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The effects of surface neuromuscular electrical stimulation on post-stroke dysphagia: A systemic review and meta-analysis

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Abstract

Objective: In this study, we intended to evaluate whether swallow treatment with neuromuscular electrical stimulation is superior to that without neuromuscular electrical stimulation, and whether neuromuscular electrical stimulation alone is superior to swallow therapy.

Methods: We searched the PubMed and Scopus databases from their earliest record to 31 December 2014 for randomized and quasi-randomized controlled trials that used neuromuscular electrical stimulation to treat post-stroke dysphagia. The Jadad scale was used to assess the quality of the included studies. We extracted the mean differences and standard deviation (SD) between baseline and posttreatment or posttreatment mean and SD for selected outcomes measured in the experimental and control groups for subsequent meta-analyses.

Results: Eight studies were identified. For the comparison "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation," we found a significant standardized mean difference (SMD) of 1.27 (95% confidence interval (CI) = 0.51–2.02, $P = 0.001$) with significant heterogeneity ($I^2 = 85\%$). The meta-analysis for the comparison of neuromuscular electrical stimulation alone and swallow therapy demonstrated a non-significant SMD of 0.25 (95% CI = –0.16–0.65, $P = 0.23$) without significant heterogeneity ($I^2 = 16\%$).

Conclusion: Swallow treatment with neuromuscular electrical stimulation seems to be more effective than that without neuromuscular electrical stimulation for post-stroke dysphagia in the short term considering the limited number of studies available. Evidence was insufficient to indicate that neuromuscular electrical stimulation alone was superior to swallow therapy.

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Introduction

Dysphagia is common following acute stroke and has a reported incidence of between 37% using cursory screening techniques and 78% using instrumental testing.[1] Although the prevalence of dysphagia decreases with time after stroke,[2] 50% of patients still have dysphagia clinically at six months after stroke.[3] Dysphagia leads to an increased risk of malnutrition, dehydration, aspiration pneumonia, and even death.[4] Post-stroke complications can delay functional recovery and reduce quality of life when patients are unable to eat or drink previously enjoyed foods and beverages.[5] Effectively restoring the swallowing function can therefore help to avoid the risk of complications and to increase quality of life for stroke patients.

Treatment of dysphagia relies on traditional swallowing training, which focuses on enhancing sensory feedback from the oropharynx to the central pattern generator, strengthening the disused oropharyngeal musculature, preventing atrophy and reduced motor output from the central pattern generator, and minimizing symptoms through the use of compensatory postural adjustments. Nowadays, several adjunctive treatment options exist that can potentially improve the dysphagia recovery. These treatments include surface neuromuscular electrical stimulation, pharyngeal electrical stimulation, repetitive transcranial magnetic stimulation, and transcranial direct current stimulation.[6] The first two treatments act on the neuromuscular system peripherally in an attempt to strengthen the weakened oropharyngeal musculature, and the last two are to stimulate pharyngeal motor cortex to promote the neural plasticity after stroke. Compared with the other treatment options, the surface neuromuscular electrical stimulation is the cheapest and most easy to apply.

Speech–language pathologists and physiatrists working with swallowing disorders are showing great interest in neuromuscular electrical stimulation as a new swallow treatment modality. Although it has been hypothesized that neuromuscular electrical stimulation might enhance post-stroke muscle strength in weak and disused pharyngeal muscles, its clinical effectiveness remains unclear. Two meta-analysis studies that evaluated the effectiveness of neuromuscular electrical stimulation for dysphagia have been published and their results supported its use.[7,8] However, these meta-analyses included studies with differing dysphagia etiologies (e.g. stroke, Parkinson disease, radiation damage, various head, and neck cancers) and compiled data from studies with differing comparisons (e.g. swallow therapy + neuromuscular electrical stimulation vs. swallow therapy, neuromuscular electrical stimulation vs. swallow therapy). Consequently, to interpret the effectiveness of neuromuscular electrical stimulation for post-stroke dysphagia is difficult. Moreover, methodological problems in these reviews of non-randomized control trials limited the strength of the results. Therefore, an update review with randomized or quasi-randomized controlled trials must be conducted to explore the effectiveness of surface neuromuscular electrical stimulation in treating post-stroke dysphagia. The purpose of this study was to evaluate whether swallow treatment with neuromuscular electrical stimulation is superior to that without neuromuscular electrical stimulation and whether neuromuscular electrical stimulation alone is superior to swallow therapy in post-stroke dysphagia treatment.

Methods

Study selection

We systematically searched for all relevant articles in the PubMed and Scopus databases from their

earliest record to 31 December 2014. Our key search terms were [(*swallow*) OR (*dysphag*) OR (*pharyn*)] AND [(*electr*) OR (vitalstim) OR (vocastim) OR (*stimul*)] AND [(*stroke*) OR (cerebr*) OR (CVA*)] (see Appendix, available online). Cochrane Central Register of Controlled Clinical Trials, Cochrane Systematic Reviews, and ClinicalTrials.gov were scrutinized for additional references. The review included randomized and quasi-randomized controlled trials published in English language. Studies were eligible if they enrolled adult participants with dysphagia caused by stroke and focused on the treatment effectiveness of neuromuscular electrical stimulation for dysphagia. We excluded electrical stimulations other than surface neuromuscular electrical stimulation (e.g. electrical acupuncture and pharyngeal electrical stimulation). Two authors (YNL and YWC) independently searched and evaluated the literature for inclusion of studies based on their titles and abstracts and then reviewed the full text of relevant articles. Articles were also excluded if we failed to obtained analyzable data from them.

Quality assessment

The Jadad scale was used to assess the quality of the included studies.[9] The quality of each study was assessed according to the following criteria: (1) random allocation, (2) blinding procedure, and (3) drop-out explanation. The aggregate scores ranged from 0 to 5 points. Trials with scores of <3 were considered to have a lower methodological quality.[10] Discrepancies between two independent evaluations for potential articles were resolved through discussion to reach a consensus.

Quantitative analyses

Relevant data from each study were independently extracted by two reviewers, using a standard data recording form that included the number of participants, mean age, stroke duration, and intervention protocol (i.e. neuromuscular electrical stimulation intensity, number of sessions, and additional interventions), as well as information regarding study quality and outcome measures. We extracted the mean differences and standard deviations (SD) between baseline and posttreatment for selected outcomes measured in the experimental and control groups. If the mean differences were not reported, the posttreatment mean and SD were used. One article provided original data of pretest and posttreatment values for each participant instead of the mean and SD;[11] however, we could calculate the mean difference and SD. Two articles reported data with median and interquarter range values;[12,13] we successfully obtained the values of the mean and SD from the authors of one study through an email request. When multiple measures were used in a study, we used the first outcome that was reported with a mean and SD in the results section. For studies that had repeated follow-ups,[14,15] we used the posttreatment data.

Statistical analysis

The meta-analysis comprised two main comparisons: (1) swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation and (2) neuromuscular electrical stimulation vs. swallow therapy. We defined the "swallow therapy" as the swallow treatment involving the elements of traditional swallow therapy (e.g. thermal stimulation, effortful swallowing, and postural adjustments). The "swallow treatment" was designated for any treatment trying to improve dysphagia including swallow therapy and neuromuscular electrical stimulation. In the first comparison, the same conditions were set for both the experiment and control groups, except for neuromuscular electrical stimulation. We pooled the standard mean differences (SMDs) with a random-effect model and presented a point estimate with a 95% confidence interval (CI). The SMDs were calculated based on the differences between posttreatment evaluations or the mean differences between pre- and posttreatment. The SMDs ranging from 0.2 to 0.5 were considered to be small, and a value larger than 0.5 was considered clinically meaningful.[16] Heterogeneity across studies was tested using the I^2 test. An I^2 score >50% indicated significant heterogeneity. The statistical significance level was

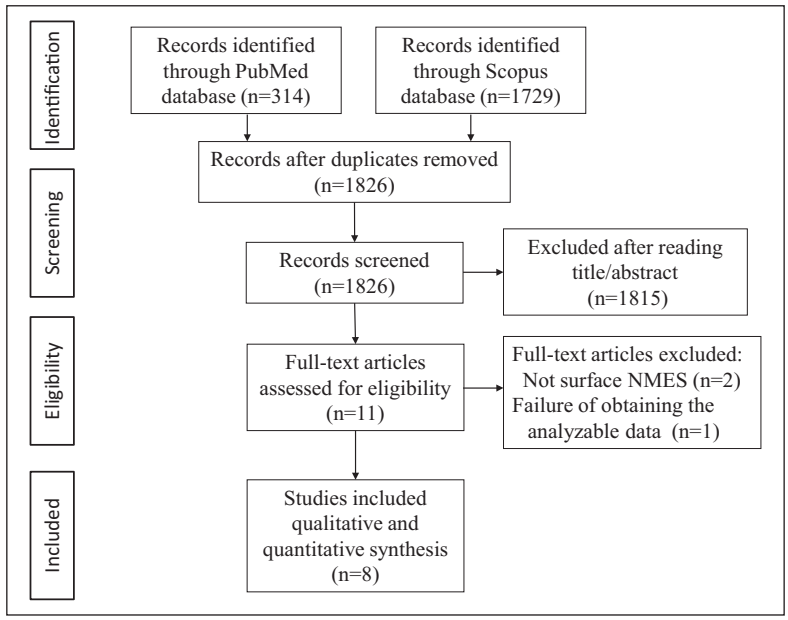

Figure 1. Flow diagram of the evaluation process for the inclusion or exclusion of studies.
NMES: neuromuscular electrical stimulation.

set at 0.05. Meta-analysis was performed using Review Manager Software 5.3.

Results

Searches yielded 1826 non-duplicate records. After exclusion based on title, abstract, and full-text review, we identified nine articles that met our inclusion criteria. Of them, one was excluded because of the failure of obtaining the analyzable data (Figure 1).

Characteristics of included patients

Table 1 shows the main characteristics of the eight studies (Nos. 1–8[11,12,14,15,17–20]) included in our meta-analysis. A total of 329 patients completed the interventions; however, information regarding the participant characteristics was limited in some studies. Study Nos. 3[18] and 6[14] recruited patients in the acute phase (<1 month); Study 8 recruited patients in subacute phase (<3 months); whereas Study Nos. 1,[12] 5,[19] and 7[20] recruited patients in the chronic phase (>3 months). Study Nos. 1,[12] 6,[14] and 7[20] assessed lesion sites and specified a supratentorial stroke in their inclusion criteria. Study Nos. 1,[12] 4,[11] and 7[20] recruited participants who presented at least some swallow function. Study Nos. 5[19] and 6[14] specified the dysphagia severity of the participants with the Penetration-Aspiration Scale and Functional Oral Intake Scale, respectively.

Intervention

Various intervention programs were used in these studies (Table 1). Study Nos. 2[17] and 4 to 6[11,14,19] compared effectiveness between swallow therapy + neuromuscular electrical stimulation and swallow therapy; and Study Nos. 1[12] and 3[18] compared effectiveness between neuromuscular electrical stimulation alone and swallow therapy. Study No. 7[20] included the three treatment arms of neuromuscular electrical stimulation + swallow therapy, neuromuscular electrical stimulation, and swallow therapy, values extracted from this study were used for both comparisons of "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation" and

Table 1. Summary of studies using NMES to treat post-stroke dysphagia.

Study No.	Authors, published year, and reference No.	No. of participants who completed the study (Exp/Ctr)	Intervention settings	NMES intensity	Comparison	Characteristics of participants (stroke duration, type, severity)	Outcome measures	Assessment timing	Quality assessment
1	Bulow et al., 2008[12]	25 (12/13)	NMES was administered in 1-h sessions, 5 sessions per week, for 3 weeks (15 sessions)	Exp: 4.5–25 mA, average 13 mA.	NMES vs. ST	1. Onset >3 month 2. Supratentorial stroke 3. Without NG tube, but could have PEG 4. Some pharyngeal swallow can be elicited 5. No brainstem involvement 6. First-time stroke or a recurrence	1. ANS* 2. VAS 3. OMFT 4. VFSS scores	0 and 3 weeks	2
2	Lim et al., 2009[17]	28 (16/12)	NMES was administered in 1-h sessions, 5 sessions per week for 4 weeks (20 sessions)	Sufficient to induce tingling sensations, at approximately 7 mA	NMES + ST vs. ST	Onset >6 months: 6 patients; onset <6 months: 22 patients	1. SFSS* 2. Discomfort and satisfactory scores (1–10 point) 3. PAS 4. PTT	0 and 4 week	1
3	Permsirivanich et al., 2009[18]	23 (12/11)	NMES was administered in 1-h sessions, 5 sessions per week for 4 week (20 sessions)	Sufficient to induce "grabbing" sensations	NMES vs. ST	1. Average stroke duration: 23.7 days 2. Persistent dysphagia >2 weeks	FOIS*	0 and 4 weeks	3
4	Park et al. 2012[11]	18 (9/9)	NMES was administered in 20-minute sessions, 3 sessions per week, for 4 weeks (12 sessions)	Exp: Sufficient to induce visible muscle contraction. Average: 7.33 mA Ctr: Sufficient to induce tingling sensations. Average: 2.89 mA	Motor NMES + ST vs. sensory NMES + ST	1. Stroke onset >1 month 2. Able to elevate the hyolaryngeal complex during motoric electrical stimulation	Excursion of the hyoid and larynx	0 and 4 weeks	5

(Continued)

Table 1. (Continued)

Study No.	Authors, published year, and reference No.	No. of participants who completed the study (Exp/Ctr)	Intervention settings	NMES intensity	Comparison	Characteristics of participants (stroke duration, type, severity)	Outcome measures	Assessment timing	Quality assessment
5	Rofes et al. 2013[19]	20 (10/10)	NMES was administered in 1-h sessions, for 10 consecutive weekdays (10 sessions)	Exp: motor threshold Ctr: 75% of motor threshold	Motor NMES vs. sensory NMES	1. Stroke onset >3 months 2. PAS ≧3	1. EAT-10 2. SSQ 3. Bolus residues 4. Biomechanic changes based on VFSS	0 and 2 weeks	3
6	Lee et al., 2014[14]	57 (31/26)	NMES was administered in 30-minute sessions, 5 sessions per week, for 3 weeks (15 sessions)	120% of the threshold value at which the patient began to feel pain or discomfort	NMES + ST vs. ST	1. Supratentorial ischemic stroke 2. Stroke onset <10 day 3. FOIS≦5	FOIS*	0, 3, 6, and 12 weeks	1
7	Li et al., 2014[20]	118 (40[a]/38[b]/40[c])	NMES was administered in 1-h sessions, 5 sessions per week, for 4 weeks (20 sessions)	Sufficient to induce tingling sensations, at approximately 7 mA	NMES + ST vs. NMES vs. ST	1. Stroke onset > 3 months 2. Patients with symptoms typical for brainstem stroke were excluded 3. Recurrent stroke patients were included	1. VAS 2. SSA 3. sEMG. 4. Bolus transit time (OTT, PTT, LCD)	0 and 4 weeks	3
8	Lim et al., 2014[15]	40 (20/20)	NMES was administered in 30-minute sessions, 5 sessions per week, for 2 weeks (10 sessions)	7–9 mA	NMES+STvs. ST	1. Stroke onset <3 months	1. FDS 2. PTT 3. PAS 4. ASHA NOMS swallowing scale*	0, 2 and 4 weeks	3

ANS: actual nutrition status; ASHA NOMS: the American Speech-Language Hearing Association National Outcomes Measurement System; EAT-10: Eating Assessment Tool; Exp: experimental group; Ctr: control group; FDS: Functional Dysphagia Score; FOIS: Functional Oral Intake Scale; LCD: laryngeal closure duration; NG: nasogastric; NMES: neuromuscular electrical stimulation; OTT: oral transit time; PAS: Penetration-Aspiration Scale; PTT: pharyngeal transit time; sEMG: surface electromyography; SFSS: Swallow Function Score System; SSA: Standardized Swallowing Assessment; SSQ: Sydney Swallow Questionnaire; ST: swallow training; VAS: Visual Analog Scale; OMFT: Oral motor function test; VFSS: Videofluoroscopic swallow study; PEG: percutaneous endoscopic gastrostomy.

*ANS = SFSS = FOIS = ASHA NOMS swallowing scale.

[a]NMES + ST group.

[b]NMES group.

[c]ST group.

"neuromuscular electrical stimulation alone vs. swallow therapy". Study No. 8 included the three treatment arms of repetitive transcranial magnetic stimulation + swallow therapy, neuromuscular electrical stimulation + swallow therapy, and swallow therapy only, values extracted from this study were used for the comparisons of "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation". All studies involved swallow therapy in interventions, except Study No. 5,[19] and swallow therapy programs differed among studies. General swallow therapy was used in Study Nos. 1,[12] 3,[18] 6,[14] 7,[20] and 8.[15] Study Nos. 2[17] and 4[11] specified their swallow therapy to be thermal-tactile stimulation and effortful swallowing, respectively. The neuromuscular electrical stimulation settings varied among studies. However, five studies used a one-hour session and seven studies gave daily treatment during weekdays. The total numbers of sessions were ranged from 12 to 20. Additionally, control groups in Study Nos. 4[11] and 5[19] received low intensity neuromuscular electrical stimulation in contrast to the experiment groups which received high intensity neuromuscular electrical stimulation. In this situation, the low-intensity neuromuscular electrical stimulation can be considered a sham treatment; therefore, these two studies were included in the comparison "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation".

Outcome measures

Various outcome measures were used in the selected articles (Table 1), and an outcome was chosen for a particular study to perform meta-analysis. During intake, the Actual Nutrition Status Scale was used for Study No. 1[12] and the Functional Oral Scale was used for Study Nos. 3[18] and 6.[14] These scales both use seven levels to describe the feeding status from complete tube feeding to complete oral feeding. Study Nos. 2,[17] 4,[11] 5,[19] 7,[20] and 8[15] provided data for videofluoroscopic swallowing study outcomes, which included pharyngeal transit time (Study Nos. 2[17] and 7[20]), biomechanical laryngeal excursion (Study No. 4[11]), and bolus velocity (Study No. 5[19]). Study No. 4[11] reported four biomechanical variables: anterior–posterior and vertical excursion of the hyoid and larynx. The vertical excursion of the larynx was most relevant to swallowing functions and was used in the meta-analysis. Study No. 8[15] reported multiple videofluoroscopic swallowing study-based outcomes including functional dysphagia scale[21] and pharyngeal transit time. For Study No. 8,[15] we selected the functional dysphagia scale measured for liquid material for the subsequent meta-analysis. For subsequent meta-analyses, a minus sign was added to the extracted value of posttreatment pharyngeal transit time (Study Nos. 2[17] and 7[20]) to match direction of other outcomes with higher scores representing superior functions. Only Study No. 6[14] had long-term follow-up. Accordingly, meta-analysis of these studies was consistently focused on the short-term effects (i.e. before–after treatment) of neuromuscular electrical stimulation.

Methodological quality

The results of quality assessment for the included studies are shown in Table 1. Random allocation was employed in all trials. However, two studies failed to achieve adequate randomization (i.e. quasi-randomized). Study No. 2[17] assigned participants to treatment groups in order of enrollment. Study No. 6[14] excluded participants after the completion of randomization. Six studies implemented blinding of the assessors (Study Nos. 1,[12] 2,[17] 4,[11] 5,[19] 7,[20] and 8[15]); however, only Study Nos. 4[11] and 5[19] blinded both patients and assessors.

Meta-analysis

The results of the comparison of "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation" are shown in Figure 2. The SMD was obtained from six articles (Study Nos. 2[17] and 4–8[11,14,15,19,20]) involving 243 patients with stroke. The meta-analysis demonstrated a large SMD of 1.27 (95% CI=0.51–2.02, P=0.001). However, heterogeneity was significant (I^2=85%). Because five of the six studies used videofluoroscopic swallowing

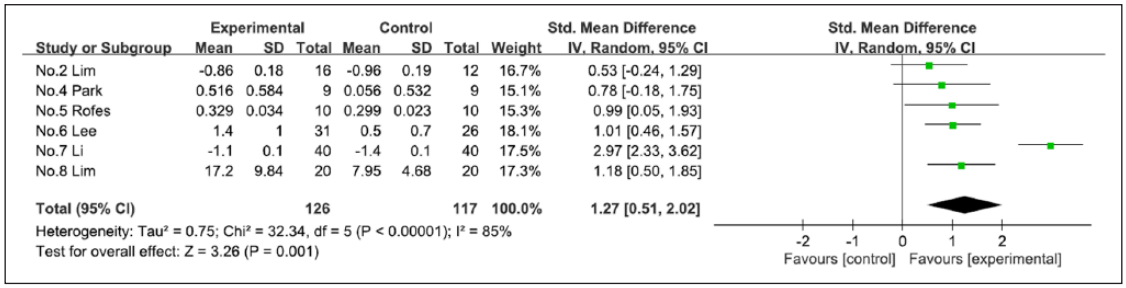

Figure 2. Forest plot comparison of the effectiveness between swallow treatment with neuromuscular electrical stimulation and swallow treatment without neuromuscular electrical stimulation.

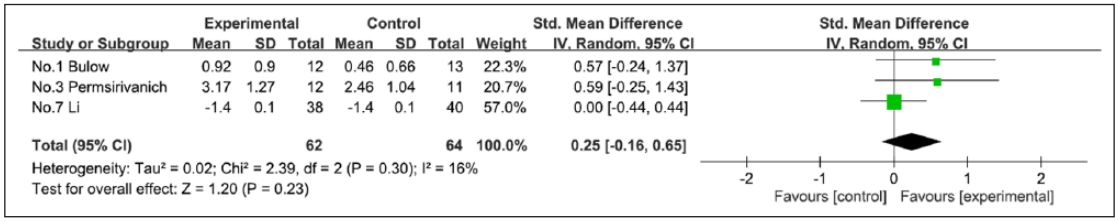

Figure 3. Forest plot comparison of functional changes between neuromuscular electrical stimulation and swallow therapy.

study-based outcomes, a videofluoroscopic swallowing study subgroup analysis of these five showed an SMD of 1.31 (95% CI=0.35–2.27, P=0.007) with significant heterogeneity (I^2=87%). Study No. 7[20] appeared to be the source of heterogeneity. Removing this article demonstrated a significant SMD of 0.93 (P<0.001) for the comparison "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation", and of 0.89 (P<0.001) for videofluoroscopic swallowing study subgroup analysis. No further significant heterogeneity was found (I^2=0).

We made an effort to explore the effects of stroke chronology on the treatment effectiveness caused by neuromuscular electrical simulation by the subgroup meta-analysis within the comparison "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation". Among the six studies included, four recruited relatively homogenous samples regarding the stroke chronology. Study Nos. 6[14] and 8[15] recruited acute and subacute stroke patients with onset of less than three months and Study Nos. 5[19] and 7[20] recruited chronic stroke patients with onset more than three months. The SMD (95% CI) = 1.08 (0.65–1.51) and 2.01 (0.07–3.95) for the acute/subacute subgroup and chronic subgroup, respectively. Both subgroups showed significant effectiveness favoring neuromuscular electrical stimulation treatment (P<0.05). The comparison of SMD between these two subgroups yielded no significant difference (t=–0.92, P=0.36).

Figure 3 shows the result of the comparison between neuromuscular electrical stimulation and swallow therapy, based on three articles (Study Nos. 1,[12] 3,[18] and 7[20]) involving 126 patients. The meta-analysis showed an SMD of 0.25 (95% CI=–0.16–0.65, P=0.23) without significant heterogeneity (I^2=16%).

Discussion

In this study, we found that treatment with neuromuscular electrical stimulation was more effective than that without neuromuscular electrical stimulation for post-stroke dysphagia in the short term

(SMD: 1.27; 95% CI = 0.51–2.02, $P = 0.001$). However, evidence was insufficient to indicate that neuromuscular electrical stimulation is superior to swallow therapy (SMD: 0.25; 95% CI = –0.16–0.65, $P = 0.23$). These findings provide further supporting evidence to understand the treatment effects of surface neuromuscular electrical stimulation on dysphagia in post-stroke patients.

Meta-analysis of "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation" showed a large SMD, but with significant heterogeneity. Heterogeneity might have been caused by the differences in study samples (e.g. stroke type and duration), study design (e.g. sample size, blinding), and intervention setting (e.g. treatment dosage). For example, Study Nos. 4[11] and 5[19] compared effectiveness between high-intensity neuromuscular electrical stimulation and low-intensity neuromuscular electrical stimulation. Low-intensity at sensory levels might exert an effect on treatment.[22] These studies might have underestimated the effectiveness of neuromuscular electrical stimulation. However, Study No. 7[20] appeared to be the source of heterogeneity, and removing this study eliminated it. This Chinese Study recruited chronic stroke patients (>3 months) from a large sample size ($n = 45$ in each treatment arm) and compared the effectiveness of the three treatments of neuromuscular electrical stimulation + swallow therapy, neuromuscular electrical stimulation, and swallow therapy. The drop-out rate was low (12.6%) and no significant methodological flaw was observed, other than the lack of double-blinding. However, information regarding treatment setting was insufficient to allow us to compare the protocol with other studies. It is unclear why the result of this study was much more positive than others.

Five of six studies provided videofluoroscopic swallowing study-based outcomes in the comparison of "swallow treatment with neuromuscular electrical stimulation vs. swallow treatment without neuromuscular electrical stimulation". An opportunity existed to provide insight into the neuromuscular electrical stimulation effects on videofluoroscopic swallowing study by compiling the videofluoroscopic swallowing study-based values from these five studies, and this was crucial because the videofluoroscopic swallowing study is the accepted standard for objectively evaluating swallowing abnormalities.[21] Videofluoroscopic swallowing study frequently reveals that patients with post-stroke dysphagia have a delayed swallow reflex and a reduced elevation of the larynx.[21] Laryngeal elevation triggered by the swallow reflex helps to protect the airway while it assists in opening the relaxed upper esophageal sphincter. Therefore, therapy directed at improving laryngeal elevation would likely improve swallowing and decrease food transit time. The SMD of 1.31 ($P < 0.01$) in the videofluoroscopic swallowing study subgroup analysis indicated that swallow treatment with neuromuscular electrical stimulation was more effective than that without neuromuscular electrical stimulation in improving the swallowing performance on videofluoroscopic swallowing study. This finding provided valuable biomechanical information in explaining the effectiveness of neuromuscular electrical stimulation on dysphagia in post-stroke patients.

To presume the best time to receive for the surface neuromuscular electrical stimulation, we conducted subgroup analyses among the four studies (i.e. Study Nos. 5–8[14,15,19,20]) that clearly clarified the stroke chronology of the recruited sample. We found a significant SMD of 1.08 and 2.01 for acute/subacute and chronic subgroup, respectively, but the difference of SMD between the two subgroups was not significant. Although this finding may imply that the neuromuscular electrical stimulation can be effective both in patients with acute/subacute and with chronic stroke, it should be interpreted with cautions. The small number of studies included and the diverse protocol of these studies may limit the evidence strength for this notion.

A previous meta-analysis study conducted by Tan et al.[8] evaluated the treatment effect of neuromuscular electrical stimulation on dysphagia, concluding that neuromuscular electrical stimulation is not superior to swallow therapy.[8] Their study included two randomized controlled trials and two clinical controlled trials for post-stroke dysphagia. However, the authors inappropriately included studies with differing comparisons (e.g. "neuromuscular electrical

stimulation + swallow therapy vs. swallow therapy" and "neuromuscular electrical stimulation vs. swallow therapy") into a meta-analysis for "neuromuscular electrical stimulation vs. swallow therapy". Their results have caused difficulty in interpreting the results. Additionally, they used an estimated mean and SD for two studies that provided data expressed as the median and inter-quarter range, which could be a methodological problem for meta-analysis. In the present study, we included three randomized controlled trials with the same study purpose to compare effectiveness between neuromuscular electrical stimulation and swallow therapy. We obtained mean and SD values for Study No. 1,[12] in which all values were expressed as the median and inter-quarter range. Our meta-analysis showed a non-significant SMD of 0.25 ($P=0.23$), indicating that the neuromuscular electrical stimulation was not superior to swallow therapy (Figure 3). Despite similar results, the evidence provided by our study is stronger.

Although neuromuscular electrical stimulation is thought to affect the neuromuscular system peripherally, it may also play a role in modulating the central nervous system, in which peripheral stimulation might be capable of influencing neural plasticity.[23–25] The excitability of the pharyngeal motor cortex might be able to change by applying electrical stimulation to the pharynx, namely pharyngeal electrical stimulation.[26,27] A British team introduced a novel method to create a virtual lesion in the brain through repetitive transcranial magnetic stimulation to suppress the corticobulbar excitability and to produce artificial dysphagia.[28,29] They found that the pharyngeal electrical stimulation could reverse the suppressed corticobulbar excitability that had been produced by the repetitive transcranial magnetic stimulation.[29] They also demonstrated that improvement in the swallowing function was associated with the change of corticobulbar excitability induced by pharyngeal electrical stimulation.[27] Whether surface neuromuscular electrical stimulation exerts a similar effect is unknown. Both these two methods provide electrical stimulation at the pharyngeal area, but the patient must swallow an intraluminal catheter either transnasally or transorally during pharyngeal electrical stimulation. This process can cause discomfort to patients and the exact location of the catheter may not be easily checked.[30] Therefore, surface neuromuscular electrical stimulation that is easier to apply warrants further study to elucidate its effect on neural plasticity.

Although numerous clinical trials have been conducted to explore the effectiveness of neuromuscular electrical stimulation on motor recovery after a stroke, efforts made to explore the effectiveness of neuromuscular electrical stimulation on post-stroke dysphagia have been limited. The first randomized controlled trial of neuromuscular electrical stimulation for treating post-stroke dysphagia was published in 2008, seven years after the approval of "VitalStim" by the US Food and Drug Administration. We found only nine randomized or quasi-randomized controlled trials in our database search, three of which had Jadad scores <3, and all but two was before–after design. Considering that post-stroke dysphagia is prevalent and can cause significant impact on quality of life, the neuromuscular electrical stimulation that is potentially beneficial in treating dysphagia needs to be further explored with high-quality randomized controlled trials.

Limitations

The present study had several limitations. First, the methodological flaws in the included studies decreased the evidential strength of our study. Second, the included studies differed considerably regarding the study population (e.g. stroke onset, type, and severity), intervention settings, and outcome assessments. These differences among the studies might have contributed to the evident heterogeneity. Third, the swallow therapy programs used in the included studies may represent potential confounders for the comparisons. Fourth, the meta-analysis in the present study focused on comparisons of short-term effectiveness. Whether neuromuscular electrical stimulation exerts a longer treatment effect is unknown. Finally, we might have excluded relevant studies that were published in languages other than English.

Clinical message

- Swallow treatment with neuromuscular electrical stimulation seems to be more effective than that without neuromuscular electrical stimulation for post-stroke dysphagia in the short term considering the limited number of studies available.
- Evidence is insufficient to indicate that neuromuscular electrical stimulation alone is superior to swallow therapy.

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Conflict of interest

The authors declare that there is no conflict of interest.

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References

1. Martino R, Foley N, Bhogal S, Diamant N, Speechley M and Teasell R. Dysphagia after stroke: Incidence, diagnosis, and pulmonary complications. *Stroke* 2005; 36: 2756–2763.
2. Finestone HM, Greene-Finestone LS, Wilson ES and Teasell RW. Malnutrition in stroke patients on the rehabilitation service and at follow-up: Prevalence and predictors. *Arch Phys Med Rehabil* 1995; 76: 310–316.
3. Mann G, Hankey GJ and Cameron D. Swallowing function after stroke: Prognosis and prognostic factors at 6 months. *Stroke* 1999; 30: 744–748.
4. Holas MA, DePippo KL and Reding MJ. Aspiration and relative risk of medical complications following stroke. *Arch Neurol* 1994; 51: 1051–1053.
5. Silbergleit AK, Schultz L, Jacobson BH, Beardsley T and Johnson AF. The Dysphagia handicap index: Development and validation. *Dysphagia* 2012; 27: 46–52.
6. Geeganage C, Beavan J, Ellender S and Bath PM. Interventions for dysphagia and nutritional support in acute and subacute stroke. *Cochrane Database Syst Rev*. Epub ahead of print 17 October 2012. Doi: 10.1002/14651858.
7. Carnaby-Mann GD and Crary MA. Examining the evidence on neuromuscular electrical stimulation for swallowing: A meta-analysis. *Arch Otolaryngol Head Neck Surg* 2007; 133: 564–571.
8. Tan C, Liu Y, Li W, Liu J and Chen L. Transcutaneous neuromuscular electrical stimulation can improve swallowing function in patients with dysphagia caused by non-stroke diseases: A meta-analysis. *J Oral Rehabil* 2013; 40: 472–480.
9. Jadad AR, Moore RA, Carroll D, et al. Assessing the quality of reports of randomized clinical trials: Is blinding necessary? *Control Clin Trials* 1996; 17: 1–12.
10. Ezzo J, Berman B, Hadhazy VA, Jadad AR, Lao L and Singh BB. Is acupuncture effective for the treatment of chronic pain? A systematic review. *Pain* 2000; 86: 217–225.
11. Park JW, Kim Y, Oh JC and Lee HJ. Effortful swallowing training combined with electrical stimulation in post-stroke dysphagia: A randomized controlled study. *Dysphagia* 2012; 27: 521–527.
12. Bulow M, Speyer R, Baijens L, Woisard V and Ekberg O. Neuromuscular electrical stimulation (NMES) in stroke patients with oral and pharyngeal dysfunction. *Dysphagia* 2008; 23: 302–309.
13. Huang KL, Liu TY, Huang YC, Leong CP, Lin WC and Pong YP. Functional outcome in acute stroke patients with oropharyngeal Dysphagia after swallowing therapy. *J Stroke Cerebrovasc Dis* 2014; 23: 2547–2553.
14. Lee KW, Kim SB, Lee JH, Lee SJ, Ri JW and Park JG. The effect of early neuromuscular electrical stimulation therapy in acute/subacute ischemic stroke patients with Dysphagia. *Ann Rehabil Med* 2014; 38: 153–159.
15. Lim KB, Lee HJ, Yoo J and Kwon YG. Effect of low-frequency rTMS and NMES on subacute unilateral hemispheric stroke with dysphagia. *Ann Rehabil Med* 2014; 38: 592–602.
16. Cohen J. *Statistical power analysis for the behavioral sciences.* 2nd ed. New York: Lawrence Erbaum Associates, 1998.
17. Lim KB, Lee HJ, Lim SS and Choi YI. Neuromuscular electrical and thermal-tactile stimulation for dysphagia caused by stroke: A randomized controlled trial. *J Rehabil Med* 2009; 41: 174–178.
18. Permsirivanich W, Tipchatyotin S, Wongchai M, et al. Comparing the effects of rehabilitation swallowing therapy vs. neuromuscular electrical stimulation therapy among stroke patients with persistent pharyngeal dysphagia: a randomized controlled study. *J Med Assoc Thai* 2009; 92: 259–265.
19. Rofes L, Arreola V, López I, et al. Effect of surface sensory and motor electrical stimulation on chronic post-stroke oropharyngeal dysfunction. *Neurogastroenterol Motil* 2013; 25: 888-e701.
20. Li L, Li Y, Huang R, Yin J, Shen Y and Shi J. Study of transcutaneous neuromuscular electrical stimulation (vitalstim) therapy for post-stroke dysphagia. *Eur J Phys Rehabil Med.* Epub ahead of print 23 July 2014.

21. Han TR, Paik NJ and Park JW. Quantifying swallowing function after stroke: A functional dysphagia scale based on videofluoroscopic studies. *Arch Phys Med Rehabil* 2001; 82: 677–682.
22. Gallas S, Marie JP, Leroi AM and Verin E. Sensory transcutaneous electrical stimulation improves post-stroke dysphagic patients. *Dysphagia* 2010; 25: 291–297.
23. Kimberley TJ, Lewis SM, Auerbach EJ, Dorsey LL, Lojovich JM and Carey JR. Electrical stimulation driving functional improvements and cortical changes in subjects with stroke. *Exp Brain Res* 2004; 154: 450–460.
24. Nudo RJ, Plautz EJ and Frost SB. Role of adaptive plasticity in recovery of function after damage to motor cortex. *Muscle Nerve* 2001; 24: 1000–1019.
25. Ridding MC, Brouwer B, Miles TS, Pitcher JB and Thompson PD. Changes in muscle responses to stimulation of the motor cortex induced by peripheral nerve stimulation in human subjects. *Exp Brain Res* 2000; 131: 135–143.
26. Fraser C, Power M, Hamdy S, et al. Driving plasticity in human adult motor cortex is associated with improved motor function after brain injury. *Neuron* 2002; 34: 831–840.
27. Michou E, Mistry S, Jefferson S, Tyrrell P and Hamdy S. Characterizing the mechanisms of central and peripheral forms of neurostimulation in chronic dysphagic stroke patients. *Brain Stimul* 2014; 7: 66–73.
28. Verin E, Michou E, Leroi AM, Hamdy S and Marie JP. "Virtual" lesioning of the human oropharyngeal motor cortex: a videofluoroscopic study. *Arch Phys Med Rehabil* 2012; 93: 1987–1990.
29. Jayasekeran V, Singh S, Tyrrell P, et al. Adjunctive functional pharyngeal electrical stimulation reverses swallowing disability after brain lesions. *Gastroenterology* 2010; 138: 1737–1746.
30. Plowman-Prine EK, Triggs WJ, Malcolm MP and Rosenbek JC. Reliability of transcranial magnetic stimulation for mapping swallowing musculature in the human motor cortex. *Clin Neurophysiol* 2008; 119: 2298–2303.