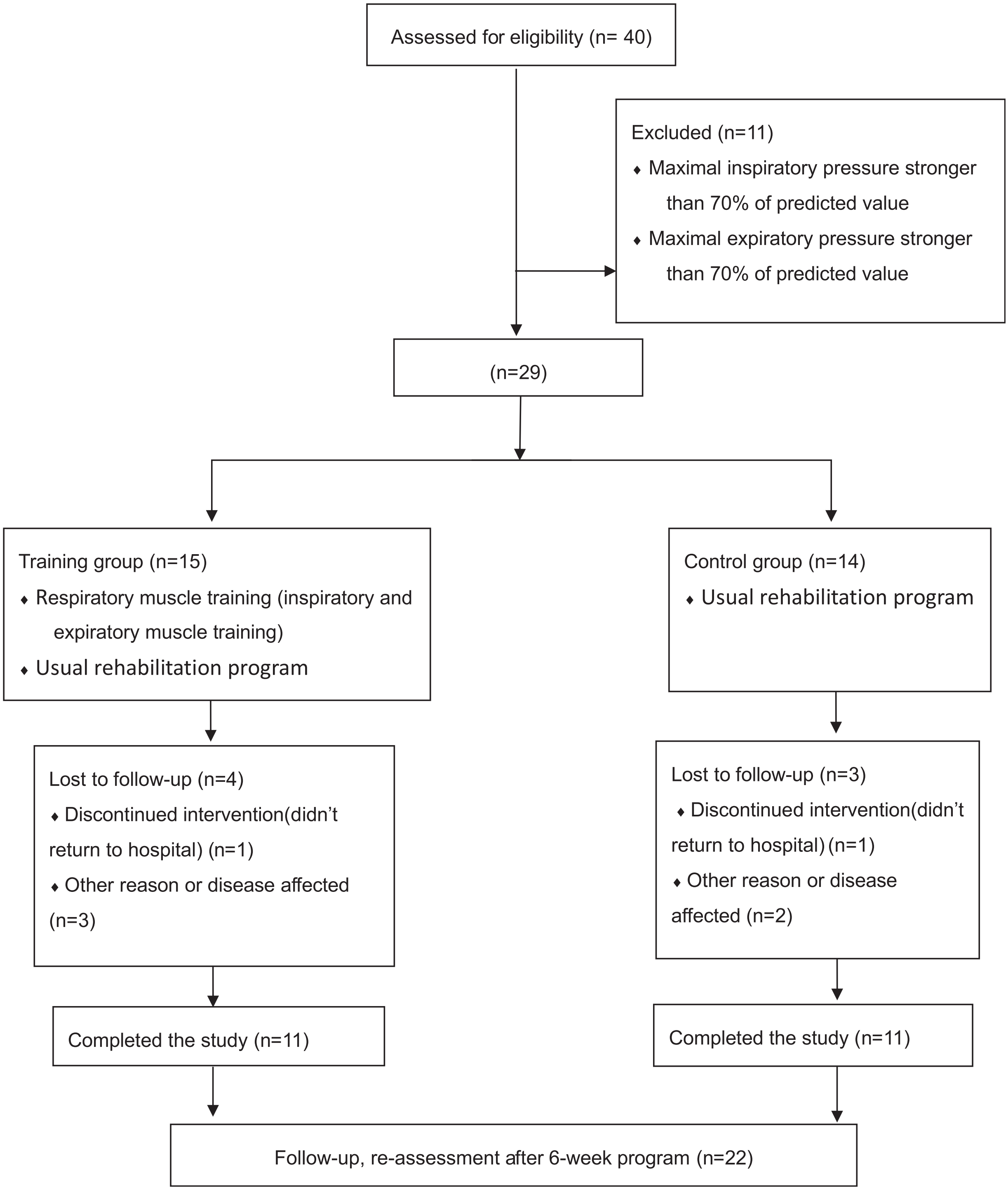

Figure 1. Design and flow of participants through the study.

was set at 15% and at 50% of each patient's MEP. A minimum of 30 seconds to 1 minute rest was required between tasks. The sEMG signals between the unaffected side and the affected side were compared.

2.4. Signal processing

The analog sEMG signal was filtered and rectified, and a smoothed sEMG waveform was obtained. The raw signal was band-pass filtered (25 Hz–1.5 KHz), with a notch filter at 60 Hz, and integrated with a time constant of 500 ms/division and amplitude of 50 uV/division.

2.5. sEMG analysis

Resting baseline EMG with waveform levels set at <5 mV root mean square[22,23] were obtained first. The activity patterns of the sEMG of the 4 swallowing muscles during the 4 swallowing tasks

Table 1

The characteristics of subjects in training and control groups.

Group	Total n=22	Training n=11	Control n=11	*P* value
Gender				**.028**[*]
Male	12 (50.00%)	4 (36.36%)	8 (72.73%)	
Female	10 (50.00%)	7 (63.64%)	3 (27.27%)	
Age (yr)	64.27 (10.99)	70.40 (5.82)	60.30 (10.77)	**.018**[*]
Body height (m)	1.63 (0.10)	1.57 (0.09)	1.69 (0.08)	**.012**[*]
Body w (kg)	63.87 (9.79)	64.00 (8.31)	62.12 (9.96)	.652
BMI (kg/m^2)	24.09 (3.60)	25.67 (2.58)	21.76 (2.50)	**.003**[**]
Respiratory weakness	22 (100%)	11 (100%)	11 (100%)	1.000
Swallowing disturbance	9 (40.91%)	5 (45.45%)	4 (36.36%)	.673
Stroke duration (mo)	2.90 (1.58)	3.20 (1.87)	2.30 (0.68)	.180
Stroke type				.196
Hemorrhage	10 (45.45%)	4 (36.36%)	6 (54.55%)	
Location (patient no.)		Putamen (3), thalamic (1)	Thalamic (1), putamen (1), middle cerebral artery (3), basal ganglion (1)	
Ischemic	12 (54.55%)	7 (63.64%)	5 (45.45%)	
Location (patient no.)		Basal ganglion and corona radiate (1), middle cerebral artery (3), lentiformin nucleus and corona radiate (1), pons and medulla (1), pons (1)	Basal ganglion and corona radiate (3), middle cerebral artery (2)	
Affected side				.628
Right	6 (27.27%)	3 (27.27%)	3 (27.27%)	
Left	16 (72.73%)	8 (72.73%)	8 (72.73%)	

Mann–Whitney *U* test was used for continuous variables. Fisher exact test for categorical variables. Values were presented as mean (standard deviation).

[*] $P < .05$.

[**] $P < .01$.

Table 2

Functional and pulmonary baselines of patients in the training and control group.

	Intention to treat analysis				Per protocol analysis			
Group	Total (n=29) Mean (SD)	training (n=15) Mean (SD)	Control (n=14) Mean (SD)	*P* value	Total (n=22) Mean (SD)	Training (n=11) Mean (SD)	Control (n=11) Mean (SD)	*P* value
Brunnstrom stage								
Upper limb								
Proximal part	2.76(1.06)	3.07(1.33)	2.47(0.64)	.126	2.68(0.99)	2.91(1.30)	2.45(0.52)	.295
Distal part	2.62(1.05)	3.07(1.21)	2.20(0.68)	.022*	2.50(0.96)	2.91(1.14)	2.09(0.54)	**.043***
Lower limb	3.24(0.91)	3.60 (1.02)	2.93(0.70)	.058	3.14(0.83)	3.36(0.92)	2.91(0.70)	.208
Barthel index	27.93(19.43)	28.21(19.38)	27.67(20.17)	.941	24.09(16.01)	24.09(15.78)	24.09(17.00)	1.000
FOIS	4.00(2.44)	4.21(2.49)	3.80(2.46)	.655	4.00(2.56)	4.27(2.69)	3.73(2.53)	.630
MRS	4.24(0.79)	4.29(0.91)	4.20(0.68)	.775	4.36(0.66)	4.55(0.69)	4.18(0.60)	.202
Hand grip of unaffected side (kg)	24.00(9.45)	22.48(10.54)	25.40(8.43)	.415	22.94(9.04)	21.00(9.45)	24.88(8.60)	.326
FAS	23.93(6.60)	24.78(6.30)	23.13(6.98)	.510	24.50(7.03)	24.54(7.65)	24.45(6.73)	.977
Rest heart rate (beat/min)	83.43(13.81)	77.23(10.29)	88.80(14.51)	.024	82.86(13.43)	82.00(15.59)	83.64(11.87)	.788
Peak cough (L/min)	253.70 (110.70)	246.67 (107.56)	259.33 (116.59)	.774	255.00 (106.94)	248.89 (118.16)	260.00(102.47)	.824
SpO_2 at rest (%)	97.38(1.21)	97.64(1.21)	97.13(1.19)	.264	97.36(1.17)	97.50(1.18)	97.27(1.19)	.288
Borg scale	0.50(0.42)	0.61(0.53)	0.40(0.28)	.192	0.50(0.46)	0.65(0.58)	0.45(0.27)	.370
MIP (cm H_2O)	46.41(27.26)	37.57(16.44)	54.67(32.92)	.092	44.36(21.24)	38.73(21.40)	50.00(20.49)	.222
MEP (cm H_2O)	49.10(17.33)	45.29(16.93)	52.67(17.52)	.259	49.72(20.04)	43.09(18.46)	56.36(20.14)	.123
Pulmonary function test								
FVC (L)	2.14(0.77)	1.96(0.77)	2.33(0.75)	.219	2.00(0.73)	1.72 (0.66)	2.33(0.70)	.062
FVC (% pred)	67.51(19.82)	73.59(22.95)	60.96(13.81)	.099	66.51(20.33)	68.79 (25.56)	63.71(12.22)	.592
FEV1 (liter)	1.81(0.64)	1.65(0.59)	1.99(0.67)	.174	1.71(0.63)	1.48 (0.52)	2.00(0.66)	.066
FEV1 (% pred)	71.75(19.59)	77.51(22.89)	65.55(13.55)	.114	71.45(20.12)	73.87 (24.87)	68.48(13.06)	.565
FEV1/FVC (%)	86.09(9.74)	85.94(10.06)	86.25(9.80)	.936	86.85(9.60)	87.81 (9.54)	85.67 (10.12)	.633
MMEF (L/s)	2.34(1.10)	2.26(1.12)	2.42(1.11)	.727	2.22(0.97)	1.96 (0.62)	2.54 (1.24)	.187
MMEF (%)	72.51(26.78)	77.35(22.25)	73.67(31.57)	.830	73.19(27.91)	70.64 (23.27)	76.02 (33.55)	.687

Mann–Whitney *U* Test (*$P < .05$).

FAS = fatigue assessment scale, FEV1 = forced expiratory volume in first second, FOIS = functional oral intake scale, FVC = forced vital capacity, MEP = maximal expiratory pressure, MIP = maximal inspiratory pressure, MMEF = maximum mid-expiratory flow, MRS = modified Rankin scale, SpO_2 = oxyhemoglobin saturation by pulse oximetry.

Table 3

Baseline surface EMG activities of submental muscles of 4 tasks between affected side and sound side in total group.

	Total group (n = 22)		
Task	**Affected side mean (SD)**	**Sound side mean (SD)**	***P* value between sides**
Dry swallow			
Latency (ms)	396.1(270.8)	312.9(175.3)	.901
Duration (ms)	1810.6(559.6)	2176.5(687.0)	.245
Amplitude (uV)	36.49(21.9)	45.82(30.2)	.215
Force (ms.uV)	67,081.3(44,496.6)	105,211.8(75,743.0)	.072
Water swallow (2 mL)			
Latency (ms)	271.7(154.2)	228.3(202.7)	.273
Duration (ms)	1607.8(602.6)	1672.9(340.4)	.727
Amplitude (uV)	40.0(19.4)	42.5(24.2)	.767
Force (ms × uV)	64,666.1(43,205.2)	74,268.2(56,134.9)	.636
Blow through 50% MEP			
Duration (ms)	1902.9(650.3)	2034.1(658.1)	.488
Amplitude (uV)	47.3(18.8)	51.9(17.4)	.318
Force (ms × uV)	96,499.8(48,860.5)	107,704.4(60,631.2)	.325
Blow through 15% MEP			
Duration (ms)	1735.6(449.7)	1775.6(427.72)	.590
Amplitude (uV)	44.6(22.6)	45.74(20.26)	.807
Force (ms × uV)	79,623.8(48,060.18)	81,750.6(41,542.8)	.811

Value expressed mean ± SD.
Force = duration × amplitude.
MEP = maximal expiratory pressure.

were recorded. The latency, duration, peak amplitude, and force "amplitude × duration of submental muscles during forceful expiration" were measured on the submental muscles.

Latency (in milliseconds) was defined as the electrical activity from the onset of sEMG signals of the oral stage to the onset of submental muscle activity. Duration (in milliseconds) was the time point of rising from baseline to the offset time point of returning to baseline of a single swallow or forced expiration. Peak amplitude (in uV) was measured. The force "amplitude × duration" was related to the number of motor units recruited during muscle activation, reflecting the strength of muscle contraction.

2.6. *Study outcomes*

The primary outcomes of this study were the latency, duration, peak amplitude, and force of sEMG signals during dry swallowing and water swallowing tasks, and the duration, amplitude, and force of submental muscles during forced exhalation at 15% and 50% of individual MEP.

2.7. *Statistical analysis*

Data were expressed as mean (standard deviation). The chi-square test was used for categorical variables. Mann–Whitney *U* test were used for the comparison of non-normally distributed continuous variables. Fisher exact test was employed for categorical variables. The intention-to-treat analysis and

Table 4

The comparison of electric activities of submental muscles of 4 tasks over affected side and sound side between the training and the control group before program.

	Training group (n = 11)			Control group (n = 11)			
Side	**Affected mean (SD)**	**Sound mean (SD)**	***P* value between sides**	**Affected mean (SD)**	**Sound mean (SD)**	***P* value between sides**	***P* value between groups**
Task							
Dry swallow							
Latency (ms)	487.78(289.26)	310.00(167.93)	.336	304.44(230.82)	316.25(194.86)	.324	.158
Duration (ms)	1694.44(407.43)	2181.11(781.88)	.074	1926.67(685.00)	2171.25(616.50)	.914	.398
Amplitude (uV)	28.62(20.06)	37.85(19.09)	.385	44.38(21.93)	54.78(38.65)	.370	.131
Force (ms.uV)	54,486.09 (44,977.82)	88,362.15 (64,269.20)	.142	79,676.51 (42,748.62)	124,167.8 (89,249.11)	.288	.241
Water swallow (2 mL)							
Latency (ms)	275.56(153.79)	290.00(198.37)	1.000	267.78(163.84)	158.75(196.21)	.139	.919
Duration (ms)	1748.89(463.77)	1603.33(290.13)	.785	1466.67(715.35)	1751.25(394.15)	.561	.335
Amplitude (uV)	30.11(13.48)	34.47(14.59)	.945	49.93(19.99)	51.49(30.39)	.678	**.025***
Force (ms × uV)	54,049.51 (34,810.57)	56,492.68 (27,012.30)	.932	75,282.76 (50,013.36)	94,265.64 (74,198.45)	.563	.311
Blow through 50% MEP							
Duration (ms)	1743.33(374.87)	2000.00(691.01)	.723	2082.50(858.16)	2072.50(664.18)	.562	.298
Amplitude (uV)	51.30(22.40)	46.89(17.20)	.884	42.43(24.91)	57.49(16.95)	.189	.373
Force (ms × uV)	100,406.26 (49,786.77)	92,300.04 (49,144.43)	.843	92,105.04 (50,816.1)	125,034.33 (70,668.87)	.300	.739
Blow through 15% MEP							
Duration (ms)	1766.25(428.05)	1942.50(466.96)	.537	1705.00(497.97)	1608.75(323.79)	.875	.796
Amplitude (uV)	46.83(21.45)	41.14(21.01)	.794	42.43(24.91)	50.34(19.75)	.576	.711
Force (ms × uV)	80,658.59 (43,167.27)	81,831.00 (49,106.66)	.859	78,589.10 (55,530.80)	81,670.15 (35,870.18)	.880	.935

Mann–Whitney *U* test was used for continuous variables and Fisher exact test for categorical variables.
Value expressed mean ± SD (*$P < .05$).
Force = duration × amplitude.
MEP = maximal expiration pressure.

Table 5

Electric activities of submental muscles at dry swallowing before and after 6-week study in the training and control groups.

	Baseline		Post 6-week					
Group-side	**Mean (SD)**		**Mean (SD)**		**Change from baseline mean (SD)**	***P* value for change from baseline**	***P* value between sides in each group**	***P* value between groups Affected side Sound side**
Latency (ms)								
Training-affected	488.75	(309.21)	318.75	(273.57)	−170.00(208.33)	.054	.097	.431
Training-sound	325.00	(172.96)	435.00	(276.97)	110.00(353.51)	.408		
Control-affected	321.11	(245.18)	295.56	(229.35)	−25.55(289.40)	.798	.191	**.048***
Control-sound	317.50	(194.11)	198.75	(113.57)	−118.75(188.71)	.118		
Duration (ms)								
Training-affected	1722.50	(426.17)	1846.25	(495.78)	123.75(532.59)	.532	.122	.906
Training-sound side	2222.50	(825.26)	1832.50	(681.15)	−390.00(720.99)	.170		
Control-affected	1963.33	(656.72)	2090.00	(722.82)	126.67(776.38)	.638	.844	.186
Control-sound	2101.25	(637.71)	1948.75	(483.90)	−152.50(639.95)	.522		
Amplitude (uV)								
Training-affected	29.82	(21.09)	34.90	(23.24)	5.08(17.08)	.428	.156	.426
Training-sound side	40.52	(18.53)	31.25	(11.53)	−9.27(14.38)	.111		
Control-affected	46.51	(25.25)	55.00	(21.94)	8.49 (40.60)	.548	.570	.574
Control-sound	50.31	(40.72)	56.57	(53.11)	6.27(57.07)	.765		
Force (ms × uV)								
Training-affected	57,803.76	(46,891.26)	69,130.85	(56,410.42)	11,327.089 (31,803.91)	.347	**.011***	.268
Training-sound side	95,584.86	(64,684.05)	60,416.39	(38,807.76)	−35,168.48 (38,078.67)	**.035***		
Control-affected	84,958.34	(43,466.35)	123,723.87	(70,550.38)	38,765.52 (89,826.65)	.232	.233	.304
Control-sound	112,795.66	(95,104.11)	109,763.96	(101,755.62)	−3031.70 (90,730.29)	.927		

*$P < .05$. Paired *t* test. Wilcoxon signed rank test.

perprotocol analysis were used for all data analyses. The Wilcoxon signed rank test was used to analyze changes in clinical data from baseline in the training and control groups. The Mann–Whitney test was used to compare 2 groups. The independent Student *t* test was used in normally distributed values. Paired samples t-tests were used to compare the differences in the values obtained at baseline and after 6 weeks within a group. All data were analyzed using the SPSS Statistics Version 22.0 (IBM Corp., Armonk, NY). A *P* value < .05 was considered statistically significant.

Table 6

Electric activities of submental muscles at 2 mL water swallowing before and after 6-week study in the training and control groups.

	Baseline		Post 6-week					
Group-side	**Mean (SD)**		**Mean (SD)**		**Change from baseline mean (SD)**	***P* value (change from baseline)**	***P* value between sides in each group**	***P* value between groups Affected side Sound side**
Water swallow – Latency (ms)								
Training-affected–Affected side	281.25	(163.40)	268.75	(162.69)	−12.50 (254.43)	.893	.052	.189
Training-sound	278.75	(208.97)	436.25	(160.80)	157.50 (279.89)	.155		
Control-affected	276.25	(164.75)	140.00	(110.19)	−136.25 (221.40)	.112	**.041***	.120
Control-sound	205.00	(231.58)	286.25	(182.52)	81.25 (214.84)	.320		
Water swallow – Duration (ms)								
Training-affected	1782.50	(483.93)	1603.62	(318.83)	−146.25(696.75)	.571	.476	.102
Training-sound	1622.50	(304.01)	1785.00	(308.64)	162.50(277.73)	.142		
Control-affected	1520.00	(762.89)	1932.50	(520.54)	412.50(455.72)	**.038***	.348	.801
Control-sound	1703.75	(434.44)	1738.75	(305.73)	35.00(326.01)	.770		
Water swallow – Amplitude (uV)								
Training-affected	28.49	(13.44)	28.70	(21.40)	0.20(19.47)	.977	.209	.887
Training-sound	36.55	(14.10)	31.58	(13.29)	−4.98 (13.40)	.328		
Control-affected	57.54	(35.87)	61.15	(39.86)	3.61(36.51)	.788	.945	.574
Control-sound	48.92	(32.32)	47.15	(30.03)	−1.77(50.37)	.924		
Water swallow – Force (ms × uV)								
Training-affected	52,834.05	(37,009.34)	50,211.23	(38,610.46)	−2622.82(44,174.88)	.871	.701	.418
Training-sound	60,322.58	(26,134.84)	55876.28	(29,128.26)	−4446.30(23,739.19)	.613		
Control-affected	92,984.65	(73,717.70)	116,895.56	(73,763.35)	23,910.91(65,893.24)	.339	.577	.883
Control-sound	89,202.41	(77,823.58)	82,350.50	(58,486.62)	6851.91(106,974.49)	0.861		

*$P < .05$. Paired *t* test. Wilcoxon signed rank test.

Table 7

Electric activities of submental muscles blow set at the 50% maximal expiratory pressure before and after 6-week study in the training and control groups.

Group-side	Baseline mean (SD)	Post 6-week mean (SD)	Change from baseline mean (SD)	*P* value change from baseline	*P* value between side in each group	*P* value between groups Affected side Sound side
Blow with 50% MEP – Duration (ms)						
Training-affected	1686.25 (356.49)	2842.50 (851.92)	1156.25 (1020.05)	**.015***	.119	.812
Training-sound	1983.75 (736.88)	2396.25 (891.16)	412.50 (886.84)	.230		
Control-affected	2000.00 (764.16)	2831.25 (903.60)	831.25 (1434.03)	.145	.910	.239
Control-sound	2147.50 (670.60)	2953.75 (1045.44)	806.25 (1170.20)	.092		
Blow with 50% MEP – Amplitude (uV)						
Training-affected	55.27 (20.28)	46.55 (22.51)	−8.73 (25.20)	.360	.855	.190
Training-sound	50.21 (14.99)	53.73 (39.83)	3.52 (39.37)	.808		
Control-affected	44.51 (13.93)	61.88 (32.05)	17.38 (41.48)	.275	.424	.880
Control-sound	58.15 (17.28)	56.39 (42.00)	−1.76 (43.95)	.913		
Blow with 50% MEP – Force (ms × uV)						
Training-affected	107,586.29 (47,985.07)	150,452.94 (78,850.45)	42,866.65 (79,085.41)	.169	.901	.384
Training-sound	98,427.35 (48,724.06)	150,600.83 (152,133.72)	52,173.48 (138,089.05)	.321		
Control-affected	93,174.99 (51,534.44)	183,748.89 (96,487.92)	90,573.90 (141,950.31)	.114	.334	.977
Control-sound	131,373.64 (72,054.17)	155,956.88 (101,673.73)	24,583.24 (113,057.14)	.558		

Value expressed mean ± SD for continuous variables and number (%) for categorical variables. (*$P < .05$) Paired *t* test. Wilcoxon signed rank test.
MEP = maximal expiration pressure.

3. Results

A total of 40 patients with first episode of unilateral stroke was selected for our sEMG study. After the exclusion of 11 patients, 15 were allocated to the RMT group and 14 to the control group. However, 7 patients (24.1%) dropped out of the study. Finally, 22 patients completed the study (RMT group, n = 11; control group, n = 11) (Fig. 1). No statistically significant between-group difference was found in the clinical characteristics of the participants, except sex ($P = .028$), age ($P = .018$, height ($P = .012$), and body mass index (25.67 ± 2.58 vs $21.76 \pm 2.5\,\text{kg/m}^2$, $P = .003$, $P < .01$) (Table 1). A significant difference was found only on the Brunnstrom stage of the distal part over the affected upper limb (3.07 ± 1.21 vs 2.20 ± 0.68, $P = .022$ in the intention-to-treat analysis and 2.91 ± 1.14 vs 2.09 ± 0.54, $P = .043$ in the perprotocol analysis) among the functional and pulmonary baseline parameters (Table 2).

In the RMT group, 1 patient was excluded because the patient did not return to our hospital for rehabilitation, as the nursing home was located far from the hospital, and 3 patients were dropped from the study because they developed other diseases. Among them, 1 patient had unilateral visual impairment; 1 had difficulty in relaxing his lip and masseter compared to the unaffected side, even with simultaneous stimulation of the lips, masseter, and submental muscles; and 1 had facial soreness and experienced pain at night when lying on the craniotomy side. In

Table 8

Electric activities of submental muscles blow set at the intensity of 15% maximal expiratory pressure before and after 6-week study in the training and the control groups.

Group-side	Baseline mean (SD)	Post 6-week mean (SD)	Change from baseline mean (SD)	*P* value change from baseline	*P* value between side in each group	*P* value between group Affected side Sound side
Blow with 15% MEP – Duration (ms)						
Training-affected	1764.29(462.31)	2077.14(704.10)	312.86(1139.78)	.495	.958	.458
Training-sound	1921.43(500.25)	2242.86(593.62)	321.43(874.63)	.368		
Control-affected	1658.75(490.14)	2336.25(784.71)	677.50(1013.43)	.101	.647	.457
Control-sound	1595.00(323.15)	2296.25(625.41)	701.25(491.72)	**.005** **		
Blow with 15% MEP – Amplitude (uV)						
Training-affected	51.40(18.50)	62.56(29.51)	11.16(24.49)	.273	.582	.434
Training-sound	44.97(19.44)	45.76(32.67)	0.79(31.97)	.950		
Control-affected	41.60(24.88)	54.50(35.20)	12.90(36.06)	.345	.578	.533
Control-sound	44.43(20.77)	53.29(29.69)	8.85(38.33)	.534		
Blow with 15% MEP – Force (ms × uV)						
Training-affected	88,407.64 (40,168.84)	126,035.59 (71,481.85)	37,627.94 (75,079.09)	.233	.775	.407
Training-sound	89,245.60 (47,961.05)	110,396.91 (88,995.04)	21,151.31 (90,895.69)	.561		
Control-affected	75,162.31 (55,630.89)	137,306.73 (105,234.92)	62,144.41 (114,365.16)	.168	.703	.443
Control-sound	71,519.86 (37,043.12)	127,432.55 (86,170.64)	55,912.69 (92,900.63)	.132		

Value expressed mean ± SD for continuous variables and number (%) for categorical variables. (**$P < 0.01$) Paired t- test.

Table 9

Comparison of electric activities of submental muscles at 50% MEP blow and 15% MEP blow of the maximal expiratory pressure before and after 6-week training in the training group.

Total group (n = 11)					
Group-side	**50% MEP mean (SD)**		**15% MEP mean (SD)**		***P* value between 50% and 15%**
Training-affected					
Baseline					
Duration (ms)	1686.25	(356.49)	1764.29	(462.31)	.666
Amplitude (uV)	55.27	(20.28)	51.40	(18.50)	.965
Force (ms × uV)	107,586.29	(47,985.07)	88,407.64	(40,168.84)	.652
Post 6-week					
Duration (ms)	2842.50	(851.92)	2077.14	(704.10)	.111
Amplitude (uV)	46.55	(22.51)	62.56	(29.51)	.531
Force (ms × uV)	150,452.94	(78,850.45)	126,035.59	(71,481.85)	.523
Training-sound					
Baseline					
Duration (ms)	1983.75	(736.88)	1921.43	(500.25)	.780
Amplitude (uV)	50.21	(14.99)	44.97	(19.44)	.630
Force (ms.uV)	98,427.35	(48,724.06)	89,245.60	(47,961.05)	.670
Post 6-week					
Duration (ms)	2396.25	(891.16)	2242.86	(593.62)	.434
Amplitude (uV)	53.73	(39.83)	45.76	(32.67)	.501
Force (ms × uV)	150,600.83	(152,133.72)	110,396.91	(88,995.04)	.393

Value expressed mean ± SD.
Force = duration × amplitude. Mann–Whitney *U* test was used for continuous variables.
Fisher exact test for categorical variables.
MEP = maximal expiration pressure.

the control group, 1 patient was to lost follow-up and 2 patients developed other diseases, which included upper gastrointestinal bleeding and craniotomy with mild headache during the 50% MEP forced exhalation task. Broken teeth and braces could have interfered with these tasks.

In the analysis including all participants, no significant between-side difference was found at the baseline sEMG activity of the submental muscles during the 4 tasks, despite longer mean latency, shorter duration, lower amplitude, and lesser force on the affected side. Shorter latency and less force were observed

Table 10

Comparison of electric activities of submental muscles at 50% MEP blow and 15% MEP blow of the maximal expiratory pressure before and after 6-week study in the control group.

Total group (n = 11)					
Group-side	**50% MEP mean (SD)**		**15% MEP mean (SD)**		***P* value between 50% and 15%**
Control-affected					
Baseline					
Duration (ms)	2000.00	(764.16)	1658.75	(490.14)	.780
Amplitude (uV)	44.51	(13.93)	41.60	(24.88)	.630
Force (ms × uV)	93174.99	(51534.44)	75162.31	(55630.89)	.670
Post-6 week					
Duration (ms)	2831.25	(903.60)	2336.25	(784.71)	.434
Amplitude (uV)	61.88	(32.05)	54.50	(35.20)	.501
Force (ms × uV)	183,748.89	(96,487.92)	137,306.73	(105,234.92)	.393
Control-sound					
Baseline					
Duration (ms)	2147.50	(670.60)	1595.00	(323.15)	.136
Amplitude (uV)	58.15	(17.28)	44.43	(20.77)	.435
Force (ms × uV)	131,373.64	(72,054.17)	71,519.86	(37,043.12)	.174
Post 6-week					
Duration (ms)	2953.75	(1045.44)	2296.25	(625.41)	**.049***
Amplitude (uV)	56.39	(42.00)	53.29	(29.69)	.806
Force (ms × uV)	155,956.88	(101,673.73)	127,432.55	(86,170.64)	.380

Value expressed mean ± SD (**P* < .05).
Force = duration × amplitude. Mann–Whitney *U* test was used for continuous variables.
Fisher exact test for categorical variables.
MEP, maximal expiration pressure.

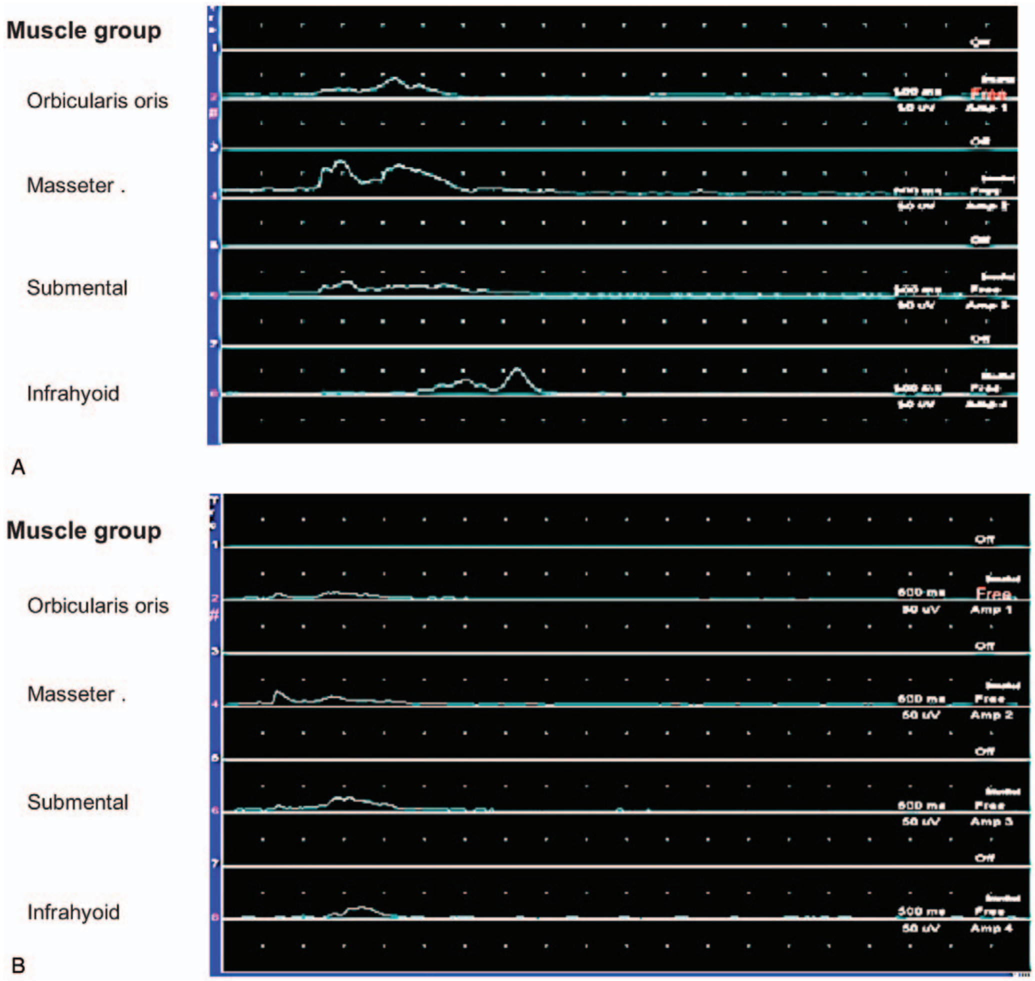

Figure 2. A 4-channel surface EMG recording, rectified and filtered. A: during dry swallowing. B: during the swallowing of 2 cc of water. EMG = electromyography.

during the water swallowing task than during the dry swallowing task (Table 3).

In the comparison of sEMG activities of the submental muscles during the 4 tasks, no significant between-side differences were found within each group, except the amplitude during water swallowing was significant between the groups (*P* = .025) (Table 4).

With regard to the dry swallowing task before and after the 6-week RMT program, a decrease in the latency on submental muscles over the affected side was found in the RMT group, as compared with the unaffected side in the training group (*P* = .054 on the affected side vs *P* = .408 on the unaffected side), and significant between-group difference was found on the unaffected side (*P* = .048). Meanwhile, significant change in baseline force on the unaffected side (*P* = .035) and significant between-side difference (*P* = .011) were obtained in the RMT group (Table 5).

For the water swallowing task, there was significant between-side difference in the latency on submental muscles after the study in the control group (*P* = .041), and significant change from baseline in the duration over the affected side of control group (*P* = .038) (Table 6).

In the comparison of the electrical activities of submental muscles set at 50% MEP inhalation and 15% MEP inhalation before and after the 6-week RMT for both group, significant change in the duration from baseline was observed on the affected side of the RMT group when blowing was set at 50% MEP (*P* = .015) (Table 7), and on the unaffected side of the control group when blowing set at 15% MEP (*P* = .005) (Table 8). No significant difference in sEMG variables at baseline and after the program was found in either group, except in the duration set at 50% MEP on the unaffected side of the control group (*P* = .049) (Tables 9 and 10).

A 4-channel surface EMG recording, rectified and filtered, during dry swallowing and during the swallowing of 2 cc of water were shown (Fig. 2A, B). Four-share swallows during dry swallowing was shown (Fig. 3).

4. Discussion

In the analysis of all patients, no significant between-side difference in the electrical activity of submental muscles at baseline was observed, but longer mean latency, shorter duration, reduced amplitude, and less force in the affected side than those in the unaffected side were noted. This finding was probably due to the small sample size, and the decrease in the electrical activity of the submental muscles in the affected side can still be related to the location of the brain lesion.

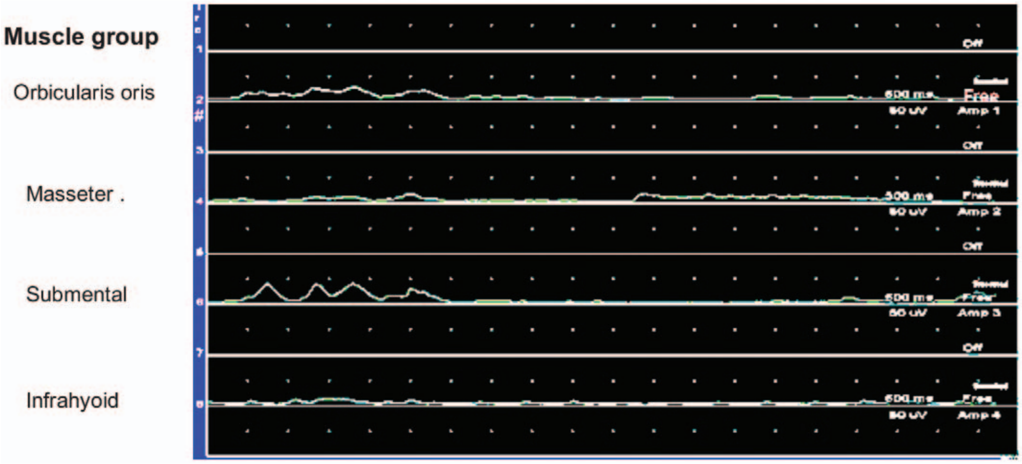

Figure 3. A 4-channel surface EMG recording, rectified and filtered. Four-share swallows are shown during dry swallowing. EMG = electromyography.

Shorter latency and less force were noted with the water swallowing than with the dry swallowing task. This implied that swallowing 2 mL of water may be easier than swallowing saliva. This is consistent with the findings of Vaiman et al[18] in that the duration of dry swallowing was longer than that of wet swallowing. Almost every patient could tolerate the water swallowing task without choking. Therefore, to reduce dehydration in stroke patients with respiratory muscle weakness, we advocate swallowing a small amount of water a few times, providing no choking occurs, or after dry saliva.

With regard to the dry swallowing task, the RMT group showed significant between-group difference in the unaffected side in terms of latency and significant change from the force at baseline in the unaffected side and significant between-side difference after the 6-week RMT program. The findings showed that RMT had a greater effect on the unaffected side than on the affected side. This finding may be explained by Hamdy et al[14] report that, with the existence of the compensatory reorganization in the undamaged hemisphere, RMT could stimulate and markedly increase the area of pharyngeal representation in the undamaged hemisphere, but they found no changes in the damaged hemisphere in stroke patients over a period of weeks.

As a resistance lower than 30% of MIP was insufficient to result in improvement in pulmonary function.[24] In our study, we used the threshold of 15% of MEP as a control to compare with that of 50% of MEP. A significant difference in the duration of submental sEMG was observed in the unaffected side of the control group after the RMT between exhalation at 50% of MEP and that at 15% MEP. This finding indicated that the facilitating or stimulatory effect of forceful exhalation over submental muscles and higher blow force is preferred.

However, given the fluctuations of sEMG signals during swallowing, it was not easy to quantitatively and qualitatively evaluate the activation patterns, timing, and relationship between the 4 main swallowing muscles, especially for the oral phase, because this is under conscious control. We observed a large variability in the amplitude and duration of electrical activities. These findings were similar as that reported in studies of swallowing of the normal subjects by Vaiman et al.[18] The recorded sEMG signals increased with an increase in the intensity of threshold training. Therefore, peak amplitude,[25] which was used to indicate the maximum myoelectrical activity during swallowing, and the force of the submental muscle sEMG during forced exhalation were measured in our study. We also used swallow-to-command techniques to obtain maximal effort.[23]

In our study, some patients became exhausted during the forced exhalation tasks. Therefore, we tried to schedule the sEMG study at the same time of a day and performed sEMG on 1 side at a time.

sEMG can provide complementary information on the timing, activity, and pattern of swallowing muscles. We supposed that one share in electric activity occurred during one swallow. In our study, single-share, double-share, or triple-share of the sEMG activity in the submental muscles were found during the saliva and water swallowing tasks. This may be attributed to the after effect of wet swallowing. In addition, the sEMG patterns usually stabilize at the second and third swallowing trials. This might be an indication of the adaptation of patients with incomplete muscle relaxation or the lack of good coordination among the activities of different swallowing muscles in our subjects as reported by Vaiman et al.[18]

We suggest that sEMG can be used to examine the electrical activity of swallowing related muscles for stroke patients with respiratory muscle weakness and/or dysphagia. It also can be used as biofeedback training[23] to relax spastic lips and masseter muscles or to reduce involuntary swallowing movements. Further studies may observe the temporary relationship and electrical activities between submental and infra-hyoid muscles, and examine coordination between both muscles.

4.1. Limitations

Previous studies had discussed the effect of lesion localization in stroke patients related to dysphagia. Although dysphagia has been reported to primarily associate with right hemispheric lesions, and more significantly with swallowing impairment, some studies had contradictory results.[26–29] Moreover, brainstem infarcts have different impact on dysphagia.[30] Generalizability of the study results was limited. Due to the small sample size, the relationship of the effect of RMT with the lesion locations, lesion side, and the type of stroke was not statistically analyzed. Further, the short follow-up period, and lack of healthy, age-matched subjects or placebo group as controls are other limitations.

In conclusion, for patients with respiratory muscle weakness, sEMG can provide information related to swallowing of saliva and of a small amount of water. A 6-week RMT can improve the electric signal of the affected swallowing muscles and have more effect on the unaffected side than on the affected side, during dry swallowing. RMT with 50% MEP rather than 15% can facilitate more submental muscle activity on the affected side in stroke patients with respiratory muscle weakness.

5. Clinical messages

In stroke patients with respiratory muscle weakness:

1. RMT had a greater effect on the unaffected side than on the affected side during dry swallowing.
2. A 6-week RMT could improve the electric signal of the affected swallowing muscles and increase the force of the sEMG on the unaffected side of submental muscles.
3. RMT with 50% MEP rather than 15% MEP could facilitate more submental muscle activity in stroke patients with respiratory muscle weakness.

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