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Proposal for a Modified Jaw Opening Exercise for Dysphagia: A Randomized, Controlled Trial

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Objective: To verify the feasibility and effectiveness of a newly developed modified jaw opening exercise (MJOE) in post-stroke patients with pharyngeal residue who completed a six-week exercise regimen.
Design: Double-blind, randomized, controlled trial.
Participants: 16 patients with stroke-related dysphagia.
Interventions: Participants were allocated to an intervention group (MJOE: one set of five repetitions at 80% maximum voluntary contraction (MVC) for 6 seconds) or a control group (isometric jaw closing exercise: one set of five repetitions at 20% MVC for 6 seconds). Each group performed four sets a day, five times a week, for a total of six weeks.
Main Outcome Measures: A videofluorographic swallowing study was performed before and after exercise. The distance between the mental spine and the hyoid bone (DMH) and hyoid displacement (HD) were measured.
Results: Twelve participants completed the study. No pain in the temporomandibular joint and/or anterior region of the neck occurred during the exercise period. In the intervention group (N=6), a decrease in DMH where anterior HD ended and an increase in anterior HD were seen. In the control group (N=6), no changes were seen.
Conclusions: MJOE is feasible without any adverse events in post-stroke patients, and it promotes anterior HD during swallowing.

Key words: deglutition disorder, dysphagia, jaw opening, strength exercise

INTRODUCTION

Superior and anterior displacement of the hyoid bone during pharyngeal swallowing is critical to epiglottic closure for airway protection and the opening of the upper esophageal sphincter. Perlman *et al.* reported a significant correlation between reduced hyoid displacement and penetration/aspiration in dysphagic patients with neurogenic disorders [1].

Recent clinical studies of dysphagia have shown increasing interest in treatment with an emphasis on functional improvement. Shaker reported an exercise method backed by considerable evidence that improves pharyngeal motor function [2]. The strengthening effect on the anterior neck muscles is cited as the mechanism for this improvement; however, it is difficult to selectively contract the suprahyoid muscles (SHMs). This means that an exercise method that simultaneously contracts the SHMs (digastric, mylohyoid, geniohyoid, and stylohyoid muscles) and infrahyoid muscles (IHMs) cannot be excluded.

In addition to elevating the hyoid bone and larynx forward and upward during swallowing, the SHMs depress the mandible to open the jaw. To address this, Wada *et al.* devised a jaw opening exercise (JOE) in which the jaw is opened to its maximum and held in this position for 10 seconds, and they reported that this was an effective treatment for dysphagia caused by dysfunction of hyoid elevation and upper esophageal sphincter opening [3].

Kraaijenga *et al.* also reported significant increases in jaw opening strength and muscle volume of the SHMs following jaw opening against resistance exercise using an originally developed Swallow Exercise Aid [4].

The SHMs and IHMs are the primary muscles involved in jaw opening movement. In general, the role of the SHMs in jaw-opening movement is to open the mouth by contracting, while the position of the hyoid bone is fixed by contraction of the IHMs.

On the other hand, Muto *et al.* reported that the hyoid bone moved downward and backward with increased jaw opening [5]. This means that, if the contractile force of the IHMs is greater than that of the SHMs, the SHMs undergo eccentric contraction. In other words, eccentric contraction of the SHMs appears to pose the risk of excessively elongating the SHMs. In addition, while muscle spindles are generally abundant in human skeletal muscles, there appears to be a lack or paucity of spindle cells in the SHMs [6]. Therefore, evaluation and exercise methods that include this type of movement may consequently be detrimental to the

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swallowing function of elderly individuals with a low hyoid and larynx at rest.

To address this, we hypothesized that pressing and holding the tongue anteriorly against the hard palate serves as a useful anchor to suppress eccentric contraction of the SHMs during jaw opening against resistance exercise.

Previous reports were limited to JOE with the jaw open and the tongue free [3, 4, 7]. We therefore devised an exercise method in which upward vertical resistance is applied to the jaw while the mouth is closed with the tongue held in the tipper swallow position to prevent the mouth from opening.

The aim of this study was to verify the feasibility of MJOE and its effectiveness to promote anterior displacement of the hyoid bone during swallowing.

METHODS

Participants

Patients undergoing post-stroke rehabilitation were recruited between September 2011 and November 2013 from the inpatient Department of Rehabilitation of Tokai University Oiso Hospital. Forty-one participants were assessed for eligibility. The inclusion criteria were: (1) dysphagia including hypopharyngeal residue found by videofluorographic swallowing study (VFSS); and (2) the ability to perform the real or sham exercise in this study according to instructions. Patients who met both of the above criteria were included among the participants. Exclusion criteria were: (1) level 1 to 4 on the Functional Oral Intake Scale (FOIS) [8] and/or pulmonary aspiration with 2 ml of barium water in the VFSS; (2) past or present temporomandibular joint (TMJ) disease and/or tumor of the head and neck; and (3) past or present progressive disease causing dysphagia (e.g., Parkinson's disease). Patients were excluded if they met one or more of the above criteria.

Wada *et al.* reported that the effect size of JOE for forward movement of the hyoid bone was 0.69 [3]. We hypothesized that the effect size of MJOE would be similar to that of JOE. When the total sample size was calculated according to the effect size of 0.69, an alpha of 0.05, and a power of 80%, the result was at least 11 patients. To account for possible participant dropouts, 16 participants were recruited.

In the present study, 16 patients were excluded because they did not meet the inclusion criteria, and 9 patients were excluded because they had FOIS level 1–4 and/or 2 ml of liquid aspiration. In total, 16 participants (6 women and 10 men) were recruited to participate in this randomized, double-blind study. All participants signed informed consent forms in accordance with the Declaration of Helsinki, and this study was approved by the Medical Ethics Committee of Tokai University (11R-094). The experimental design is shown as a flow diagram in Fig. 1.

Randomization, Blinding

One speech-language pathologist was in charge of patient allocation. The 16 participants were randomly allocated to an intervention group (N=8; real exercise) or a control group (N=8; sham exercise) using a random number chart. One physician was placed in charge of evaluation, including performing VFSS. Both the patients and the evaluator were blinded to the type of exercise. Specifically, throughout the study period, the participants performed exercises in a dedicated private room, which anyone other than the trainer was prohibited from entering. The trainer and participants were also under strict orders not to discuss the content of the exercise regimen outside of the exercise settings.

Interventions

Real exercise (MJOE): Surface electrodes attached to the SHMs at the mandibular midline were connected to biofeedback equipment (Oisaka Electronic Equipment Ltd., Hiroshima, Japan). Participants were then asked to close their mouth in a comfortable sitting position and to press the front half of their tongue lightly against their hard palate (tipper swallow tongue position) [9]. The trainer placed one hand under the participant's chin and applied upward vertical resistance to prevent the participant from opening the mouth. At this point, visual feedback was given to the participant on the intensity of the isometric opening movement of the mandible while the mouth was closed and the front half of the tongue was still pressed against the hard palate. Participants were then instructed to maintain 80% maximum voluntary contraction (MVC) for 6 seconds. This was repeated five times, forming one set. Four sets were performed per day, five times a week, for a total of six weeks. The resistive load remained the same as it was at the start of exercise for the six weeks. (Fig. 2)

Sham exercise (isometric jaw closing exercise): Surface electrodes attached to the masseter were connected to biofeedback equipment. Participants were given visual feedback on the intensity of isometric closing movement of the mandible while their jaw was occluded in a comfortable sitting position. Participants were then instructed to maintain 20% MVC for 6 seconds. This was repeated five times, forming one set. Four sets were performed per day, five times a week, for a total of six weeks. The resistive load remained the same as it was at the start of exercise for the six weeks.

Discontinuance criteria were feeling pain in the TMJ and/or anterior region of the neck during exercise.

Outcome Measurements

VFSS: To obtain aspiration evasion and posture reproducibility, command swallowing of 2 ml of barium water held in the floor of the mouth was repeated six times and recorded in lateral-view images while participants sat in a comfortable 60° reclining position with their neck slightly flexed. This was performed before starting and after completing the exercise. Recorded frame-by-frame images (30 frames per second) of three endpoints (distance between the inferior mental spine and the central portion of the hyoid bone [DMH], hyoid displacement [HD], and pharyngeal residue) were evaluated using two-dimensional motion analysis software (DIPP-Motion PRO 2D, DITECT Corporation, Tokyo, Japan).

Main Outcome Measure: DMH

The virtual length of the geniohyoid muscle was

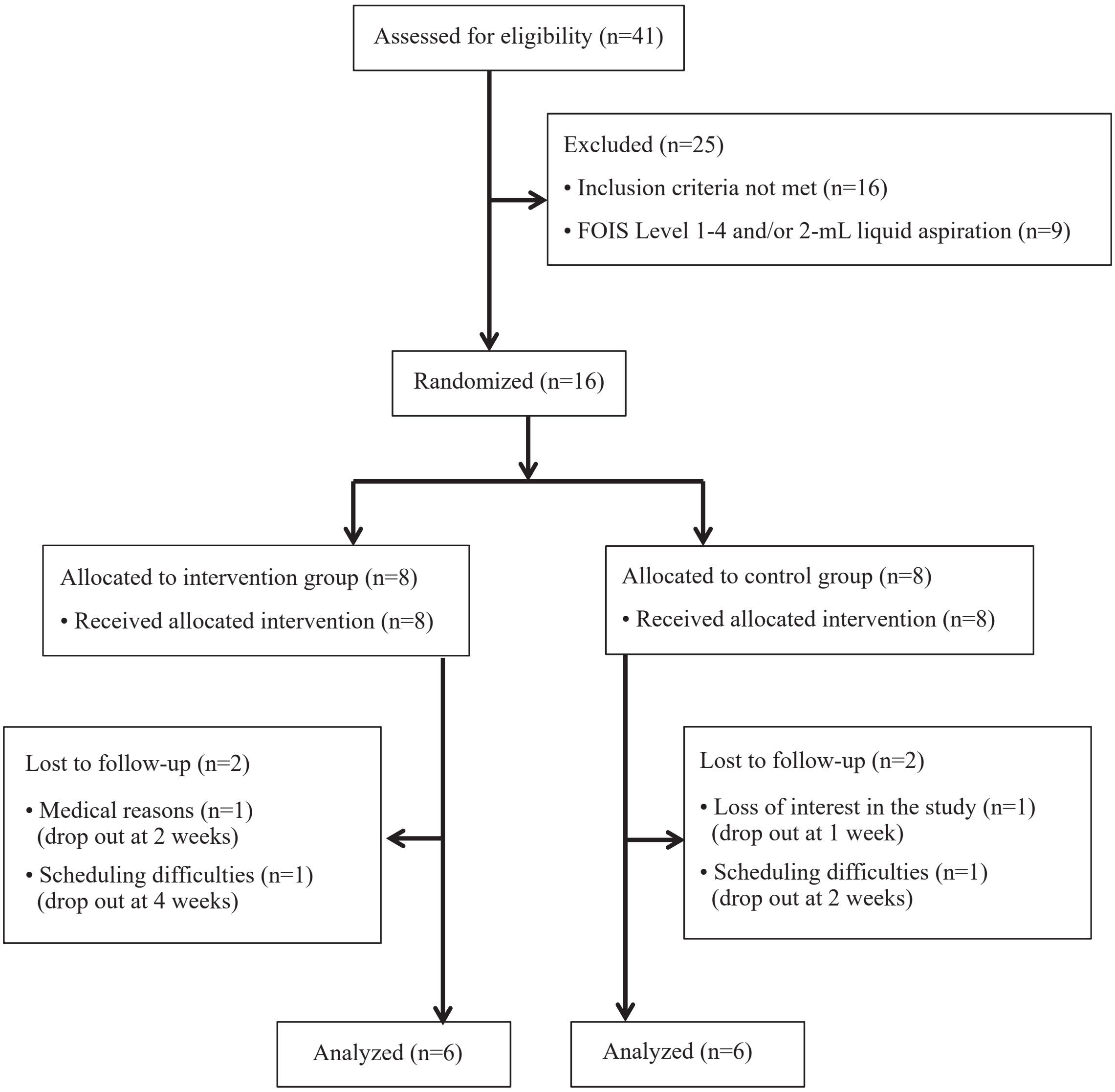

Fig. 1 Flowchart of the randomized trial.

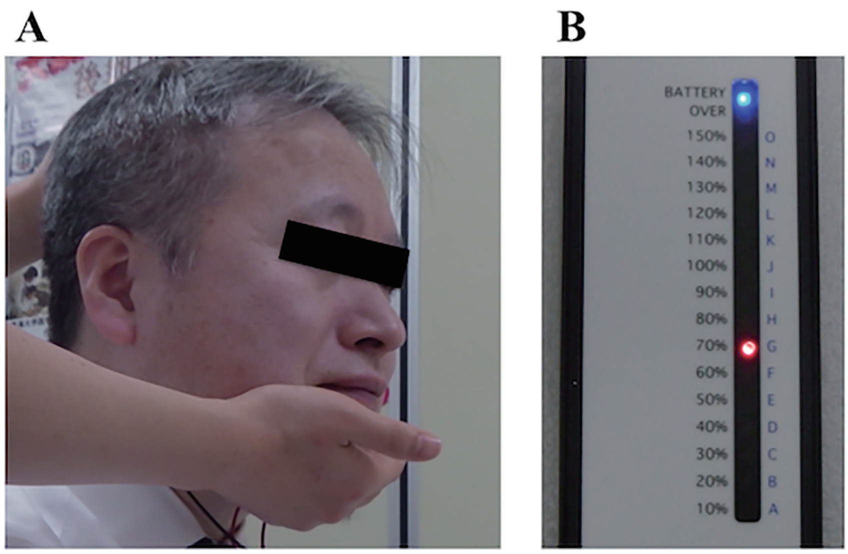

Fig. 2 Modified jaw opening exercise: Participants keep their mouths closed throughout the exercise.

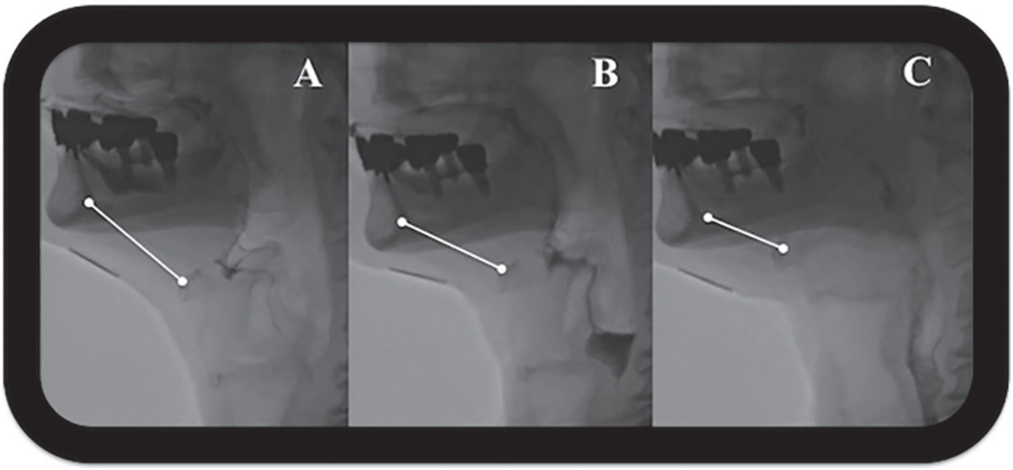

Fig. 3 Distance between the inferior mental spine and the central portion of the hyoid bone [DMH]
A: hyoid in the resting position, B: anterior displacement start position,
C: anterior displacement end position

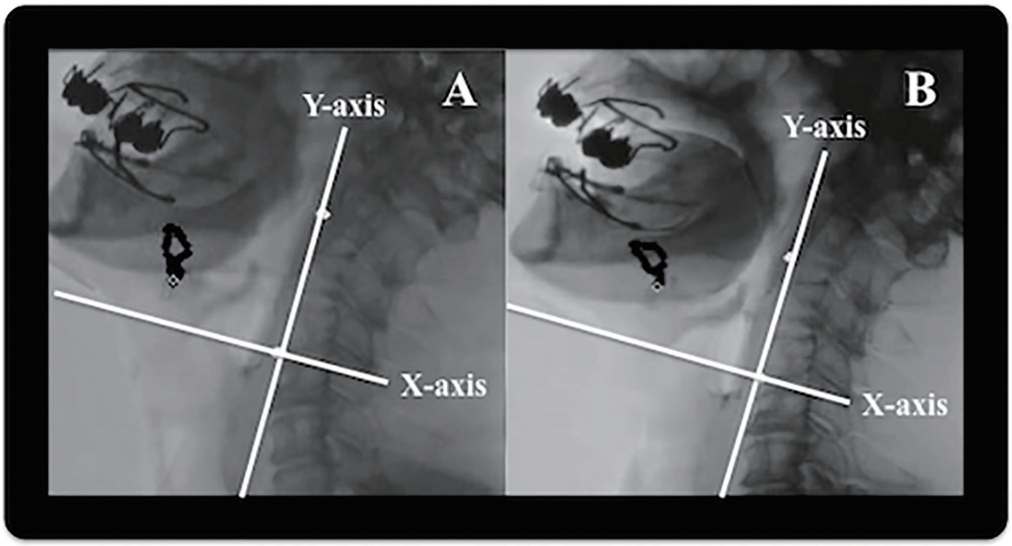

Fig. 4 The black line shows the trajectory of hyoid displacement during oropharyngeal swallow
A: Pre exercise, B: Post exercise

measured as the distance between the inferior mental spine and the central portion of the hyoid bone. This distance was measured with the hyoid in the resting position, the anterior displacement start position, and the anterior displacement end position (Fig. 3).

Secondary Outcome Measure: HD

Anterior and superior displacement of the hyoid was measured relative to a Y-axis connecting the front lower corners of the second and fourth cervical vertebrae and an X-axis intersecting the Y-axis perpendicularly at the front lower corner of the fourth cervical vertebra (Fig. 4).

Pharyngeal Residue

Presence of residue was evaluated at the vallecula and piriform sinus and described as "present" or "not present". Adherence of barium to mucosa was deemed not present.

Data Analysis

Statistical analyses were performed using SPSS 20.0, with P values <0.05 indicating significance. For analysis, the mean of six measurements was used to reduce the effect of intra-individual variability in the DMH and HD data of each participant [10].

The Wilcoxon signed-rank test was used for comparisons of DMH and HD before and after exercise in each participant and each group, while the Mann-Whitney U test was used to compare the intervention and control groups. Pearson's chi-squared test was used to compare pharyngeal residue before and after exercise in each group.

RESULTS

None of the participants who took part in the study experienced any adverse events in the form of pain in

Table 1 Characteristics of the study participants

Characteristic	Intervention Group (n = 6)	Control Group (n = 6)	*P*
Age, y, mean (SD)	66.0 (9.3)	71.8 (7.6)	0.172
Men / women, n	5 / 1	5 / 1	1.000
Post-onset weeks, mean (SD)	6.7 (2.1)	9.2 (4.0)	0.168
Stroke location, n			
Supratentorial / infratentorial	1 / 5	1 / 5	1.000
Multiple lesions, n			
Multiple / single	2 / 4	1 / 5	1.000
FOIS, n			
Level 5 / Level 6	3 / 3	4 / 2	1.000

P by Fisher's exact test or Wilcoxon's signed-rank test; **P* < 0.05

Table 2 DMH: Intragroup comparison

Parameter	Intervention group (n = 6)					Control group (n = 6)				
	Pre-Ex	Post-Ex	Z Score	Effect Size r	*P*	Pre-Ex	Post-Ex	Z Score	Effect Size r	*P*
DMH (mm)										
Rest position	44.9 (4.2)	44.8 (3.5)	-0.405	0.165	0.686	44.1 (6.9)	45.4 (5.8)	-0.943	0.385	0.075
Initial position of AD	45.7 (4.2)	45.9 (3.4)	-0.314	0.128	0.753	44.9 (5.4)	45.4 (5.8)	-0.210	0.086	0.207
End position of AD	34.6 (4.2)	32.9 (3.5)	-1.997	0.815	0.046*	34.5 (4.1)	34.3 (4.3)	-1.472	0.601	0.462

Values are means (standard deviation); P by Wilcoxon's signed-rank test; *P < 0.05
DMH: distance between the inferior mental spine and the central portion of the hyoid bone
AD: anterior displacement

the TMJ and/or anterior region of the neck during the study period. Six participants (one woman and five men) in both the intervention and control groups completed the study, showing attrition of 25% (Fig. 1). There were no significant differences in sex, age, characteristics of stroke including weeks since onset, or the degree of dysphagia (Table 1). Furthermore, none of the participants had a history of invasive treatment (e.g. tracheotomy) of the anterior neck muscles.

On VFSS, participants were likely to protrude their chin to compensate for hypopharyngeal residue on occasion. It was not possible to fully control mandibular movement in this study.

DMH

Intragroup comparison: No significant difference in the hyoid resting position or the start position of hyoid anterior displacement was seen in either group. As for the end position of hyoid anterior displacement (the end distance between the inferior mental spine and the central portion of the hyoid bone), a significant decrease was seen in the intervention group, with no significant difference in the control group (Table 2).

Intergroup comparison: No significant difference was seen between the two groups for the distance between two points in the hyoid resting position or the start position of hyoid anterior displacement. However, a significant decrease was seen in the end position of hyoid anterior displacement in the intervention group (Table 3).

HD

Intragroup comparison: No significant difference in superior displacement was seen in either group. Anterior displacement increased significantly in the intervention group, but it did not differ significantly in the control group (Table 4).

Intergroup comparison: No significant difference was seen between the two groups for the distance between two points in superior displacement. However, a significant increase in anterior displacement was seen in the intervention group (Table 5).

Pharyngeal Residue

The presence of pharyngeal residue was evaluated a total of 36 times in the six members of each group. While a significant improvement was seen in the piriform sinus in the intervention group, no significant difference was seen in the control group. Furthermore, no significant difference was seen in the vallecula in either group (Table 6).

DISCUSSION

Kraaijenga *et al.* reported significant increases in jaw opening strength and muscle volume of the SHMs following six weeks of jaw opening against resistance exercise [5]. In general, one set of 8–12 repetitions at 50%–75% of one repetition maximum (1RM), or one set of 5–6 repetitions at 80%–90% of 1RM, at 3–5 sets per exercise session, is required to strengthen the muscles.11 In the present study, sham exercise was 20% of 1RM without the muscular strengthening effect. The

Table 3 DMH: Intergroup comparison

Parameter	Intervention Group (n = 6)	Control Group (n = 6)	Z Score	Effect Size r	*P*
DMH (mm)					
Δ Rest position	-0.1 (0.9)	0.9 (2.0)	-1.050	0.303	0.394
Δ Initial position of anterior displacement	0.2 (1.2)	0.2 (1.0)	-0.080	0.023	1.000
Δ End position of anterior displacement	-1.6 (1.2)	-0.4 (0.6)	-2.096	0.605	0.041*

Δ= post exercise – pre exercise; Values are means (standard deviation); *P* by the Mann-Whitney U test; **P* < 0.05
DMH: distance between the inferior mental spine and the central portion of the hyoid bone

Table 4 Hyoid displacement: Intragroup comparison

	Intervention group (n = 6)					Control group (n = 6)				
Parameter	Pre-Ex	Post-Ex	Z Score	Effect Size r	*P*	Pre-Ex	Post-Ex	Z Score	Effect Size r	*P*
Hyoid displacement (mm)										
Superior displacement	15.0 (3.4)	17.0 (5.5)	-0.943	0.385	0.345	12.5 (2.3)	12.4 (2.5)	-0.420	0.172	0.674
Anterior displacement	11.0 (2.0)	13.8 (2.1)	-2.201	0.899	0.028*	13.0 (2.2)	13.2 (2.6)	-0.677	0.277	0.498

Values are means (standard deviation); *P* by Wilcoxon's signed-rank test; **P* < 0.05
Ex: exercise

Table 5 Hyoid displacement: Intergroup comparison

Parameter	Intervention Group (n = 6)	Control Group (n = 6)	Z Score	Effect Size r	*P*
Hyoid displacement (mm)					
Δ Superior displacement	2.0 (3.1)	0.1 (0.9)	-0.882	0.255	0.394
Δ Anterior displacement	2.8 (1.0)	0.2 (0.7)	-2.889	0.834	0.002*

Δ = post exercise – pre exercise; Values are means (standard deviation); *P* by the Mann-Whitney *U* test; **P* < 0.05

Table 6 Pharyngeal residue: Intragroup comparison

	Intervention group			Control group		
Parameter	Pre-Ex	Post-Ex	*P*	Pre-Ex	Post-Ex	*P*
Pharyngeal residue						
Vallecular, No/Av	12/24	20/16	0.058	14/22	19/17	0.237
Piriform sinus, No/Av	12/24	26/10	0.001*	8/28	14/22	0.125

No/Av, not available/available; *P* by Pearson χ^2 test; **P* < 0.05
Ex: exercise

resistive load at the start of exercise was set at 80% MVC, but no adverse events such as pain in the TMJ or anterior region of the neck occurred throughout six weeks of exercise. In other words, it was possible to confirm that MJOE was feasible without any adverse events in post-stroke elderly individuals.

Superior and anterior displacement of the hyoid bone during oropharyngeal swallowing is important information that reflects the complex activity of the SHMs and IHMs.

In terms of the effects of MJOE confirmed in the present study, it is important to note that comparison of measurements before and after exercise showed an increase in the amount of AD of the hyoid combined with a decrease in DMH at the end position of hyoid AD. The same results were obtained in a comparison of the intervention and control groups. Furthermore, none of the participants had a history of invasive treatment of the anterior neck muscles that could cause restricted elongation of the IHMs during SHM contraction.

These facts support the conclusion that the increase in the amount of AD of the hyoid was not the result of improved extensibility of the IHMs, but the result of increased contraction of the geniohyoid and other muscles. On the other hand, while the mylohyoid is considered to have the highest potential for superior displacement of the hyoid [12], the amount of superior displacement of the hyoid did not change significantly between before and after real exercise or between the intervention group and the control group. Thus, MJOE resulted in a significant increase in AD as opposed to superior displacement of the hyoid.

Hind *et al.* described a three-point rating scale [0 = no residue, 1 = coating (line of barium), 2 = pooling of barium] that measures residue at the valleculae, posterior pharyngeal wall, pyriform sinuses, oral cavity, and upper esophageal sphincter [13]. In the present study, adherence of barium to mucosa was deemed not present. In other words, assessment of pharyngeal residue used a two-point rating scale ("present" or "not present"), and it was limited to 2-mL liquid swallow. It is natural that this assessment does not differentiate between moderate and severe quantities of residue. One should not conclude that a pharyngeal residue decrease can be brought about by MJOE without an appropriate quantitative evaluation. However, it is plausible to assume that MJOE had the potential to decrease hypopharyngeal residue. This supports the possibility that MJOE enhanced upper esophageal sphincter opening.

STUDY LIMITATIONS

In terms of participants who completed the study, attrition of 25% occurred in both the intervention and control groups. This method is comprised of a dual task in which the jaw is opened while the tongue is held in the tipper swallow position. Therefore, compared to conventional JOE, this exercise presents a high degree of difficulty to not only patients with tongue movement disorders, but also patients with reduced cognitive and attentional function. However, the biggest factor behind this attrition was not the degree of difficulty of the exercise method, but the relentless exercise schedule. For example, participants in both the intervention and control groups were considered to have dropped out if they missed even one session in their schedule of six consecutive weeks of four sets per day, five times a week. Specifically, staying out overnight on weekdays and mild health problems resulted in an incomplete schedule. If these problems were resolved by changing the study design to one that provided a suitable respite plan, it may have been possible to lower attrition to 10%.

This study focused on the geniohyoid muscle, which is considered to have the highest potential for anterior displacement of the hyoid bone [11], and the distance from the point of origin to the insertion of this muscle was set as the virtual muscle length. This new endpoint requires caution regarding rotation of the neck during data acquisition, but it was considered less susceptible to the effects of jaw pulling and jaw protrusion than conventional motion analyses of the hyoid bone that use the cervical spine as an indicator. In addition, we should be careful about comparing DMH without taking into account the sex differences and the correction of data because DMH changes depending on the size of the head and neck. For example, we should add a virtual muscular contraction percentage including DMH to the endpoint.

In the next MJOE study, the control group will perform conventional exercise including JOE, and the study will be designed with an appropriate sample size to accurately determine the effect of this exercise.

CONCLUSIONS

A new exercise method (MJOE) that differs from conventional JOE, in which upward vertical resistance is applied to the jaw while the mouth is closed with the tongue held in the tipper swallow position to prevent the mouth from opening, was devised. MJOE is feasible without any adverse events in post-stroke elderly individuals, and it promotes anterior displacement of the hyoid bone during swallowing.

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LIST OF ABBREVIATIONS

FOIS functional oral intake scale **HD** hyoid displacement
IHMs infrahyoid muscles **MJOE** modified jaw opening exercise
MVC maximum voluntary contraction
SHMs suprahyoid muscles
TMJ temporomandibular joint
DMH distance between the inferior mental spine and the central portion of the hyoid bone
VFSS videofluorographic swallowing study
1RM one repetition maximum

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SUPPLIERS

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b. DITECT Corp, 1-8, Nanpeidai, Shibuya, Tokyo, Japan, 150-0036.
c. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 6060.