Department of Veterans Affairs

JRRD Volume 44, Number 3, 2007
Pages 373–380
Journal of Rehabilitation Research & Development

Effect of temperature on electrophysiological parameters of swallowing

Barin Selçuk, MD;[1*] Hilmi Uysal, MD;[2] Ibrahim Aydogdu, MD;[2] Müfit Akyuz, MD;[1] Cumhur Ertekin, MD[3]
[1]Ankara Physical Medicine and Rehabilitation Education and Research Hospital of Ministry of Health, Ankara, Turkey; [2]Neurology Department, Faculty of Medicine, Akdeniz University, Antalya, Turkey; [3]Neurophysiology and Neurology Department, Faculty of Medicine, Ege University, Izmir, Turkey

Abstract—The effect of three different temperature ranges on the triggering of voluntary-induced swallowing and on the duration of the pharyngeal phase of oropharyngeal swallowing was studied electrophysiologically. The relationship between volume and temperature of liquids swallowed was also explored. This study included 40 nondisabled volunteers (23 male and 17 female). Laryngeal vertical movements and submental electromyographic activity were recorded as each subject swallowed water at three different temperature ranges: normal (23–25 °C), cold (8–10 °C), and hot (58–60 °C). The time for triggering of the pharyngeal phase of swallowing was found to be shorter for cold and hot water than for normal temperature water ($p < 0.01$). The duration of the pharyngeal phase of oropharyngeal swallowing was also shorter for cold and hot water than for normal temperature water ($p < 0.05$). The maximum capacity of a single bolus (dysphagia limit) was >20 mL of water in all nondisabled subjects for different temperatures. However, the capacity was significantly less for hot water relative to normal temperature water and cold water ($p < 0.05$). In conclusion, the temperature ranges used in this study were found to be effective in triggering voluntary-induced swallowing.

Key words: deglutition, dysphagia, electrophysiological method, laryngeal sensor, neurophysiology, rehabilitation, sensory, submental EMG, swallowing, temperatures, thermal stimulation.

INTRODUCTION

The sensory receptors in the oropharyngeal mucosae are involved with initiating voluntary-induced swallows, and they relay the information to the brain about the size, viscosity, and temperature of the bolus to be swallowed. The importance of sensory inputs during swallowing has been shown in research without [1–3] and with human subjects [4–10]. Among the sensory variables, the effects of bolus volume and viscosity on swallowing have been frequently studied [9–12]. On the other hand, the effects of bolus temperature on oropharyngeal swallowing have been scarcely documented [13–16]. Logemann has proposed that thermal stimulation increases oral awareness, provides an alerting sensory stimulus to the pharyngeal swallow, and is triggered more rapidly by initiation of swallowing at the oral cavity [13]. Other research has shown that a therapy technique called "thermal stimulation" is helpful in shortening the duration of delay of pharyngeal phase swallowing in dysphagic patients [11,13–14,16–18]. However, Shaker et al. has shown that temperature does not have any significant effect on the threshold volume for triggering pharyngeal swallowing [15].

Previous studies have mainly focused on the triggering of swallows, especially around the mucosae of the posterior oral cavity, but none has focused on the changes to the pharyngeal phase of swallowing in different temperatures. The effects of extreme temperature changes (cold vs hot)

Abbreviations: CPG = central pattern generator, EMG = electromyographical, SM-EMG = submental EMG.

***Address all correspondence to Barin Selçuk, MD; Kasim Gülek Sok (50. Sok) 1/10 Bahçelievler, 06500 Ankara, Turkey; +90-312-213-8356; fax: +90-312-310-4242.**
Email: barinselcuk@yahoo.com

DOI: 10.1682/JRRD.2006.08.0089

and their influence on bolus volume and oropharyngeal swallowing have not been systematically studied. Therefore, this study had three purposes. First, this study explored the effects of three different temperature ranges (i.e., cold, hot, and normal) on the triggering of voluntary-induced swallowing. Second, this study investigated the effect of different temperatures on the duration of the pharyngeal phase of swallowing. Finally, we investigated the relationship between the size and the temperature of liquids to be swallowed. All the aspects of swallowing were studied with use of the electrophysiological methods described in other research [8–9,19].

MATERIALS AND METHODS

Study participants included 40 nondisabled volunteers (23 males and 17 females at an average age of 47.9 ± 15.6 [mean ± standard deviation]), most of whom were hospital staff, including the authors. This study was approved by the ethics committee of our hospital, and informed consent was obtained from each subject.

The nondisabled subjects were asked to sit on an examination couch and instructed to hold their heads in a natural upright position. Electrophysiological measurements were then taken [8–10]. For detection of laryngeal movements (upward and downward), a mechanical laryngeal sensor that consists of a single piezoelectric wafer with a 4.0 × 2.5 mm rubber bulge fixed at its center was placed over the cricothyrotomy region between the cricoid and thyroid cartilages on the midline. The sensor was secured with a rubber band tied around the neck, and its output was connected to the first channel of the electromyographical (EMG) apparatus (Neuropack *μ*, Nihon Kohden Corp, Tokyo, Japan) (**Figure 1(a)–(b)**). The sensor amplifier output was also bandpass-filtered (cutoff frequencies 0.01–20.00 Hz). The sensor detected two deflections of generally opposing polarity during each swallow. The first deflection of the laryngeal sensor signals represents the upward movement of the larynx and the second deflection represents the downward movement (**Figure 1(c)**). The upward and downward deflections of the laryngeal sensor were sometimes diphasic or triphasic. Their shortest time with high amplitude at the beginning of deflection from the baseline was important and accepted as the point of onset. The leading or trailing edge of the first deflection was used to trigger the delay-line circuitry of the recording apparatus so that all signals were time-locked to the same instant.

We recorded EMG activity (or submental EMG [SM-EMG]) on the second channel of the EMG apparatus using bipolar silver chloride EEG (electroencephalographic) electrodes taped under the chin over the mylohyoid-geniohyoid-anterior digastric muscle complex (**Figure 1(a)–(b)**). The EMG signals were bandpass-filtered (100 Hz–10 kHz), amplified, rectified, and averaged.

Because the SM-EMG activity coincided with the laryngeal upward movement, the rectified-integrated SM-EMG activity was also time-locked to the laryngeal sensor signals. Total analysis time was adjusted to 2 seconds, and at least five successive sensor and SM-EMG traces were recorded. The individual traces were examined, superimposed, and then averaged.

Results were recorded as each subject (n = 40) swallowed water at three different temperature ranges: normal (23–25 °C), cold (8–10 °C), and hot (58–60 °C). A repeated design measure was used in which the subjects were administered each of the three conditions, and trials were separated by 5-minute rest periods. At least five successive sensor and EMG traces were recorded for each type of swallow. We evaluated two parts for this testing method: single-bolus analysis and dysphagia limit.

In the single bolus analysis, every swallow was initiated with 3 mL of water positioned on the tongue with the tongue tip touching the upper incisors as parameters were measured. The onset of two deflections in the laryngeal sensor signal recordings was denoted as “0” and “2” (**Figure 1(c)**). The interval between the onset of two deflections (0–2 interval) is thought to reflect the time necessary for the elevation, closure, and upward relocation of the larynx [8].

The onset and duration of oropharyngeal swallowing were recorded from the SM-EMG activity (of the mylohyoid-geniohyoid-anterior digastric muscle complex). Total duration was labeled as “A–C” interval (**Figure 1(c)**), and peak amplitude of the SM-EMG was measured from averaged traces. SM-EMG or A–C interval gives considerable information about the onset and duration of the oropharyngeal swallowing [2,20–21]. Oral and pharyngeal times of swallowing were included in the SM-EMG duration [20].

We were able to use laryngeal sensor and SM-EMG traces simultaneously to measure the triggering of the pharyngeal phase of swallowing determined by the time interval between the onset of the SM-EMG and the first deflection of the signal of the laryngeal sensor. This

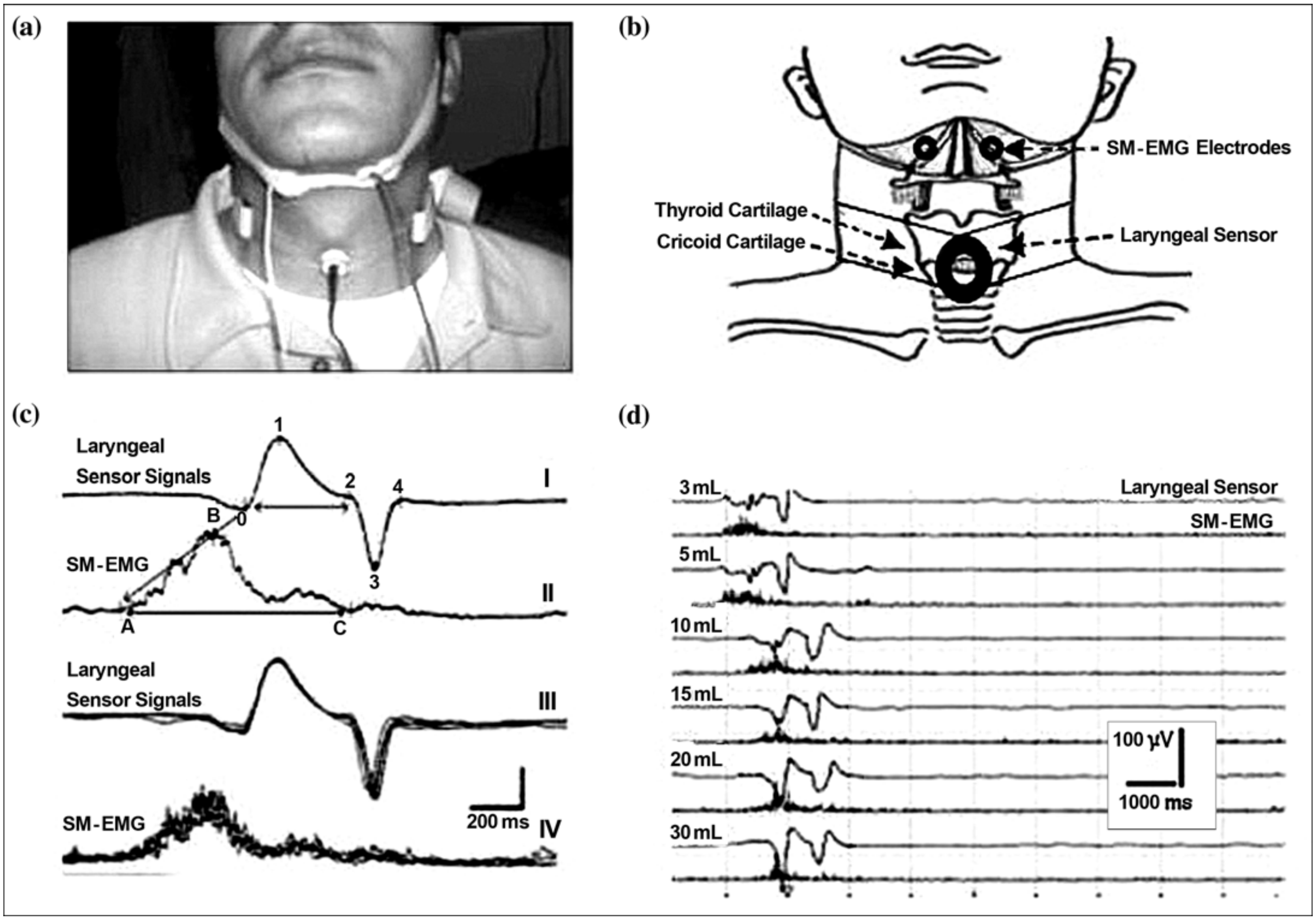

Figure 1.
(a)–(b) Positions of laryngeal sensor and submental electromyographical (SM-EMG) electrodes for swallowing study. For laryngeal movement recording, piezoelectric movement sensor is placed between thyroid and cricoid cartilages at midline. For SM-EMG activity recording, surface silver electrodes are taped under chin. **(c)** Laryngeal sensor signals (I and III) and integrated SM-EMG activity (II and IV) during 3 mL single-bolus swallowing. I and II denote average of 5 successive responses; III and IV are same 5 responses superimposed. 0 and 1 define, respectively, onset and negative peak of first deflection of laryngeal sensor signal. Second deflection of sensor signal defined between points 2 and 4 represents downward movement of larynx. Interval between onsets of 2 deflections (0–2 interval) is thought to reflect time necessary for elevation, closure, and upward relocation of larynx. Points A, B, and C (in II) denote the onset, peak, and end of SM-EMG activity of SM muscles (mylohyoid-geniohyoid-anterior digastric muscle complex). Total duration is A–C interval and shows onset and duration of oropharyngeal swallowing. Interval between onset of SM-EMG and first deflection of laryngeal sensor that is related to triggering of reflex swallow (A–0 interval) shows temporal relationship between instant of voluntary activation of SM muscle complex and instant of reflex triggering of swallowing response. **(d)** Laryngeal sensor signals (top traces in each pair) and integrated SM-EMG activities (lower traces in each pair) during swallowing different water amounts, increasing in quantity step-by-step from 3 to 30 mL (piecemeal deglutition).

deflection is one of the first events of the pharyngeal phase of swallowing [2,22–23]. In other words, the “A–0” interval (time parameter) between the onset of the SM-EMG and the onset of the first deflection of the laryngeal sensor provided information about the temporal relationship between the instant of the voluntary activation of the SM-EMG and the instant of reflex triggering of the swallowing response (**Figure 1(c)**) [23].

In the second part of the method, we measured dysphagia limits, also called “piecemeal deglutitions.” The phenomenas of piecemeal deglutition or dysphagia limit have also been investigated using the same measuring technique [9,11]. Dysphagia limit is based on the detection of a physiological phenomena that occurs when an oral bolus of large liquid volume is divided into two or more pieces that are then swallowed successively (hence it is also known as piecemeal deglutition) [9,11]. We investigated dysphagia limit using the sweep time of the oscilloscope set at 10 seconds and delay line started 2 seconds after the onset of the single sweep. Therefore, after a water amount was drunk, the effect of the bolus was followed for 8 seconds.

All subjects were given 3, 5, 10, 15, 20, and 30 mL of water, and oscilloscope traces were started at the examiner's order to swallow. The laryngeal sensor signals and the SM-EMG integrated activities were recorded from the beginning of these long sweeps of the oscilloscope (**Figure 1(d)**). The patients were asked to swallow all the liquid given in a single effort. If no recurrence of SM-EMG and laryngeal activity occurred with these smaller amounts of water, 40 and 50 mL of water were given until two or more swallows occurred. Any swallowing-related recurrence of the SM-EMG activity and the laryngeal sensor signal within 8 seconds after the onset of the sweep was accepted as piecemeal deglutition or as a sign of dysphagia limit. However, as the piecemeal deglutition was observed physiologically in nondisabled subjects when swallowing >20 mL of water, duplication or multiplication at or below the 20 mL of water is referred to as the "dysphagia limit" [9].

We calculated the mean ± standard error of the mean for all parameters measured and performed statistical analyses to assess the differences in swallowing parameters using variance and correlation analysis as appropriate. All results obtained from subjects were compared with corresponding values obtained from ingestion of water at different temperatures. Paired *t*-tests were also undertaken for comparisons. A univariate one-way analysis of variance for repeated measurements and Tukey's honest significant difference test (SPSS for Windows release 10.0; SPSS Inc, Chicago, Illinois) were applied to the data obtained for different temperatures.

RESULTS

The statistical findings of electrophysiological parameters are illustrated in the **Table**. The time necessary for triggering the pharyngeal phase of swallowing (calculated from A–0 interval) was significantly shorter for cold and hot water than that for swallowing water at normal temperature ($p < 0.01$). (**Figure 2** shows results of nondisabled subject swallowing water at 23–25 °C [normal temperature].) The duration of the pharyngeal phase of swallowing (calculated from 0–2 interval) was also significantly shorter for hot and cold water compared with water at normal temperature ($p < 0.05$). (**Figure 3** shows results of nondisabled subject swallowing water at 8–10 °C [cold temperature].) The other parameters of the oropharyngeal swallowing, including the total duration of the SM-EMG, were not significantly changed.

Different bolus volumes at various temperature ranges have revealed that all nondisabled subjects could swallow the bolus volumes just above 20 mL of water with one try at cold, hot, and normal temperatures. However, after 20 mL water, some subjects failed to swallow the bolus after the first try and they had to divide the bolus into two or more pieces as piecemeal deglutition at the hotter temperature range (58–60 °C) (**Figure 4)**.

DISCUSSION

Sensory inputs from the oropharyngeal region, especially the tonsillar pillars, the base of the tongue, and oropharyngeal mucosae, have been proposed to be important for triggering swallowing [1–2,4–7,21,23–24]. The belief is that sensory inputs originating from these structures may be modified by the changes in bolus temperature [11,13,16]. Studies have also reported that the

Table.
Average values (mean ± standard error of the mean) of water temperature for electrophysiological parameters obtained from nondisabled subjects during swallowing.

Parameter	Water at 23–25 °C (Normal)	Water at 8–10 °C (Cold)	Water at 58–60 °C (Hot)
0–2 (ms)*	564.0 ± 102.7	522.2 ± 87.4	503.3 ± 104.8
A–0 (ms)†	137.9 ± 58.0	128.2 ± 50.5	124.7 ± 62.5
A–C (ms)‡	722.6 ± 161.7	711.6 ± 175.3	671.8 ± 151.0
Dysphagia Limit (mL)	30.5 ± 7.8	29.8 ± 8.0	27.8 ± 7.7

*Time for pharyngeal phase of swallowing.
†Time for triggering of pharyngeal phase of swallowing.
‡Duration of submental electromyographical activities.

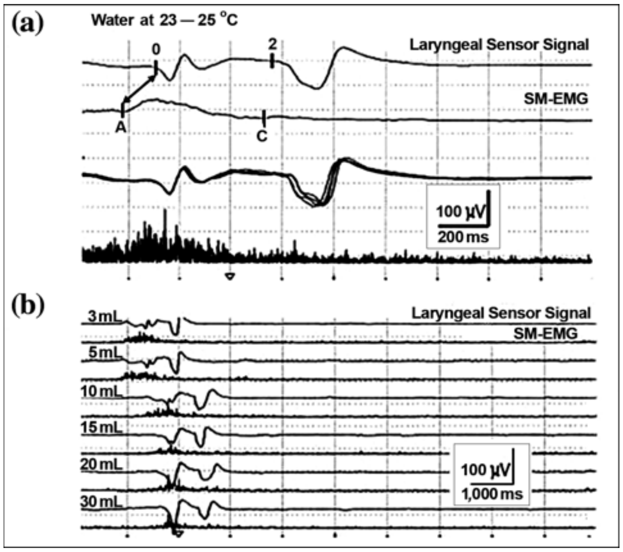

Figure 2.
Laryngeal sensor signals (upper traces in each pair) and integrated submental electromyographical (SM-EMG) activities (lower traces in each pair) obtained from nondisabled subject **(a)** swallowing water at 23 to 25 °C (upper 2 traces are averages; lower 2 traces are superimposes of 5 responses) and **(b)** swallowing different water amounts increasing from 3 to 30 mL. Dysphagia limit was >20 mL of water in all nondisabled subjects for water at 23 to 25 °C.

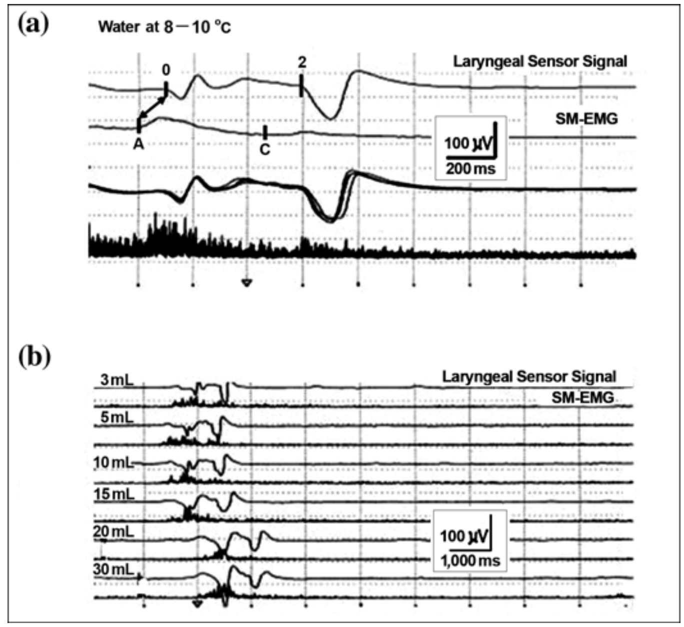

Figure 3.
Laryngeal sensor signals (upper traces in each pair) and integrated submental electromyographical (SM-EMG) activities (lower traces in each pair) obtained from normal subject **(a)** swallowing water at 8 to 10 °C (upper 2 traces are averages; lower 2 traces are superimposes of 5 responses) and **(b)** swallowing different water amounts increasing from 3 to 30 mL. 0–2 and A–0 intervals are shorter for cold water (8–10 °C) compared with normal temperature water (23–25 °C). Dysphagia limit was >20 mL of water in all nondisabled subjects for water at 8 to 10 °C.

triggering of the pharyngeal phase of swallowing has been shortened by the thermal stimulation in nondisabled subjects and dysphagic patients [11,14,16–18,25–27].

Our electrophysiological findings were compatible with the previous studies mentioned here. The time parameter denoted as the A–0 interval is closely linked with the time necessary for the triggering of the pharyngeal phase of the swallowing [19,23]. The A–0 interval for swallowing water was significantly shorter for cold and hot water compared with the A–0 interval at normal temperature. Since our study focused on voluntary-induced water swallowing, the A–0 interval was found to be under cortical control either directly or via the brain stem central pattern generator (CPG) [7,19–20,22–23,28–30]. At the brain stem level, all the afferent nerve fibers from the oral cavity involved in initiating or facilitating swallowing converge in the CPG, especially in the nucleus tractus solitarius along with cortical drive. That is, brain stem CPG receives the main sensory input from the oropharyngeal region and cortical-descending inputs reach similar areas of CPG. Therefore, some sensory inputs such as the temperature extremes (cold and hot water) that initiate swallowing are transmitted to the region of the cortex that facilitates the initiation of the swallowing [21]. When triggered at body temperature, both cold and hot water swallowing can be unexpected and warning stimuli for the oropharyngeal apparatus, and therefore, they seem to be more alarming. Taken together, the temperature variables (cold and hot) are effective in facilitating the triggering of voluntary-induced swallowing.

The pharyngeal phase of swallowing after triggering the oropharyngeal deglutition has not been well documented in previous temperature-related studies. Among these, Sciortino et al. examined the different sensory modalities that have been used to stimulate the anterior faucial pillars at the posterior oral cavity, when applied alone and in all combinations, and to record SM-EMG activity [26]. SM-EMG did not give many cues, and SM-EMG duration did not differ significantly among the conditions. However, using only a surface EMG recording of submental muscles does not provide sufficient information in any swallowing study unless it can be combined with other recording parameters, such as measuring the

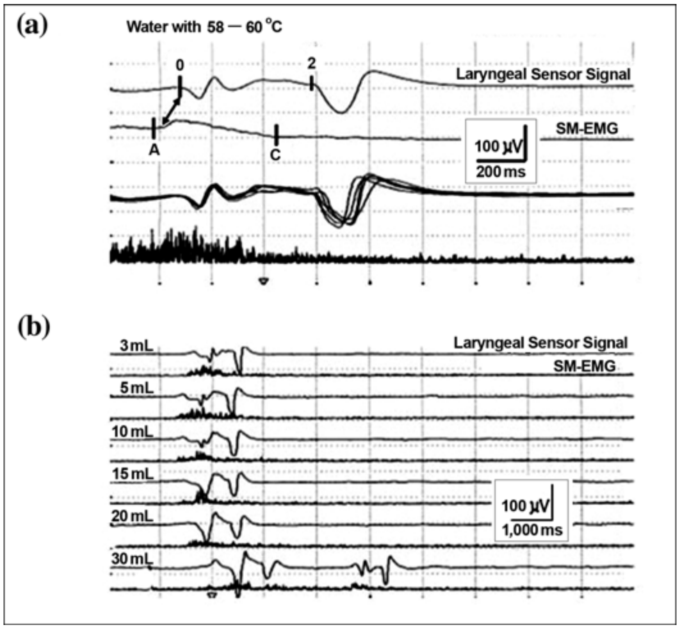

Figure 4.
Laryngeal sensor signals (upper traces in each pair) and integrated submental electromyographical (SM-EMG) activities (lower traces in each pair) obtained from nondisabled subject **(a)** swallowing water at 58 to 60 °C (upper 2 traces are averages; lower 2 traces are superimposes of 5 responses) and **(b)** swallowing different amounts increasing from 3 to 30 mL. 0–2 and A–0 intervals are shorter for hot water (58–60 °C) compared with normal temperature water (23–25 °C). Dysphagia limit was >20 mL of water in all nondisabled subjects for water at 58 to 60 °C, whereas bolus divided in 2 separate swallow sequences during 30 mL hot water swallowing (note traces at 30 mL). Dysphagia limit was 20 mL for this subject.

pharyngeal phase of swallowing using a laryngeal sensor [8,19]. Although the total SM-EMG duration denoted as A–C interval has not been changed significantly for all temperatures, like Sciortino et al. [26], the pharyngeal transit time has been significantly shortened by the temperature extremes (cold/hot). This finding has been calculated by the onset of time interval of two deflections of the laryngeal sensor denoted as the 0–2 interval that was assumed for the time necessary for the elevation, closure, and upward relocation of the larynx [8]. Thus, this time reflects the duration of pharyngeal phase of swallowing or pharyngeal transit time [23]. Therefore, the hot and cold water temperature ranges significantly shortened the time for triggering the pharyngeal phase of swallowing and also shortened the pharyngeal transit time compared with the same amount of bolus ingested at normal water temperature. Bisch et al. reported that pharyngeal response time, laryngeal elevation, and laryngeal closure have been significantly shortened by 1 mL cold boluses in patients with mildly dysphagic stroke [16]. But in nondisabled subjects, 1 mL liquid iced boluses have resulted in longer pharyngeal response times and laryngeal elevation. This finding shows that heightened sensory input has not shortened swallow measurements in nondisabled subjects because of sensory input that is already optimal. Helfrich-Miller et al. reported that thermal stimulation decreases the pharyngeal transit time [27].

In a small volume swallow (1–2 mL), such as saliva, no oral preparation exists and the oral and pharyngeal phases occur in sequence [10]. The size of the bolus does not alter the sequence of events during oropharyngeal swallowing but modulates the timing of each part of the swallow [10,16]. As the bolus size increases, the pharyngeal transit time increases as do laryngeal closure and elevation [10–11,16,20]. Above 20 mL volumes of water, nondisabled subjects tend to divide the liquid into two or more pieces [9]. As mentioned previously, this is called piecemeal deglutition [11] or dysphagia limit [9]. Patients with neurogenic dysphagia are obliged to divide the bolus into two or more swallows successively below 20 mL volume of drinking water [9,19]. When we consider these phenomenas together with the temperature variable in nondisabled subjects, the dysphagia limit was never found below the 20 mL water volume at hot, cold, and normal temperature ranges. However, above the 20 mL water volume, the dysphagia limits altered with the various temperature ranges in the same subjects. Maximum amount of water swallowed at one time just before piecemeal deglutition was determined to be highest for the water at normal temperature. When nondisabled subjects swallowed cold water, the maximum amount of water was dropped slightly to a lower level, but this was not statistically significant. However, when nondisabled subjects swallowed hot water, their dysphagia limits remained significantly lower in bolus sizes compared with their limits when they swallowed normal and cold temperature water ($p < 0.05$). Although the use of cold and hot water in this study was acceptable to all nondisabled subjects, this study favors cold stimulation for the treatment of dysphagia patients. Although the dysphagia limits were >20 mL of water in all temperature ranges, cold and normal temperatures performed well in respect to bolus size. On the other hand, because swallowing with hot water lowered the dysphagia limits to 20 mL of water (even if slightly above), hot water may be somewhat nociceptive for the oropharyngeal swallowing apparatus.

Dysphagia limits protect against possible hazards of hot water to the oropharyngeal mucosae, most likely prevented by the swallowing reflex mechanisms. The deviation of sensory coding by hot water would produce an uncertain evaluation in the central nervous system, and the bolus volume would be divided into two or more swallows instead of a single swallow. This process can be explained by the compensation or protection mechanisms being triggered by some unexpected and somewhat nociceptive sensory information such as hot water. Thus, these second or subsequent multiple swallows with less hot water would be elicited reflexively from the oropharyngeal spaces. These repeated swallows of a single bolus are akin to spontaneous/reflex swallows [6,28,31–32].

CONCLUSIONS

In clinical practice, thermal-tactile stimulation is a facilitative technique designed to increase the speed of swallowing in neurogenic dysphagia. It can be performed with a laryngeal mirror or a metal rod. The mirror or rod is placed in ice until cold and then placed along the area of the anterior facial arch and rubbed five times [11]. This technique can be performed frequently throughout the day as well as before or during mealtimes in patients with delayed triggering of the swallowing reflex [14].

As a result, the cold stimulation seems to be a useful treatment method in neurogenic dysphagia. Drinking cold water as a thermal stimulation also affects the oropharyngeal swallowing, especially in patients with delayed triggering of the swallowing reflex. The swallowing of hot water is never attempted by dysphagic patients. Further studies of swallowing patterns for non-disabled patients and patients with neurogenic dysphagic should ideally develop in terms of thermal tactile stimulation in different size and viscosity to determine the optimal intervention and treatment strategies for neurogenic dysphagic patients.

ACKNOWLEDGMENTS

We are grateful to Dr. Adin Selçuk for her invaluable help in drawing the graphs. Also, the work should be attributed to Ankara Physical Medicine and Rehabilitation Education and Research Hospital of Ministry of Health, Ankara, Turkey.

This material is the result of work supported in part by the Turkish Academy of Sciences, Ankara, Turkey.

The authors have declared that no competing interests exist.

REFERENCES

1. Miller AJ. Significance of sensory inflow to the swallowing reflex. Brain Res. 1972;43(1):147–59. [PMID: 5050187]
2. Miller AJ. Deglutition. Physiol Rev. 1982;62(1):129–84. [PMID: 7034008]
3. Kessler JP, Jean A. Identification of the medullary swallowing regions in the rat. Exp Brain Res. 1985;57(2):256–63. [PMID: 3972029]
4. Mansson I, Sandberg N. Salivary stimulus and swallowing reflex in man. Acta Otolaryngol. 1975;79(5–6):445–50. [PMID: 1155054]
5. Hollshwandner CH, Brenman HS, Friedmann MH. Role of afferent sensors in the initiation of swallowing in man. J Dent Res. 1975;54(1):83–88. [PMID: 1053777]
6. Nishino T. Swallowing as a protective reflex for the upper respiratory tract. Anesthesiology. 1993;79(3):588–601. [PMID: 8363086]
7. Ertekin C, Kiylioglu N, Tarlaci S, Keskin A, Aydogdu I. Effect of mucosal anaesthesia on oropharyngeal swallowing. Neurogastroenterol Motil. 2000;12(6):567–72. [PMID: 11123712]
8. Ertekin C, Pehlivan M, Aydogdu I, Ertas M, Uludag B, Celebi G, Colakoglu Z, Sagduyu A, Yüceyar N. An electrophysiological investigation of deglutition in man. Muscle Nerve. 1995;18(10):1177–86. [PMID: 7659112]
9. Ertekin C, Aydogdu I, Yüceyar N. Piecemeal deglutition and dysphagia limit in normal subjects and in patients with swallowing disorders. J Neurol Neurosurg Psychiatry. 1996; 61(5):491–96. [PMID: 8937344]
10. Ertekin C, Aydogdu I, Yüceyar N, Pehlivan M, Ertas M, Uludag B, Celebi G. Effect of bolus volume on the oropharyngeal swallowing: an electrophysiologic study in man. Am J Gastroenterol. 1997;92(11):2049–53. [PMID: 9362190]
11. Logemann JA. Evaluation and treatment of swallowing disorders. 2nd ed. Austin (TX): PRO-ED Inc; 1998.
12. Kahrilas PJ, Logemann JA. Volume accommodation during swallowing. Dysphagia. 1993;8(3):259–65. [PMID: 8359048]
13. Logemann JA. The dysphagia diagnostic procedure as a treatment efficacy trial. Clin Commun Disord. 1993;3(4): 1–10. [PMID: 8111359]
14. Lazzara G, Lazarus C, Logemann JA. Impact of thermal stimulation on the triggering of the swallowing reflex. Dysphagia. 1986;1(2):73–77.

15. Shaker R, Ren J, Zamir Z, Sarna A, Liu J, Sui Z. Effect of aging, position, and temperature on the threshold volume triggering pharyngeal swallows. Gastroenterology. 1994; 107(2):396–402. [PMID: 8039616]
16. Bisch EM, Logemann JA, Rademaker AW, Kahrilas PJ, Lazarus CL. Pharyngeal effects of bolus volume, viscosity, and temperature in patients with dysphagia resulting from neurologic impairment and in normal subjects. J Speech Hear Res. 1994;37(5):1041–59. [PMID: 7823550]
17. Rosenbek JC, Robbins J, Fishback B, Levine RL. Effects of thermal application on dysphagia after stroke. J Speech Hear Res. 1991;34(6):1257–68. [PMID: 1787707]
18. Selinger M, Prescott TE, McKinley R. The efficacy of thermal stimulation: A case study. Rocky Mountain J Commun Disord. 1990;6:21–23.
19. Ertekin C, Aydogdu I, Yüceyar N, Tarlaci S, Kiylioglu N, Pehlivan M, Celebi G. Electrodiagnostic methods for neurogenic dysphagia. Electroencephalogr Clin Neurophysiol. 1998;109(4):331–40. [PMID: 9751296]
20. Ertekin C, Aydogdu I. Neurophysiology of swallowing. Clin Neurophysiol. 2003;114(12):2226–44. [PMID: 14652082]
21. Miller AJ. The neuroscientific principles of swallowing and dysphagia. San Diego (CA): Singular Publication Group; 1999.
22. Dodds WJ, Stewart ET, Logemann JA. Physiology and radiology of the normal oral and pharyngeal phases of swallowing. AJR Am J Roentgenol. 1990;154(5):953–63. [PMID: 2108569]
23. Ertekin C, Kiylioglu N, Tarlaci S, Turman AB, Secil Y, Aydogdu I. Voluntary and reflex influences on the initiation of swallowing reflex in man. Dysphagia. 2001;16(1):40–47. [PMID: 11213245]
24. Ali GN, Laundl TM, Wallace KL, Shaw DW, DeCarle DJ, Cook IJ. Influence of mucosal receptors on deglutitive regulation of pharyngeal and upper esophageal sphincter function. Am J Physiol. 1994;267(4 Pt 1):G644–49. [PMID: 7943330]
25. Ali GN, Laundl TM, Wallace KL, DeCarle DJ, Cook IJ. Influence of cold stimulation on the normal pharyngeal swallow response. Dysphagia. 1996;11(1):2–8. [PMID: 8556873]
26. Sciortino K, Liss JM, Case JL, Gerritsen KG, Katz RC. Effects of mechanical, cold, gustatory, and combined stimulation to the human anterior faucial pillars. Dysphagia. 2003;18(1):16–26. [PMID: 12497192]
27. Helfrich-Miller KR, Rector KL, Straka JA. Dysphagia: its treatment in the profoundly retarded patient with cerebral palsy. Arch Phys Med Rehabil. 1986;67(8):520–25. [PMID: 3741076]
28. Ertekin C, Aydogdu I, Yüceyar N, Kiylioglu N, Tarlaci S, Uludag B. Pathophysiological mechanisms of oropharyngeal dysphagia in amyotrophic lateral sclerosis. Brain. 2000; 123(Pt 1):125–40. [PMID: 10611127]
29. Perlman AL, Palmer PM, McCulloch TM, Vandaele DJ. Electromyographic activity from human laryngeal, pharyngeal, and submental muscles during swallowing. J Appl Physiol. 1999;86(5):1663–69. [PMID: 10233133]
30. Jean A. Brain stem control of swallowing: Neuronal network and cellular mechanisms. Physiol Rev. 2001;81(2): 929–69. [PMID: 11274347]
31. Palmer JB, Rudin NJ, Lara G, Crompton AW. Coordination of mastication and swallowing. Dysphagia. 1992;7(4): 187–200. [PMID: 1308667]
32. Pouderoux P, Logemann JA, Kahrilas PJ. Pharyngeal swallowing elicited by fluid infusion: role of volition and vallecular containment. Am J Physiol. 1996;270(2 Pt 1): G347–54. [PMID: 8779978]

Submitted for publication August 9, 2006. Accepted in revised form January 29, 2007.