Impact of Neuromuscular Electrical Stimulation on Upper Esophageal Sphincter Dynamics: A High-Resolution Manometry Study

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Abstract

Objectives: Beside traditional dysphagia therapy, neuromuscular electrical stimulation (NMES) has been proposed to treat patients with dysphagia. Considering the complexity of the nerve-muscle interaction during swallowing, the underlying physiology of NMES remains unclear. Here, we addressed the question of whether NMES can modify upper esophageal sphincter (UES) dynamics.

Methods: In a prospective study, 26 healthy volunteers performed water swallows with and without NMES. The stimulus was applied in a participant- and operator-initiated stimulation above, near, and below the motor threshold. Swallowing parameters were measured using high-resolution manometry.

Results: The UES relaxation time was found to be extended by 10%, indicating a modification in UES dynamics.

Conclusions: The chosen NMES paradigm influenced the involuntary swallowing phase by extending relaxation time, providing more time for bolus passage into the esophagus. Future studies will have to evaluate if this effect can be found in patients with dysphagia and whether it is beneficial for treatment.

Keywords

high-resolution manometry, neuromuscular electrical stimulation, upper esophageal sphincter, deglutition, dysphagia

Introduction

Dysphagia represents a steadily increasing problem mainly because of current and projected changes in the population age structure. In the United States, about 14% of patients in emergency hospitals and up to 50% of patients in nursing homes show symptoms related to dysphagia.[1] Patients with dysphagia are restricted in everyday life. A reduction in food intake leads to malnutrition and weight loss, while aspiration pneumonia represents the most serious complication of dysphagia. Apoplectic stroke is one of the most frequent causes of dysphagia, with up to 78% of the patients who have suffered a stroke being affected.[2] Fifty percent of apoplectic patients develop pneumonia within the first year after the event.[3,4]

Traditional dysphagia therapy, together with dietary modifications, has been shown to be an effective tool in dysphagia treatment and management, but outcomes are not satisfying in all patients. As a potential alternative, Freed et al[5] reported of very positive effects regarding neuromuscular electrical stimulation (NMES) therapy, leading to an increase in the use of NMES as a treatment of dysphagia. Subsequent studies by others,[6] however, did not consistently confirm the initial results of Freed et al.[5]

The principle behind the use of NMES in dysphagia therapy is to support the swallowing process and to prevent aspiration by supporting the protective mechanisms of the larynx. This is mostly attempted by submental muscle stimulation or stimulation of the musculature of the neck between the hyoid and the larynx[5,7] to improve laryngeal elevation while swallowing.[8] Also, NMES has been applied to improve vocal fold closure by transcutaneous electrical stimulation.[9] However, although several clinical trials reported improvements in swallowing abilities and a reduction in the risk of aspiration as a result of NMES,[7,10-12] others did not.[13-15]

One of the main problems concerning the use of NMES in dysphagia therapy, and a possible explanation for inconsistent results, lies in the poor understanding of the physiological processes occurring in response to NMES.[16] As yet, there is no

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consensus about stimulation protocols or electrode placement mainly because of the complexity of the swallowing process and the broad diversity of swallowing disorders. Moreover, it is difficult to determine the exact moment at which to apply the stimulus (in a synchronous single-pulse stimulation protocol).

When considering the swallowing process at the pharyngeal and esophageal phase, the upper esophageal sphincter (UES) has an important function in preventing bolus reflux. Its opening and closing procedure is very complex and susceptible to disorders. Spasms, a delayed opening, or a precipitate closing of the sphincter can lead to a discontinuous bolus passage and cause a risk of laryngeal penetration or aspiration.[17] As a method for prevention and treatment of these conditions, it would be important to have an NMES paradigm that would decrease the UES tone and improve bolus passage.

In the present study, we aimed to characterize changes in the opening and closing procedure of the UES in response to NMES. Performing NMES with a single-pulse stimulation protocol synchronized with swallowing, we used high-resolution manometry (HRM) to observe the UES tone. The aim was to evaluate the effects of NMES pulses on swallowing parameters and on physiological UES function to collect objective baseline data and to show that the involuntary part of the swallowing process can be modulated.

Materials and Methods

Study Design

This was a prospective randomized experimental trial.

Ethical Approval

The study was performed in accordance with the Declaration of Helsinki, Good Clinical Practice, and applicable regulatory requirements. The clinical trial (#5584/2010) was approved by the ethics committee of the Hannover Medical School. Participants signed an informed consent form before any study-related procedures were performed. They were not financially remunerated.

Participants

Healthy volunteers between 18 and 50 years of age were included in this study. Older persons were excluded, as a subclinical form of dysphagia might be present at older age. Other exclusion criteria were diseases of the esophagus, dysphagia, pregnancy, neck or esophageal surgery, pacemakers, brain stimulators, or metal implants. A balanced sex ratio was not considered necessary.

High-Resolution Manometry

A solid-state HRM hardware system (Solar GI HRM, Medical Measurement Systems [MMS], Enschede, the Netherlands) was used for data collection. The manometric catheter (Unisensor, Attikon, Switzerland) was specifically designed to measure the UES and had an outer diameter of 2 mm and a total of 12 unidirectional pressure sensors. Ten sensors were spaced 7.5 mm apart to measure the high-pressure zone of the UES. One additional proximal sensor and 1 distal sensor were each placed at a distance of 5 cm to these sensors to obtain reference pressures of the tongue base and upper esophagus, respectively. The penetration depth was identified using a scale on the catheter itself, which measures the distance from the nostril to the tip of the catheter. The catheter was calibrated according to the manufacturer's specifications before each measurement. All pressures were referenced to atmospheric pressure, and data were acquired at a frequency of 20 Hz for each sensor. The collected data were analyzed using MMS software (version 8.17a) modified to the above-mentioned catheter.

Neuromuscular Electrical Stimulation

Neuromuscular electrical stimulation was performed using the VocaStim System (Physiomed Elektromedizin, Schnaittach, Germany). This system is approved to treat diseases of the head and neck region and is routinely used, for example, to treat patients with vocal fold pareses.[18]

Because of the accommodation ability of healthy muscles, paretic muscles are usually treated with triangular or exponential electrical pulses. As this study focused on healthy swallowing patterns, a biphasic rectangular single-pulse stimulus was applied.[16] In an effort to enhance initial muscular activity, a short pulse of 5 milliseconds was chosen, which was applied at the onset of swallowing activity. Electrical pulses were applied via 2 electrodes measuring 3 × 4 cm, which were placed left and right to the midline of the thyroid cartilage (anode). This setup was different from the stimulation setup for patients with vocal fold pareses in which usually only the affected side is stimulated. The bilateral electrode placement was chosen to symmetrically stimulate muscle structures, associated with the UES. A neutral electrode measuring 6 × 8 cm was placed on the nape (cathode). The plate electrodes were placed into wet viscose covers to improve current conduction (Figure 1).

The motor threshold was defined as a muscle contraction in the region of the larynx or hypopharynx, which could be observed laryngoscopically. Initially, electrical pulses of increasing intensity were applied to 2 male and 2 female participants. All 4 participants showed muscular contractions at current intensities between 10 and 17 mA. Hence, an intensity of 20 mA was assumed to be above the motor threshold, while not inflicting any pain, and was defined as the stimulation intensity in this study. A motor threshold near stimulation of 10 mA and a control value of 0 mA (sham stimulation) were also chosen.

Figure 1. Electrode placement on the neck: 2 electrodes (1a and 1b) were placed left and right to the midline of the thyroid cartilage (anode), and a neutral electrode (2) was placed on the nape (cathode).

Test Setting

While participants were sitting upright with the head in a neutral position, the manometric catheter was placed transnasally into the upper esophagus and fixed in place at the tip of the nose. The catheter was positioned in a way that the high-pressure area of the UES was represented by sensors in the middle of the catheter. Because of its small diameter, the catheter passed easily through the nose. To avoid a loss of sensitivity of the mucosa, no lubricating gel containing local anesthetics was used. Participants rested for at least 5 minutes before performing the experimental swallows to get used to the catheter.

For each swallow, a 2-mL water bolus at room temperature was delivered into the oral cavity by a syringe and kept there for 5 seconds before swallowing. The participants performed 10 swallows in each test series and were instructed to swallow immediately after the auditory command "swallow." To obtain reference values, the participants first swallowed without any electrical stimulation. A total of 6 test series using sham or real electrical stimulation followed. The current was applied using a manual release key either by participant-initiated stimulation (PIS) or by operator-initiated stimulation (OIS), synchronized to the auditory command. We reasoned that the act of pressing the manual release key might influence the participants' general body tone (in PIS mode). Therefore, the OIS mode was used as a control for influences of peripheral motor actions on the swallowing pattern. The action of applying the electrical pulse was not visible to the participant when initiated by the operator. The test series were randomized with regard to current intensity (0 mA, 10 mA, or 20 mA).

Manometric Analysis

Resting pressure, residual pressure, maximum pressure, and relaxation time were recorded to examine the influence of electrical stimulation on the dynamic behavior of the UES. Resting and residual pressures were calculated automatically by the supplied software. Maximum pressure was determined manually as the highest pressure value of the peristaltic wave in the segment of the UES. The onset of the relaxation time was defined as a 10% pressure drop from the resting pressure, with the end corresponding as the point when the same pressure value was reached again because of the arrival of the peristaltic wave.[19] Pressures were recorded from the central sensor in the UES segment to avoid any influences of cranial movement of the larynx and the UES on the relaxation time.

Statistics

In each test series, mean values of all participants were calculated for all 4 parameters (resting pressure, residual pressure, maximum pressure, and relaxation time). Statistical analysis was performed using SPSS (version 18.0, IBM Corp, Armonk, New York, USA) including all the data collected. An analysis of variance for dependent repeated-measured values was carried out. At first, the Mauchly test of sphericity was performed. Depending on whether the result showed significance, different tests of within-participant effects were carried out. When results showed no significance ($P > .05$), the sphericity assumed test was performed; when significant ($P < .05$), the Greenhouse-Geisser test was applied. If one of these tests indicated significance ($P < .05$), a pairwise comparison of each test series was performed. The adjustment for multiple comparisons was achieved by Bonferroni correction. P values lower than 5% ($P < .05$) were considered significant.

Results

Patient Data

A total of 26 participants were tested (9 male and 17 female). The mean age was 26.8 years, the mean height was 169.3 cm, and the mean body mass index was 22.9 kg/m^2. The mean penetration depth of the catheter measured 27.7 cm (Table 1). All participants were in good health and showed no signs of swallowing difficulties. Participants did not report any relevant discomfort, and none of the test series had to be discontinued.

Reference Values

All participants initially performed 10 swallows without electrical stimulation to establish reference values. The

Table 1. Overview of Patient Data.[a]

	All Patients	Male Patients	Female Patients
Patients, n (%)	26 (100)	9 (37)	17 (63)
Age, y	26.8 ± 5.4	27.7 ± 6.4	26.3 ± 5.0
Height, cm	169.3 ± 8.5	177.4 ± 4.58	164.9 ± 6.7
Body mass index, kg/m^2	22.9 ± 3.1	24.4 ± 2.9	22.1 ± 3.0
Penetration depth of catheter, cm	27.7 ± 1.5	28.8 ± 1.53	27 ± 1.0

[a]Values are expressed as mean ± standard deviation.

Table 2. Reference Values of 26 Patients.

	Mean ± Standard Deviation (Range)
Resting pressure, mm Hg	38.92 ± 13.87 (12.2 to 66.7)
Residual pressure, mm Hg	−0.73 ± 5.69 (–9.6 to 13.8)
Maximum pressure, mm Hg	138.37 ± 48.73 (82.9 to 308.7)
Relaxation time, ms	777.5 ± 197 (475 to 1189)

mean resting pressure was 38.92 ± 13.87 mm Hg, the mean relaxation time was 777.5 ± 197 milliseconds, the mean residual pressure was −0.73 ± 5.69 mm Hg, and the mean maximum pressure was 138.37 ± 48.73 mm Hg (Table 2).

Relaxation Time

With sham stimulation (0 mA), the mean relaxation time was 744.61 milliseconds with OIS and 772.35 milliseconds with PIS (Table 3).

Further, OIS produced relaxation times of 817.72 milliseconds with 20 mA and 786.19 milliseconds with 10 mA of applied current. The relaxation time was, on average, 73.1 milliseconds longer when associated with a 20-mA stimulus and 41.6 milliseconds longer with a pulse intensity of 10 mA when compared to sham stimulation. A pairwise comparison of OIS with intensities of 20 mA and 0 mA showed a significant difference ($P = .006$). The near threshold stimulation (10 mA) showed no significant differences when compared to 20 mA ($P = .333$) and 0 mA ($P = .129$). However, in general, a prolongation in relaxation time could be seen in response to an increase in stimulus intensity.

Relaxation times in response to PIS were between 801.46 milliseconds (20 mA) and 804.33 milliseconds (10 mA) and also tended to be longer when an electrical stimulus was applied. When stimulated with intensities of 20 and 10 mA, relaxation times were, on average, 29.1 milliseconds (20 mA) or 32 milliseconds (10 mA) longer compared to sham stimulation, but the differences were not significant (20 mA vs 0 mA [$P = .203$]; 10 mA vs 0 mA [$P = .116$]).

Maximum Pressure

The reference swallows showed a mean maximum pressure of 138.37 mm Hg with a high standard deviation of 48.37 mm Hg. The statistical variation was also high in the stimulation series, with the lowest maximum pressure values ranging from 67 mm Hg with sham stimulation in the PIS mode to 326.8 mm Hg after OIS with 10 mA. In general, mean maximum pressures were lower in the stimulation series compared to the reference swallows (Table 3), although the difference was statistically significant only for PIS at 10 mA ($P = .05$).

Residual Pressure

The residual pressure values under real stimulation were slightly lower (−0.74 to −1.91 mm Hg) than for the reference values (–0.73 mm Hg) but did not show statistical significance.

Resting Pressure

Mean resting pressure values varied between 30.18 to 38.92 mm Hg, with individual values ranging from 8.5 mm Hg (10 mA in PIS mode) to 66.7 mm Hg in the reference swallows. Compared to reference values, the mean resting pressures were significantly lower in the stimulation series (PIS: reference value vs 20 mA [$P = .001$]; vs 10 mA [$P < .001$]; vs 0 mA [$P < .001$]; OIS: reference value vs 10 mA [$P = .028$]; vs 0 mA [$P = .002$]) except for 20 mA of OIS ($P = .195$).

Discussion

Neuromuscular electrical stimulation is widely used in physical and rehabilitative medicine to treat paretic muscles, including those of the vocal cords,[18] although it is still controversially discussed whether its effectiveness justifies its use in the treatment of dysphagia. In this study, we investigated the immediate effects of transcutaneous NMES synchronized to swallowing to provide objective data of the response of the UES.

Table 3. Data of Stimulation Trials Associated With PIS and OIS.[a]

	Resting Pressure, mm Hg	Residual Pressure, mm Hg	Relaxation Time, ms	Maximum Pressure, mm Hg
PIS				
20 mA	33.34 ± 11.33	−1.05 ± 4.99	801.46 ± 236.11	125.71 ± 43.38
10 mA	30.18 ± 10.83	−1.91 ± 5.08	804.33 ± 248.44	123.10 ± 43.83
0 mA	31.87 ± 10.26	−1.76 ± 4.75	772.35 ± 216.23	124.90 ± 41.64
OIS				
20 mA	36.06 ± 13.64	−0.74 ± 6.19	817.72 ± 228.18	136.94 ± 45.64
10 mA	34.93 ± 13.31	−0.86 ± 5.35	786.19 ± 199.76	133.68 ± 49.53
0 mA	33.55 ± 13.06	−1.36 ± 4.65	744.61 ± 177.49	131.42 ± 48.12

[a]Values are expressed as mean ± standard deviation. OIS, operator-initiated stimulation; PIS, participant-initiated stimulation.

Clinical Consequences

Relaxation time. The main finding was a prolonged relaxation time of the UES during NMES compared to sham stimulation. In both OIS and PIS settings, relaxation times tended to be longer when a stimulation pulse was applied but was only significant for OIS (20 mA vs 0 mA). Because Bonferroni adjustment was conservatively applied to correct for type I errors in multiple comparisons, the prolongation in relaxation time can be assumed to be a true finding.

Considering these results, we conclude that the use of NMES, here applied in a single-pulse paradigm, can influence UES dynamics and extend the opening phase of the sphincter during swallowing. These findings confirm that it is possible to influence the automatic component of the swallowing process, which is an effect that may have both clinical and therapeutic relevance. In patients with dysphagia, for instance, hypertension or spasms of the cricopharyngeal muscle (pars fundiformis) or a premature closure of the UES can impair bolus passage. Also, UES opening can be affected by a combination of reduced lingual or pharyngeal contraction pressure and a limited or missing laryngohyoidal elevation. This may lead to food retention above the sphincter in the sinus piriformis and can consequently cause laryngeal penetration and aspiration. Extending the relaxation time, that is, the time window allowing a food bolus to pass the UES, could, at least theoretically, lead to an improvement in bolus passage.

The single-pulse stimulation paradigm used in this study in the OIS condition resulted in an extension of 10% of the total relaxation time. Considering the very short stimulation pulse of 5 milliseconds compared to an extension in relaxation time of approximately 70 milliseconds, it is unlikely that the effect is just a consequence of current flow through the tissue. It can rather be assumed that the electrical pulse caused changes in the muscular contraction patterns, which resulted in extended relaxation times. It would therefore be interesting to investigate whether modification of this stimulation paradigm, such as using longer or repetitive pulses, could possibly extend the phase of UES opening further. Future studies should also investigate whether this effect is also present in patients with dysphagia and if this type of NMES is beneficial for treatment.

Maximum and residual pressures. Maximum and residual UES pressures did not show significant changes during NMES. The range in maximum pressure values was high in all test series, with slightly lower pressures in stimulation series compared to the reference values. The high degree of variation might have masked any potential small effects of NMES, but apparently, the electrical pulses did not modify (weaken or enhance) the peristaltic wave. This finding is important because a weakening of the muscular contraction could impair regular bolus transport or even interrupt bolus passage. Hence, an alteration of the pharyngeal peristaltic function is not to be expected when applying the stimulation protocol used in this study.

The residual pressure is defined as the minimum pressure during sphincter relaxation, which usually occurs just before complete sphincter opening. A decrease of the residual pressure could potentially ease bolus passage through the sphincter region, whereas an enhancement might mirror an incomplete sphincter opening and therefore disturb regular bolus transport. Neither was detected in this study. Hence, it is likely that the applied NMES procedure only prolonged the relaxation time but did not modify the pharyngeal muscular pressure generation.

Resting pressure. Previous studies have described that the resting pressure of the UES is maintained constantly.[20,21] The sphincter tone differs intraindividually and changes during the individual's activities, general muscle tension,[22] phonation, sleep, medication, and anesthesia.[23,24] It has also been reported that the diameter of the manometer probe can influence the pressure.[25]

The resting pressure cannot be considered as part of the so-called swallow-associated parameters, as it is measured several seconds before a swallow occurs. Therefore, it does not represent a suitable parameter in the evaluation of the UES's swallow-associated behavior.

However, significant differences in the test series have been found. All reference values, including the resting pressure, were measured at the beginning of the examination. The reference resting pressures were higher than the pressures measured in the stimulation series. It is likely that this effect rather occurred as a result of a general relaxation as well as adaptation to the examination procedure and probe rather than as a result of the stimulation protocol. It is unlikely, however, that the electrical stimulus itself had an effect on the resting pressure because a drop in all stimulation series, including sham stimulation, was noted.

Technical Aspects

HRM system. Tests were performed using an HRM system that was specially designed to evaluate the UES. The manometric catheter, 2 mm in diameter, is relatively small compared to other circumferential-measuring HRM catheters, which typically measure 4.2 mm in diameter. The use of a probe with unidirectional pressure sensors had no influence on the test results because the probe was not replaced intraindividually. A relevant torsion of the catheter, which could possibly have effected the measurements, could not be observed laryngoscopically during initial determination of the motor threshold.

Reference values of the 2-mm HRM catheter. It has been demonstrated previously that the intrabolus pressure rises with an increase in bolus volume.[26,27] Hence, a 2-mL water bolus was chosen to enable the swallow while not influencing the intrabolus pressure.

Because HRM catheters with large diameters can potentially affect UES pressure, we used a catheter with a very small diameter to minimize the risk of such an effect. Comparing the reference values (Table 2) with the results of other authors, resting pressures and maximum pressures are generally lower. Pandolfino et al[19] reported mean resting pressures of 49 mm Hg (interquartile range, 40.3-55.8 mm Hg) in healthy individuals, Takasaki et al[28] found mean resting pressures of 70.2 ± 30.0 mm Hg for male and 61.8 ± 26.7 mm Hg for female individuals, and Kwiatek et al[29] measured 55.7 mm Hg (5th-95th percentile, 26.3-85.1 mm Hg). Concerning maximum pressures, McCulloch et al[30] reported on values as high as 239 ± 78 mm Hg, and Umeki et al[31] reported 197.2 ± 88.7 mm Hg.

All of the above studies were performed with a larger diameter catheter, and it seems reasonable that these probes cause a higher UES pressure probably by dilating the sphincter. The residual pressure representing the minimum pressure during UES relaxation is not as susceptible for sphincter distension as, for example, the resting pressure and the maximum pressure because the musculature is relaxed. Because the residual pressure measured in this study (–0.73 ± 5.69 mm Hg) is within the range of those recorded from different authors (–5 mm Hg[30] to 6.2 mm Hg[29]), we can assume that the reference values measured in this study represent real UES pressures.

Relaxation time varies a lot according to its definition. In this study, onset and offset of the relaxation time were defined as a 10% pressure decrease during swallowing compared to the resting pressure, and a mean relaxation time of 777.5 milliseconds was established. Other studies defined the onset of relaxation time as a decrease of 50% or a complete relaxation of the sphincter. Using these definitions, McCulloch et al[30] recorded a mean relaxation time of 850 milliseconds, while Bulow et al[32] and Pandolfino et al[19] both measured shorter relaxation times (625 ± 25.6 ms and 400 ms, respectively). The collected data (resting pressure, residual pressure, maximum pressure, and relaxation time values of the UES) represent the first reference data for the new Unisensor 2-mm HRM catheter.

Limitations of the Study

It is generally assumed that a prolonged or more effortful laryngeal elevation extends relaxation time.[31] This can be achieved by triggering the thyrohyoid muscle or other suprahyoidal musculature. If the more superficially located sternohyoid and omohyoid muscles are triggered, the larynx will be lowered,[6] and the stimulus would be neutralized.

The physiological background of NMES causing the extension of relaxation time that was found in this study is not entirely clear. The electrical stimulus had a relatively short duration of 5 milliseconds and was triggered at the onset of swallowing, overlapping with the opening phase of the UES. It is possible that the pulse enhanced laryngeal elevation and consequently prolonged relaxation time. To find out more about the stimulus effect, it would be interesting to see if repetitive or longer pulses could further increase the relaxation time.

The peristaltic wave marks the end of sphincter relaxation and follows about 1 second after the onset of the swallow. In future studies, it would be interesting to investigate whether a correlation of the stimulation pulse to the pharyngeal pressure wave at the end of the swallow could intensify the muscular contraction and enlarge the maximum pressure. Such an effect could be useful in traditional dysphagia therapy to support effortful swallows by NMES.

Neuromuscular electrical stimulation was applied following an auditory command, which might have resulted in a lack of coordination between the electrical stimulus and the exact swallowing phase, probably reducing the stimulus effect. Also, the action of pressing the manual release key itself may have already altered the swallowing pattern in individuals. To improve coordination and to trigger more precisely, an electromyography-driven release of the stimulation pulse, for example, registered from the suprahyoidal musculature, could be more beneficial. Such a device might also enable a correlation of NMES pulses on the peristaltic wave at the end of the swallow.

The test series contained 10 swallows each and were randomized with regard to current intensity. Randomization for each swallow was not possible because the VocaStim device, for safety reasons, does not allow an increase in current intensity in steps as big as 10 mA. To reach higher current intensities, the manual release key has to be triggered several times. The software of the NMES system should be adjusted for future studies to avoid anticipation and habituation to the stimulus pulse.

Conclusions

This study demonstrated that NMES as applied here induces a prolongation of the UES relaxation time in healthy individuals. To our knowledge, this is the first HRM study that uses a single-pulse paradigm, showing that NMES can influence UES dynamics.

From a clinical point of view, an extension of the relaxation time is significant because an early closure of the UES could lead to food retention and consequently laryngeal penetration and aspiration. An extended relaxation time could at least theoretically improve swallowing in patients with dysphagia, as the enlarged time window would create a "safe zone" for the food bolus to pass the sphincter and therewith diminish the risk of aspiration. Changing the stimulation paradigm to stimuli with a longer duration or repetitive pulses might possibly extend the relaxation time even further. Future studies will have to show if patients with dysphagia benefit from this type of NMES. Moreover, these results encourage the use of HRM in clinical trials to monitor the effects of NMES in the pharyngeal region and the UES.

Authors' Note

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Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Martin Ptok and Simone Miller have given a presentation for Physiomed Elektromedizin (not related to this study) and received refunds of flight expenses from the company. All authors declare that they have no conflict of interest.

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