



Research Article

Physiological Changes In Oropharyngeal Swallowing With Age: An Electrophysiological Study

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Abstract

It is important to distinguish the effects of normal aging on oropharyngeal swallowing from many disorders which may lead to dysphagia. The purpose of this study was to determine the neurophysiological alterations of normal aging on the oropharyngeal swallowing in normal subjects with different age groups.

We studied three different age groups, a total of 110 healthy volunteers with an age range between 17 and 81 years by using electrophysiological methods. The EMG activity of submental / suprahyoid muscles (SM-EMG) and mechanical upward and downward laryngeal movements were recorded during dry and wet (3 ml water) swallowing. By this method, the total duration and the amplitude of SM-EMG, the time of upward displacement of the larynx, swallowing variability (jitter) and A-0 interval (an interval related to triggering of the swallowing reflex) were measured from subjects of the three different age groups.

All parameters were influenced by advanced age. Several parameters, including total duration of SM-EMG, time necessary for triggering of the swallowing reflex and swallowing variability were significantly increased in the oldest age group compared with those in the younger age groups. It was also found that the delay in triggering the pharyngeal stage of swallowing is one of the important parameters that altered in the elderly.

In this study, it has been demonstrated that some physiological changes occur in oropharyngeal swallowing with increasing age without any alteration in the basic pattern of deglutition.

Keywords: Age-aging, Oropharyngeal swallowing, Deglutition, Electrophysiology, submental EMG, Gender

Orofaringiyal Yutmada Yaşa Bağlı Fizyolojik Değişiklikler: Elektrofizyolojik Bir Çalışma

Özet

Normal yaşlanmanın orofaringiyal yutma üzerine olan etkilerini disfaji ile ilişkili olan bozukluklarından ayırt etmek önemlidir. Bu çalışmada farklı yaş gruplarından oluşan normal erişkin bireylerde orofaringiyal yutmanın yaşla birlikte ortaya çıkan nörofizyolojik değişikliklerini saptamak amaçlanmıştır. Bu çalışma yaşları 17-81 arasında değişen 3 farklı yaş grubundaki toplam 110 sağlıklı erişkinde elektrofizyolojik yöntemler kullanılarak yapılmıştır. Kuru ve 3 ml su yutma sırasında submental/suprahoid kasların EMG aktivitesi (SM-EMG) yüzeysel elektrodlar aracılığıyla yazdırılmış ve larinks hareketleri bir piezo-elektrik sensor kullanılarak kayıtlanmıştır. Bu yöntem ile yutma sırasında SM-EMG total süre ve amplitüdü, larinksin yukarı pozisyonda kalış süresi, yutmanın değişkenliği (yutma jitteri) ve yutma refleksinin tetiklenme süresi (A-0 intervali) 3 farklı yaş grubunda ölçülerek karşılaştırılmıştır. Tüm bu parametreler yaş ile birlikte etkilenmektedir. SM-EMG amplitüdü dışında tüm parametrelerde yaş artışı ile uzama ortaya çıkmaktadır. SM-EMG total süresi, yutmanın tetiklenme süresi ve yutma jitteri genç grub ile karşılaştırıldığında yaşlı grupta anlamlı olarak artış göstermektedir. SM-EMG amplitüdü ise yaşlı grupta anlamlı olarak düşüktür. Yutmanın faringiyal refleks fazının tetiklenmesinde gecikme ve orofaringiyal fazın total süresinin uzaması yaşlı grupta değişen en önemli parametrelerdir. Sonuç olarak, bu çalışmada artan yaş ile birlikte orofaringiyal yutmada önemli fizyolojik değişiklikler ortaya çıkmasına karşın yutmanın temel paterninde bir değişiklik olmadığı saptanmıştır.

Anahtar Kelimeler: Yaşlılık, orofaringiyal yutma, elektrofizyoloji, submental EMG, cinsiyet

INTRODUCTION

The ability to maintain adequate nutrition by means of oral intake of food is a vital function that is particularly important for the health of elderly patients. Specific changes in central neural pathways as well as peripheral end organs that occur with advancing age may predispose older adults to an increased risk for dysphagia when faced with acute or chronic medical conditions^(5,19,23,28,37).

Many neurological patients with oropharyngeal dysphagia such as stroke, suprabulbar palsy and Parkinson's disease are found above 60 years old. Therefore, it is necessary to delineate the lower/upper limits of the oropharyngeal swallowing parameters according to age. The effects of aging on swallowing have been investigated by manometric^(18,32,43) and videofluoroscopic studies^(3,6,9,24) or by methods incorporating both^(34,35,42,44). In these studies; slow transfer of the bolus to the posterior oropharynx, altered bolus kinematics and dynamics, delayed pharyngeal swallowing and closure of the larynx, delayed relaxation of the upper esophageal sphincter(UES), increased laryngeal penetration and impaired transit of food have been described. Neurological and/or clinical neurophysiological studies are scarce to demonstrate the changes in oropharyngeal swallowing with aging. One exception is the quantitative determination of sensation of the oral cavity and laryngopharynx, in which the sensitivity is significantly diminished with aging^(1,2,40). Therefore, it is necessary to make a distinction between altered function due to the normal aging and altered function due to a neurological disease. The question remains as to what extent can the effects of these two types of changes be differentiated in elderly patients with neurogenic dysphagia.

In this paper, the neurophysiological alterations that take place in oropharyngeal swallowing associated with aging is

presented. Also, the differences in events of oropharyngeal swallowing between male and female groups are examined. The study focuses especially on the changes in the elderly and the results are compared with those obtained in similar studies.

METHODS

One hundred-ten normal adult subjects were investigated. No subject reported a history of difficulty with swallowing or a related medical event and none was on medications that could affect the swallowing function. General neurological examination and a standard oropharyngeal clinical examination revealed that they were completely normal clinically⁽²⁸⁾. Those who were older than 60 years of age were found to be mentally normal; and neurological examination showed that they had no cognitive or intellectual dysfunction. Informed consent was obtained from each subject and the study was approved by the Ethics Committee of our university hospital. They were divided into three age groups:

- 1- Forty five subjects (25 females) in the age range 17-39 years (mean age: 27.8).
- 2- Thirty five subjects (15 females) in the age range 40-59 years (mean age: 49.1).
- 3- Thirty subjects (9 females) in the age range 60-81 years (mean age 67.7).

All subjects sat on an examination couch and were instructed to hold their heads in a natural upright position. Oropharyngeal swallowing was evaluated by the electrophysiological methods described previously^(10,12). Swallows were voluntarily initiated with the bolus (liquid) positioned on the tongue and the tongue tip touching the upper incisors. Subjects were instructed to hold the bolus orally until cued to swallow. Swallow signals were recorded following slow delivery from a graduated syringe of 3 ml tap water. Dry swallowing was also investigated with subjects instructed by the examiner to swallow at intervals of 0.5-1 minute between each other. In brief; the surface EMG activity of

submental muscles was recorded on an EMG apparatus (Medelec MS-20) using bipolar silver-chloride surface EEG electrodes taped under the chin over the mylohyoid-geniohyoid-anterior digastric muscle complex (SM-EMG). The EMG signals were band-pass filtered (100Hz-10kHz) amplified, rectified and integrated.

For detection of laryngeal upward and downward movements, a mechanical sensor consisting of a simple piezoelectric wafer with a 4x2.5 mm rubber bulge fixed at its centre was placed on the coniotomy region between the cricoid and thyroid cartilages at the midline^(10,11). The sensor was taped onto the neck and its output was connected to another channel of the EMG apparatus (cut off frequencies 0.01-20 Hz). The laryngeal sensor registered two deflections of generally opposing polarity during each swallow. The first deflection of the laryngeal sensor signal represents the upward movement of the larynx and the second deflection, its downward

movement^(10,12). The leading 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. Because the SM-EMG activity slightly precedes the laryngeal upward movement, the rectified-integrated SM-EMG activity was also time-locked to the laryngeal sensor signals. The pre-analysis time of the amplifier was set at 800 ms and the total sweep time was set at 2000 milliseconds. In some experiments, a 5-second sweep time was also used. At least five successive traces were recorded from each subject. The individual traces were examined, superimposed and then averaged.

By using the methods, following parameters related to oropharyngeal swallowing were investigated in different age groups. These parameters are shown in Figure 1, which were recorded from two normal subjects during swallowing 3 ml of water.

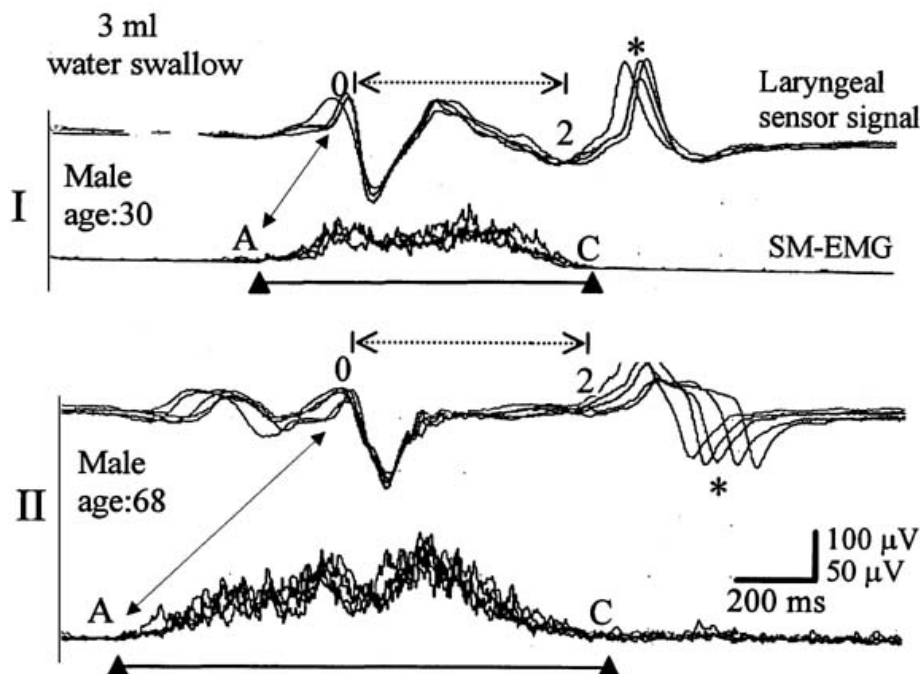


Figure 1: Laryngeal sensor signals (upper traces in each pair) and integrated submental EMG activity (lower traces in each pair) obtained from a young and an old normal subject during 3 ml water swallowing. Note the increase in total duration of SM-EMG (A-C interval), triggering time of swallowing (A-0 interval) and swallowing jitter (*) in the older subject.

Amplitude calibration: for SM-EMG is 100 mV for upper and 50 mV for lower traces. Time calibration: 200 ms in all traces. (amplitude of laryngeal sensor signal is not important).

The first is the interval between the onset of upward movement and the beginning of the downward movement of the larynx during a swallow. This interval (denoted as 0-2 interval in Figure 1) is thought to indicate the time necessary for the elevation, closure and upward location of the larynx during a swallow^(10,11) and also reflects one of the important reflex events during pharyngeal phase of swallowing⁽⁸⁾.

When the first deflection was stabilized on the EMG screen, the onset of the second deflection showed temporal variability for the same subject with boluses of the same volume. This variability of the laryngeal downward movement was measured at the peaks of the second deflections (i.e. interval from the earliest to the latest peak in superimposed records) of 5 successive swallows. This is called a “swallowing jitter” which is a measure of the variability of the swallowing responses from one swallow to another, for boluses of the same volume^(10,11) (Figure 1).

The third swallowing parameter is the duration of SM-EMG and represents the total activation time of the laryngeal elevator muscles during swallowing and is demonstrated as A-C interval in Figure 1. Since the submental muscle complex (mylohyoid, geniohyoid and anterior digastric muscles) fire concurrently to initiate a swallow, functioning as laryngeal elevators pulling the larynx upwards^(8,30,31), the rectified and integrated SM-EMG gives considerable amount of information about the onset and duration of the pharyngeal phase of swallowing. This EMG activity declined until the beginning of laryngeal downward movement. The onset and the end of SM-EMG were measured by both superimposed and averaged traces. The secondary EMG deflections of any kind or an increase of activity just after the end of the second deflection of the larynx were not included in the SM-EMG activity.

The maximal amplitude of SM-EMG, from peak to baseline was also measured in all

subjects. This fourth parameter is a measure of the recruitment capacity of the motor units of laryngeal elevator muscles, judging from the short and maximal increase of integrated EMG just before the laryngeal upward movement and progressive amplitude decline until the onset of laryngeal downward movement. The duration and the peak amplitude of the integrated EMG activities were also measured from the averaged traces.

The fifth parameter is A-0 interval (oblique arrow in Figure 1), which is the time interval between the onsets of the SM-EMG (point A) and the first deflection of laryngeal sensor signal (point 0) reflecting the upward movement of the larynx, is one of the first events of pharyngeal reflex swallowing^(7,8,30). This interval reflects the voluntary attempt to swallow until the swallowing reflex is initiated. Therefore, the A-0 interval indicate the voluntary triggered deglutition⁽¹⁵⁾.

The calculations related with swallowing parameters were performed from averaged traces except for the swallowing jitter. Mean $\pm$ SEM of all measured quantities was calculated and paired t-test was applied for comparisons. One way analysis of variance (ANOVA) and Tukey's HSD (honestly significant difference) test were also applied to the same data obtained from three age groups. Significance was tested at the 5% level. Correlation analysis (Pearson rank test) was performed to reveal any correlation between the age and swallowing parameters.

RESULTS

During 3-ml-water swallowing, the following sequences were chronologically ordered. SM-EMG activity firstly began and gradually increased to attain its maximal amplitude. When the SM-EMG activity nearly reached its maximal peak, laryngeal upward movement occurred as signaled by the first deflection of the laryngeal sensor. During the upward movement and relocation of the larynx superiorly (i.e.. 0-2 interval), activity of the

SM-EMG was continued and then gradually declined until the laryngeal downward movement was signaled (Figure 1).

All parameters of oropharyngeal swallowing were affected by age. Statistical analysis (ANOVA) showed that the oldest age group differed significantly from the other two groups with respect to all of the above parameters except to 0-2 interval. Table 1 summarizes the results of statistical analysis applied to both dry and wet (3-ml water) swallowing data obtained from the subjects. Young and middle-aged groups did not differ from each other significantly ($p > 0.05$). However, mean values of all the time-related parameters were slightly longer in the middle-aged group with respect to younger one. On the

whole, time-related parameters appeared to be increased in a staircase manner with progressing age (Figure 2). In fact, the 0-2-time interval, total duration of SM-EMG, A-0 time interval and swallowing jitter increased with age.

Duration of SM-EMG was significantly longer in the older age groups than in the youngest group, both for 3-ml-water and dry swallowing ($p < 0,05$ in the paired t-test). Tukey's HSD test showed that there were significant differences between old and young, and also old and middle age groups ($p < 0,01$). The total duration of oropharyngeal swallowing (A-C interval) increases as the age increased and; there was a significant correlation between the age and A-C interval ($r:0.51$; $p:0.000$) (Figure 3).

Table 1: Normal values of the oropharyngeal swallowing parameters obtained from three age groups of normal subjects during dry and wet swallowing. (Mean $\pm$ SEM) (SD)

Swallowing Parameters	3 ml Water Swallowing					Dry Swallowing				
	17-39 age	p	60-81 age	p	40-59 age	20-39 age	p	60-80 age	p	40-59 age
0-2 time interval of laryngeal sensor(msec)	562,8 $\pm$ 13,2	NS	585,6 $\pm$ 12,5	NS	583,3 $\pm$ 12,4	504,7 $\pm$ 14,8	<0,05	571,1 $\pm$ 14,7	NS	533,5 $\pm$ 26,3
Swallowing Jitter (msec)	88,6		68,6		72,1	79,5		62,3		108,5
	70,5 $\pm$ 5,5	0,002	103,3 $\pm$ 8,5	0,03	79,7 $\pm$ 6,6	90,8 $\pm$ 9,4	NS	108,1 $\pm$ 11,2	NS	104,7 $\pm$ 11,3
	36,7		45,9		38,4	50,8		47,5		46,5
Total Duration of SM-EMG activity(msec)	846,5 $\pm$ 16,6	0,000	1007,7 $\pm$ 24,2	0,000	893,7 $\pm$ 17,1	825,2 $\pm$ 33,4	<0,05	1092,1 $\pm$ 77,2	<0,05	895,8 $\pm$ 37,2
	111,3		132,7		101,2	179,8		327,5		153,3
A-0 time interval(msec)	259,3 $\pm$ 14,6	0,001	357,2 $\pm$ 17,6	0,03	294,6 $\pm$ 17,2	297,6 $\pm$ 28,0	NS	372,4 $\pm$ 47,4	NS	311,9 $\pm$ 43,4
	97,3		95,0		100,7	150,9		201,0		178,8
Maximal amplitude of SM-EMG activity(μ V)	77,5 $\pm$ 5,6	0,01	57,2 $\pm$ 3,7	NS	64,8 $\pm$ 3,8	92,0 $\pm$ 7,3	<0,05	68,7 $\pm$ 4,5	NS	82,1 $\pm$ 7,0
	37,5		20,3		22,7	39,3		19,3		27,9

NS: Non significant

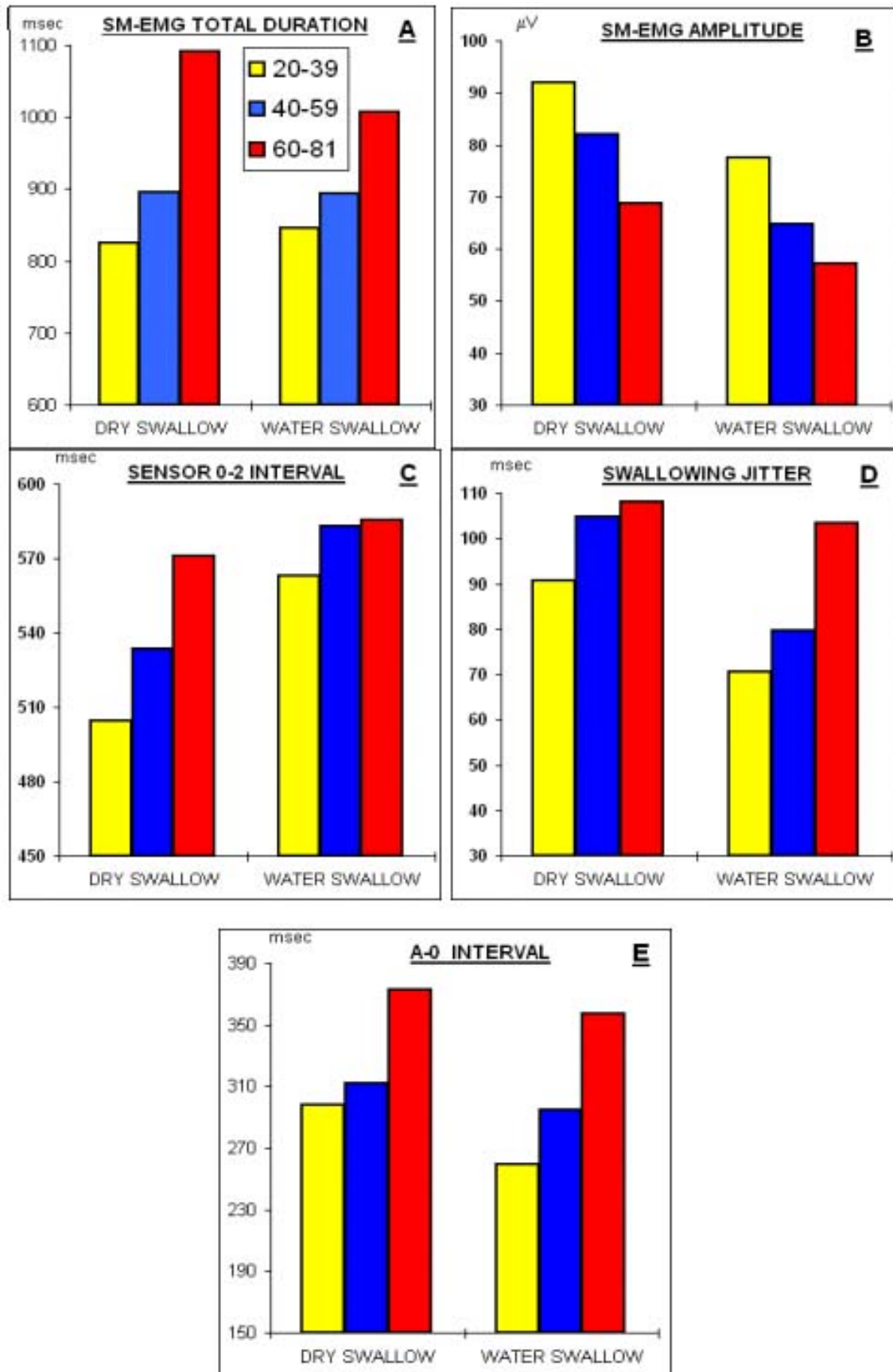


Figure 2: Mean duration of various parameters of oropharyngeal swallowing in three different age groups. Note the progressive increase of values in A, C, D, E and decrease in B.

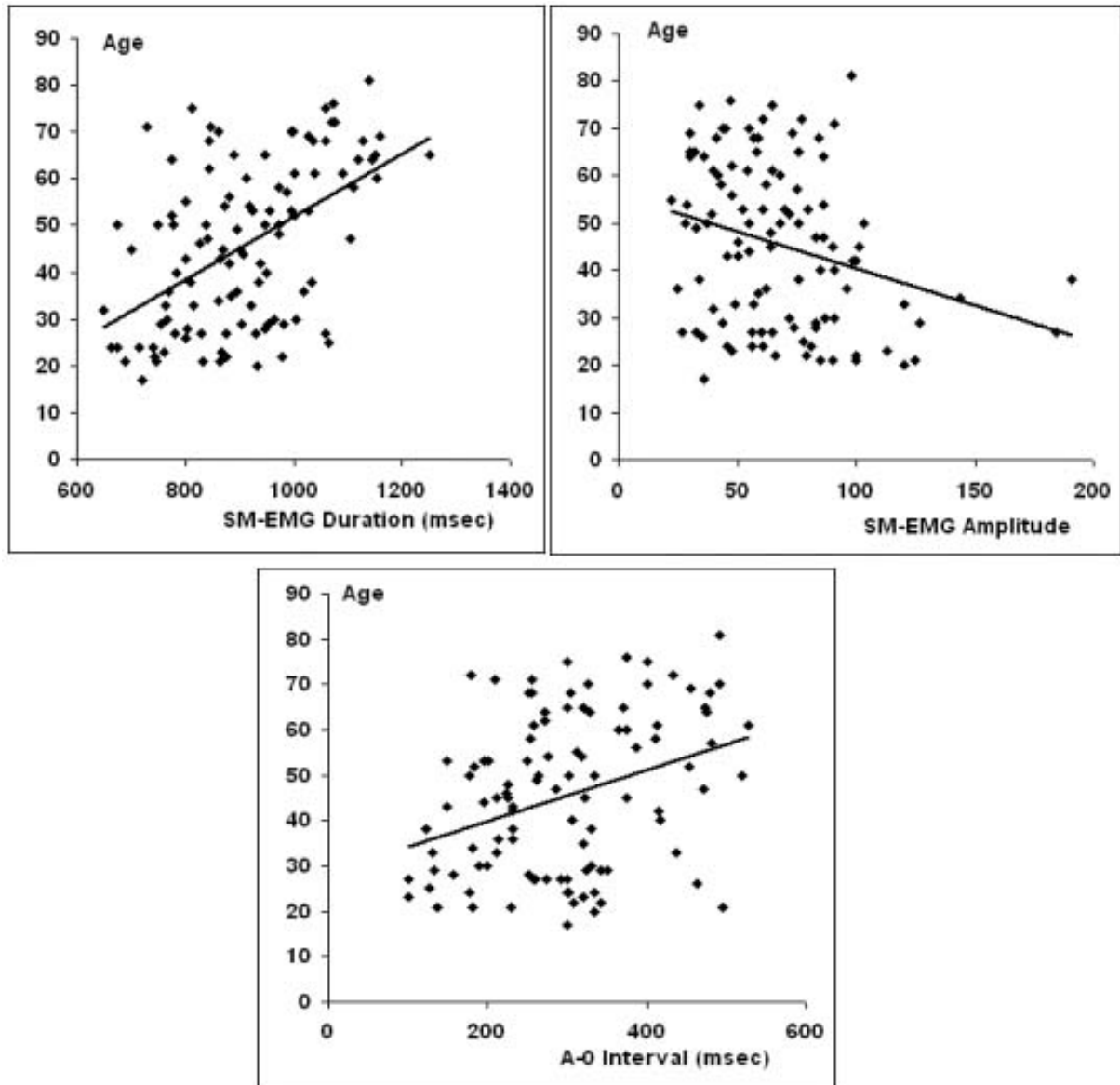


Figure 3: Graph of the regression equation showing the correlation between the age and SM-EMG duration, SM-EMG amplitude, A-0 interval obtained from all normal subjects.

On the other hand, the amplitude of SM-EMG diminished with increasing age (Figure 2B). The amplitude of SM-EMG was significantly lower in the oldest age group compared to the youngest age group, in dry and wet swallowing ($p < 0,05$ in the paired t-test). Tukey's HSD test showed a significant difference between old and young age groups. ($p < 0,01$). The correlation analysis between the age and amplitude revealed that there was a weak but inverse correlation ($r: - 0.30$; $p < 0,05$) (Figure 3).

Laryngeal upward relocation time (0-2 interval) was significantly longer in the old age group than in the younger groups only in dry swallowing ($p < 0,05$ in the paired t-test). Tukey's HSD test showed that there was a significant difference between old and young age groups only in dry swallowing ($p < 0,05$). There was no significant correlation between the age and 0-2 time interval.

The A-0 interval was also prolonged in the old age group compared to the other age groups during dry and wet swallowing.

Tukey's HSD test showed that there were significant differences between old and young, and also old and middle age groups in wet swallowing ($p < 0,01$). The correlation analysis revealed that A-0 interval increases as the age increased. There was a weak but significant correlation between the age and A-0 interval ($r:0.35$; $p:0.00$) (Figure 3)

Swallowing jitter was significantly longer in the old age group than in the younger age groups in wet swallowing ($p < 0,05$ in the paired t-test). Tukey's HSD test

showed a significant difference between old and young, and also old and middle age groups in wet swallowing ($p < 0,05$). There was a weak correlation between the age and swallowing jitter ($r:0.32$; $p:0.001$).

With regard to gender differences, results indicated that males had significantly longer durations of total submental muscle activity (A-C interval) than females ($p < 0.005$) in water swallowing. No differences in other parameters were observed.(Table-2)

Table 2: Normal values of the oropharyngeal swallowing parameters with respect to gender obtained during wet swallowing. (Mean $\pm$ SEM) (SD)

Swallowing Parameters	Female	p value	Male
0-2 time interval of laryngeal sensor (msec)	571,5 $\pm$ 11,3		578,6 $\pm$ 10,2
Swallowing Jitter (msec)	78,0	NS	79,4
	78,9 $\pm$ 5,5		85,0 $\pm$ 5,8
	38,2	NS	44,6
Total Duration of SM-EMG activity (msec)	877,6 $\pm$ 17,4		927,9 $\pm$ 17,3
	121,8	0,04	135,2
A-0 time interval (msec)	295,9 $\pm$ 16,0		297,9 $\pm$ 13,1
	109,1	NS	102,3
Maximal amplitude of SM-EMG activity (μ V)	66,5 $\pm$ 4,5		69,0 $\pm$ 3,7
	31,8	NS	29,0

NS: Non significant

DISCUSSION

It has been demonstrated that some physiological changes occur in oropharyngeal swallowing as the age progresses from 17 to 81 years. Alterations in parameters of dry and wet swallowing have been found to be significant in the oldest age group compared with the young and middle age groups. As in other studies^(9,32,35,39,41,42), the oral and pharyngeal stages of swallowing are found to be slower in the elderly. The slowness of deglutition can be attributed to two main mechanisms:

- 1) Increased threshold and delay in the triggering of the swallowing reflex may be one of the important causes of slow swallowing. In other words, the increased duration of swallowing generally occurs before the initiation of more automatic pharyngeal phase of the swallow⁽³⁶⁾. This conclusion includes the propulsive forces exerted by the tongue on the bolus, which may be weaker in the older age group than younger ones^(37,45).
- 2) The slowing in deglutition may be caused by the prolongation of the swallowing reflex at the pharyngeal phase

in which sweeping of the bolus by pharyngeal constrictor muscles and the relaxation and opening of upper esophageal sphincter may be slowed down. Since we have not investigated the cricopharyngeal muscle of upper esophageal sphincter, we will not discuss the second possibility.

The first mechanism of the delay in triggering at the oral phase of swallowing and the reduction of propulsive force of tongue may be the most important parameter in the elderly.

The A-0 time interval is significantly prolonged in the elderly during wet swallowing. This time interval denotes the time from the beginning of submental muscle contraction to the onset of upward deflection of the sensor signal, which indicates the beginning of upward location of the larynx. This interval can provide information about the temporal relation between the instant of the voluntary activation of the SM muscle complex and the instant of reflex triggering of the swallowing response⁽¹²⁾. A-0 time interval lasts for about 250-350 ms in normal subjects during swallowing voluntarily and is under the control of the central nervous system at the onset of voluntary swallowing. But it is very short (usually less than 50 ms) in spontaneous swallowing during unconscious (i.e. sleeping) and reflexive conditions^(12,15,16). Sensory inputs from the oropharyngeal region especially the tonsillar pillars, base of the tongue and oropharyngeal mucosae have been proposed to be important for the triggering of swallows^(14,30). In voluntary swallow, the A-0 interval is physiologically produced by the intact sensory innervation of oral/pharyngeal cavity and probably it is under the neural control of pyramidal-corticobulbar fibers^(12,13,22).

It has been shown that there is a relationship between slower swallowing and increased number of severity of periventricular white matter intensities in

the brain by Magnetic Resonance Imaging⁽²⁷⁾. This may indicate that the asymptomatic decline in oropharyngeal motor control mediated by cortico-bulbar pathways that travel within the periventricular white matter^(21,27). Measurements of sensory discrimination threshold showed significant increase with age for the tongue and floor of the mouth^(1,2) and the reduction in velopalatine reflexes and laryngopharynx sensitivity have also been reported^(2,29). These findings may support the idea that the delay of triggering of swallow should be one of the mechanisms in the elderly due to relative reduction of sensory perception in the oropharyngeal cavity^(2,40).

In our electrophysiological study, it has also been found that the elevation and location time of the larynx during a swallow (denoted as the 0-2-time laryngeal sensor interval) is prolonged in the elderly especially dry swallowing. This is probably due to the relative weakness of laryngeal elevator muscles compared to the younger groups. This finding confirms the results obtained from the previous studies⁽³⁵⁾.

The duration of SM-EMG muscle activity is prolonged and its amplitude is reduced. This observation may also be explained by the weaker and longer recruitment of the motor units in SM-muscles. The weakness of the tongue should be important because its propulsive force on the bolus partly determines of the triggering and the speed of swallowing. Both tongue and submental /suprahyoid muscles are striated. It is well known that there is a progressive decline in the number of functional motor units after the 5th decade, which appears to be a contributing factor to weakness of aging muscles^(4,25). Age-related muscular changes have also been described in the limb muscles^(4,26). Similar changes have been reported in the lingual muscles and there was a decline in maximum isometric tongue pressure in normal aging^(37,45). Therefore, tongue and laryngeal elevator

muscles must have been remained in usual aging process. All these findings can explain both the delay of triggering at the oral phase of swallowing and the slowing of deglutition in elderly. It was suggested that the speed of swallowing begins to slow after the age of 45 and the swallowing process is significantly slower by 75 years of age^(6,35,42). Our results also indicated that all the time-related swallowing parameters were slightly longer in the middle-aged group with respect to younger one. On the whole, time-related swallowing parameters appeared to be increased in a staircase manner with advancing age especially oldest group.

The main reason for these physiological changes could not only be limited to the deglutition muscles but also may be related with the physiological decline in the control of corticobulbar motor fibers on the bulbar swallowing center. Recent studies have demonstrated that cortical swallowing pathways can be modulated by afferent stimulation^(16,17,20,33). Alterations of sensory interaction in deglutition during aging process may be one of the reason for these changes.

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REFERENCES

1. Aviv JE, Hect C, Weinberg H, Dalton JF, Unken ML : Surface sensitivity of the floor of the mouth and tongue in healthy controls and radiated patients. *Otolaryngol Head Neck Surg* 107 :418-423,1992.
2. Aviv JE. Effects of aging on sensitivity of the pharyngeal and supraglottic areas *Am J Med* 103(5A):74S-76S, 1997.
3. Bardan E, Kern M, Arndorfer RC, Hofmann C, Shaker R. Effect of aging on bolus kinematics during the pharyngeal phase of swallowing. *Am J Physiol Gastrointest Liver Physiol* 290: G458-G465, 2006.
4. Campbell MJ, McComas AJ, Petito F: Physiological changes in aging muscle. *J Neurol Neurosurg Psychiatry* 36:174-182, 1973.
5. Castell DO: Oesophageal disorders in the elderly. *Gastroenterology Clin North Am*; 19: 235-254, 1990.
6. Daggett A, Logemann J, Rademaker A, Pauloski B. Laryngeal Penetration During Deglutition in Normal Subjects of Various Ages. *Dysphagia* 21:270-274, 2006.
7. Dodds WJ, Stewart ET, Logemann JA: Physiology and radiology of the normal oral and pharyngeal phase of swallowing. *AJR* 154: 953-963, 1990.
8. Donner MW, Bosma JF, Robertson DL: Anatomy and Physiology of the pharynx. *Gastrointest Radiol* 10: 196-212, 1985.
9. Ekberg O, Feinberg MJ: Altered swallowing function in elderly patients without dysphagia : radiological findings in 56 cases. *AJR* 156: 1181-1184,1991.
10. Ertekin C, Pehlivan M, Aydogdu I, Ertas M, Uludag B, Çelebi G, Çolakoglu Z, Sagduyu A, Yüceyar N: An electrophysiological investigation of deglutition in man. *Muscle and Nerve* 18:1177-1186, 1995.
11. Ertekin C, Aydogdu I, Yüceyar N, Pehlivan M, Ertas M, Uludag B, Çelebi G: Effects of bolus volume on oropharyngeal swallowing: An electrophysiological study in man. *Am J Gastroenterol* 92: 2049-2053, 1997.
12. Ertekin C, Aydogdu I, Yüceyar N, Tarlaci S, Kiylioglu N, Pehlivan M, Çelebi G. Electrodiagnostic methods in neurogenic dysphagia. *Electroenceph Clin Neurophysiol* 109:331-340, 1998.
13. Ertekin C, Aydogdu I, Yüceyar N, Kiylioglu N, Tarlaci S, Uludag B: Pathological mechanisms of oropharyngeal dysphagia in amyotrophic lateral sclerosis. *Brain* 123, 125-140, 2000.
14. Ertekin C, Kiylioglu N, Tarlaci S, Keskin A, Aydoğdu I: Effect of mucosal anesthesia on oropharyngeal swallowing. *Neurogastroenterology Motility*, 12:567-572, 2000.
15. 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*, 16: 40-47, 2001.
16. Ertekin C, Aydogdu I: Neurophysiology of swallowing. Review. *Clin Neurophysiol*; 114:2226-2244, 2003.
17. Fraser C, Rothwell JC, Power M, Hobson A, Barlow J, Thompson DG, Hamdy S. Differential changes in human pharyngoesophageal motor excitability induced by swallowing, pharyngeal stimulation, and

- anesthesia Am J Physiol Gastrointest Liver Physiol* 285: G137–G144, 2003.
18. Fulp SR, Daltone CB, Castell JA, Castell DO: Aging-related alternations in human upper oesophageal sphincter function. *Am J Gastroenterol* 85: 1569-1572, 1990.
19. Hall KE. Aging and Neural Control of the GI Tract II. Neural control of the aging gut: *Am J Physiol Gastrointest Liver Physiol* 283:G827–G832, 2002.
20. Hamdy S, Aziz Q, Rothwell JC, Hobson A, Thompson DG. Sensorimotor modulation of human cortical swallowing pathways *J Physiol.* 506:857-866, 1998.
21. Jaradeh S: Neurophysiology of swallowing in the aged. *Dysphagia* 9:218-220, 1994.
22. Jean A, Car A: Inputs to swallowing medullary neurons from the peripheral afferent fibers and swallowing cortical area. *Brain Res* 178: 567-572, 1979.
23. Kays S, Robbins J. Effects of sensorimotor exercise on swallowing outcomes relative to age and age-related disease. *Semin Speech Lang.* 27:245-259, 2006.
24. Kim Y, McCullough GH, Carl W. . Temporal Measurements of Pharyngeal Swallowing in Normal Populations. *Dysphagia* 20:290–296, 2005.
25. Kullman DA, Plato CC, Tobin JD: The role of muscle loss in the age-related decline of grip strength: cross-sectional and longitudinal perspectives. *J Gerontol* 45M:82-88,1990.
26. Larsson L: Morphological and functional characteristics of the aging skeletal muscle in man: a cross-sectional study. *Acta Physiol Scand* 457 (suppl): 1-36, 1978.
27. Levine R, Robbins JA, Maser A: Periventricular white matter changes and oropharyngeal swallowing in normal individuals. *Dysphagia* 7: 142-147, 1994 .
28. Linden P, Kuhlemeier KV, Patterson. The probability of correctly predicting subglottic penetration from clinical observations. *Dysphagia* 8: 170-179, 1993.
29. Logemann JA: Effects of aging on the swallowing mechanisms. *Head and neck disease in elderly. Otolaryngol Clin North Am.* 23: 1045-1056, 1990.
30. Miller AJ: Deglutition. *Physiol Rev* 62: 129-184, 1982.
31. Perlman AL, Christenson J: Topography and functional anatomy of the swallowing structures. In: Perlman AL, Schulze–Delrieu KS (eds.): *Deglutition and its disorders*, SanDiego-London: Singular Publication Group, 1997, pp: 15-42.
32. Perlman AL, Schultz JG, VanDaele DJ: Effects of age, gender, bolus volume and bolus viscosity on oropharyngeal pressure during swallowing. *J Appl Physiol* 75:33-37, 1993.
33. Power M, Fraser C, Hobson A, Rothwell JC, Mistry S, Nicholson DA, Thompson DG, Hamdy S. Changes in pharyngeal corticobulbar excitability and swallowing behavior after oral stimulation. *Am J Physiol Gastrointest Liver Physiol* 286:G45–G50, 2004.
34. Ren J, Shaker R, Zamir Z, Dodds WJ, Hogan WJ, Hoffmann RG: Effect of age and bolus variables on the coordination of the glottis and upper esophageal sphincter during swallowing. *Am J Gastroenterol* 88: 665-669, 1993.
35. Robbins J, Hamilton JM, Lof GL, Kempster GB: Oropharyngeal swallowing in normal adults of different ages. *Gastroenterology* 103: 823-829, 1992.
36. Robbins J: Normal swallowing and aging. *Seminars in Neurology* 16: 309-317, 1996.
37. Robbins JA, Levine RL, Wood J, Rocker E, Luschei E: Age effects on lingual pressure generation as a risk factor for dysphagia. *J Gerontol Med Sci* 50 (A) 5: M57-62, 1995.
38. Schindler JS, Kelly JH..Swallowing Disorders in the Elderly. *Laryngoscope*, 112:589–602, 2002.
39. Shaw DW, Cook IJ, Gabb M, Holloway RA, Simula ME, Panagopoulos V, Dent J: Influence of normal aging on oral pharyngeal and upper esophageal sphincter dysfunction during swallow. *Am J Physiol* 268: G389-G396, 1995.
40. Smith CH, Logemann JA, Burghardt WR, Zecker SG, Rademaker AW. Oral and Oropharyngeal Perceptions of Fluid Viscosity Across the Age Span. *Dysphagia* 21:209–217, 2006.
41. Sonies BC, Parent LJ, Morrish K, Baum BJ: Durational aspects of the oropharyngeal phase of swallow in normal adults. *Dysphagia* 3: 1-10, 1988.
42. Tracy JF, Logemann JA, Kahrilas PJ, Jacob P, Kobara M, Kruger C: Preliminary observations of the effects of age on oropharyngeal deglutition. *Dysphagia* 4:90-94, 1989.
43. Wilson JA, Pryde A, Macintyre CCA, Maran AGD, Heading RC: The effects of age, sex, and smoking on normal pharyngoesophageal motility. *Am J Gastroenterol* 85: 686-691, 1990.
44. Yokoyama M; Mitomi N; Tetsuka K; Tayama N Nimi S. Role of Laryngeal Movement and Effect of Aging on Swallowing Pressure in the Pharynx and Upper Esophageal Sphincter. *Laryngoscope*, 110:434–439, 2000.
45. Youmans SR, Stierwalt JA. Measures of Tongue Function Related to Normal Swallowing. *Dysphagia* 21:102–111, 2006.