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Original Article

Effect of Bolus Volume and Consistency on Swallowing Events Duration in Healthy Subjects

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Background/Aims
Swallowing is a complex function with the control of the swallowing center being located in the brain stem. Our aim in this investigation was to evaluate, in healthy volunteers, the oral and pharyngeal transit of 2 bolus volumes and 2 consistencies, and the influence of these boluses on the proportion of pharyngeal clearance duration/hyoid movement duration.

Methods
Videofluoroscopic evaluation of swallows was performed in 30 healthy volunteers, aged 29-77 years (mean 58 years). The subjects swallowed in duplicate of 5 mL and 10 mL of thick liquid barium and honey thick barium. We measured the duration of oral transit, pharyngeal transit, pharyngeal clearance, upper esophageal sphincter opening, hyoid movement, oropharyngeal transit, and the relation pharyngeal clearance duration/hyoid movement duration.

Results
A 10 mL bolus volume caused a longer UES opening duration than a 5 mL bolus volume, for both consistencies. The pharyngeal transit was longer for honey thick bolus consistency than for thick liquid, with both the volumes of 5 mL and 10 mL. For pharyngeal clearance, the difference was significant only with the 10 mL bolus volume. There was no difference associated with bolus volume or consistency in the relation between pharyngeal clearance duration and hyoid movement duration.

Conclusions
Increase in the swallowed bolus volume causes a longer UES opening duration and an increase in bolus consistency from thick liquid to honey thick causes a longer pharyngeal transit duration. The proportion between pharyngeal clearance and hyoid movement does not change with bolus volume or bolus consistency.
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Key Words
Deglutition; Esophageal sphincter, upper; Pharynx

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Introduction

Swallowing is a complex function with the control of the swallowing center being located in the brain stem. This control receives information from mouth, pharyngeal and proximal esophagus to make the adaptations to the characteristics of the swallowed bolus, in terms of volume, consistency, temperature and taste.[1-3]

The adaptation to bolus volume and consistency is important, because the loss of this control may cause dysphagia and air way aspiration, with impairment of hydration, nutrition, impact on quality of life, increased risk of pulmonary infectious disease and death.

The bolus viscosity utilized in investigations and in the treatment of dysphagic patients has a large range.[4] Previous differences found among publications about the evaluation of swallowing may be the consequences of this large variation of the viscosity of the swallowed bolus utilized in each investigation.[5] The importance of the knowledge of the effect of bolus viscosity and volume on swallowing is that for the treatment in which we must indicate the correct consistency and swallowing bolus volume for a particular patient with dysphagia. Modifications of food texture and liquid thickness have an important role on dysphagia treatment.[6]

Upper esophageal sphincter (UES) opening and closing are associated with the hyoid movement.[7] Pharyngeal transit is related to UES opening and the offset of UES opening should occur after the completion of the pharyngeal clearance. If the sphincter closes before the completion of pharyngeal clearance, bolus residues may be present on pharynx and aspiration may occur. It is important that there is a correct proportion between pharyngeal clearance duration and hyoid movement duration, which could be influenced by bolus volume and/or consistency.

Our aim in this investigation was to evaluate the oral and pharyngeal transit duration of 2 bolus volumes (5 mL and 10 mL) of thick liquid and honey thick consistencies in healthy volunteers, and the influence of these bolus volumes and consistencies on the proportion of pharyngeal clearance duration/hyoid movement duration. The hypothesis was that the modification of bolus volume and consistency to cause alteration in bolus transit duration but the proportion of pharyngeal clearance duration/hyoid movement duration was preserved.

Materials and Methods

Videofluoroscopic evaluation of swallows was performed in 30 healthy volunteers, 18 men and 12 women, aged 29-77 years and mean of 58 years. None of the volunteers had dysphagia, gastroesophageal reflux symptoms, previous surgery of the head, neck, esophagus, or stomach, respiratory and neurologic diseases, or problem with the ingestion of any kind of food. The investigation was approved by the Human Research Committee of the University Hospital of Ribeirão Preto USP. Written informed consent was given by all volunteers.

Used for videofluoroscopy was the Arcomax Phillips model BV 300 (Veenpluis, The Netherlands) radiologic instrument and the Ever Focus model EDSR 100 V1.2 (Taipei, Taiwan) digital image processing system with a DVR (Ever Focus) monitor, run at 60 frames/sec, with a clock time that indicates digital time in seconds and number of frames on each video frame.

Each subject was studied while sitting in a chair, turned laterally to the image intensifier. Lateral images were obtained of the mouth, pharynx and proximal esophagus. The subjects swallowed in duplicate of 5 mL and 10 mL of thick liquid barium (100% barium sulfate, Bariogel, Laboratório Cristália, Itapira, SP, Brazil) and 5 mL and 10 mL of honey thick barium, prepared with 50 mL of thick liquid barium plus 4.5 g of instant food thickener (Thick & Easy, Hormel Health Labs, Savannah GA, USA).

The following features were timed: (1) onset of propulsive tongue tip movement at the maxillary incisors, (2) onset and end of the hyoid movement, (3) passage of the bolus head through the fauces, (4) passage of the bolus tail through the fauces, and (5) onset and offset of upper esophageal sphincter (UES) opening. Calculated from these timings were the oral transit (tongue tip at incisors to passage of the bolus tail through the fauces), pharyngeal transit (bolus tail at fauces to offset of UES opening), pharyngeal clearance (bolus head at fauces to offset of UES opening), UES opening duration (time between onset and offset of UES opening), duration of hyoid movement (time between onset and end of the hyoid movement), oropharyngeal transit (tongue tip at incisors to offset of UES opening) and the relation of pharyngeal clearance duration/hyoid movement duration.

Statistical analysis was done by the Wilcoxon test. The differences were considered significant when $P < 0.05$ in a two-tailed statistical analysis. The results are reported as median, the minimum and maximum (range) of values found, mean and standard deviation (SD), in milliseconds (msec).

Results

The results for the bolus volumes of 5 mL and 10 mL are shown in Table 1, and for bolus consistency of thick liquid and honey thick are shown in Table 2.

A 10 mL bolus volume caused a longer UES opening duration than a 5 mL bolus volume (Fig. 1), for thick liquid bolus (5 mL: median 218 [range 120-510] milliseconds, 10 mL: 240 [150-345] milliseconds, $P = 0.010$), and honey thick bolus (5 mL: 200 [110-375] milliseconds, 10 mL: 235 [130-535] milliseconds, $P = 0.010$]. With thick liquid bolus the hyoid move-

Table 1. Oral and Pharyngeal Transit Duration, in Milliseconds, After Swallows of the Volumes of 5 mL and 10 mL Thick Liquid and Honey Thick Boluses

	5 mL			10 mL			*P*-value
	Mean (SD)	Median	Range	Mean (SD)	Median	Range	
Thick Liquid							
OT	468 (253)	375	150-1190	354 (128)	335	165-655	0.090
PT	213 (58)	208	95-230	223 (108)	203	75-690	0.770
PC	397 (133)	375	195-775	366 (80)	368	210-570	0.490
UESO	224 (81)	218	120-510	242 (46)	240	150-345	0.010
HM	533 (184)	475	335-1225	477 (157)	423	305-1085	0.040
OPT	729 (316)	635	380-1715	594 (203)	515	290-1025	0.070
Honey Thick							
OT	468 (351)	335	125-1525	358 (150)	310	175-840	0.430
PT	229 (71)	225	60-405	236 (78)	225	120-535	0.850
PC	474 (263)	390	190-1220	480 (277)	410	212-1680	0.210
UESO	205 (53)	200	110-375	248 (96)	235	130-535	0.010
HM	524 (160)	458	325-1100	558 (242)	475	295-1280	0.800
OPT	757 (470)	568	280-2145	696 (296)	623	344-1755	0.600

SD, standard deviation; OT, oral transit; PT, pharyngeal transit; PC, pharyngeal clearance; UESO, upper esophageal sphincter opening; HM, hyoid movement; OPT, oropharyngeal transit.

Table 2. Oral and Pharyngeal Transit Duration, in Milliseconds, After Swallows of Thick Liquid and Honey Thick Bolus Consistencies With the Volumes of 5 mL and 10 mL

	Thick liquid			Honey thick			*P*-value
	Mean (SD)	Median	Range	Mean (SD)	Median	Range	
5 mL							
OT	468 (253)	375	150-1190	468 (351)	335	125-1525	0.510
PT	213 (58)	208	95-230	229 (71)	225	60-405	0.030
PC	397 (133)	375	195-775	474 (263)	390	190-1220	0.210
UESO	224 (81)	218	120-510	205 (53)	200	110-375	0.500
HM	533 (184)	475	335-1225	524 (160)	458	325-1100	0.700
OPT	729 (316)	635	380-1715	757 (470)	568	280-2145	0.850
10 mL							
OT	354 (128)	335	165-655	358 (150)	310	175-840	0.910
PT	223 (108)	203	75-690	236 (78)	225	120-535	0.040
PC	366 (80)	368	210-570	480 (277)	410	212-1680	0.010
UESO	242 (46)	240	150-345	248 (96)	235	130-535	0.450
HM	477 (157)	423	305-1085	558 (243)	475	295-1280	0.150
OPT	594 (203)	515	290-1025	696 (296)	623	344-1755	0.100

SD, standard deviation; OT, oral transit; PT, pharyngeal transit; PC, pharyngeal clearance; UESO, upper esophageal sphincter opening; HM, hyoid movement; OPT, oropharyngeal transit.

ment duration was longer for 5 mL (475 [335-1225] milliseconds) than for 10 mL (423 [305-108] milliseconds, P = 0.040, Table 1).

The pharyngeal transit was longer for honey thick bolus than for thick liquid (Fig. 2), with both the volume of 5 mL (thick liquid: 208 [95-230] milliseconds and honey thick: 225 [60-405] milliseconds and, P = 0.030) and 10 mL (thick liquid: 203 [75-690] milliseconds and honey thick: 225 [120-535] milliseconds, P = 0.040). For pharyngeal clearance the difference was significant only with the 10 mL bolus volume (thick liquid: 368 [210-570] milliseconds and honey thick: 410 [212-1680] milliseconds, P = 0.010).

There was no difference associated with bolus volume or consistency in the relation between pharyngeal clearance duration and hyoid movement duration (Table 3).

Discussion

The results showed that the major influence of the increase in bolus volume from 5 mL to 10 mL was in the increase of upper esophageal sphincter opening duration, and of the increase of bolus consistency from thick liquid to honey thick was in the increase of pharyngeal transit duration. Both, bolus volume and consistency, do not change the proportion between the pharyngeal clearance duration/hyoid movement duration.

The viscosity of the bolus swallowed in this investigation was described in a previous publication to range from 4760 centipoise (cp) to 7115 cp in thick liquid, and from 7630 cp to 11 850 cp in honey thick.[4] These boluses had narrow viscosity differences than the bolus utilized in another publication, when viscosity was 200 cp for liquid barium and 60 000 cp for paste barium.[1] The influence in oral and pharyngeal transit was different. It was described that increase in bolus volume is related to an increase in UES opening duration,[8,9] and that UES opening duration is longer with high-viscosity paste barium.[1,8] The honey thick bolus we tested did not have a high consistency as the previous one. Bolus volume does not have influence on pharyngeal clearance duration, but a high viscous paste bolus has a longer pharyngeal clearance than a liquid bolus.[1] These were the same results we found

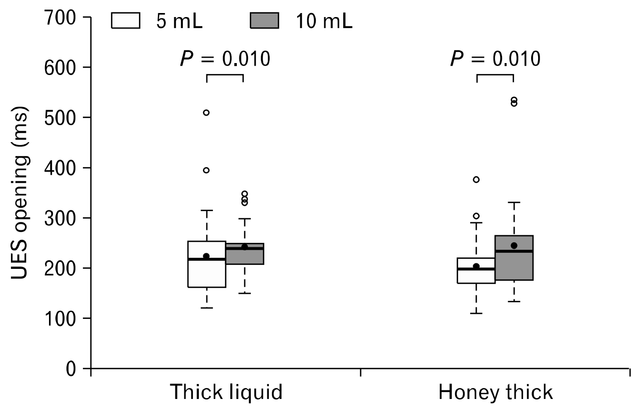

Figure 1. Upper Esophageal Sphincter (UES) opening duration after swallows of 5 mL and 10 mL of thick liquid and honey thick boluses in healthy subjects.

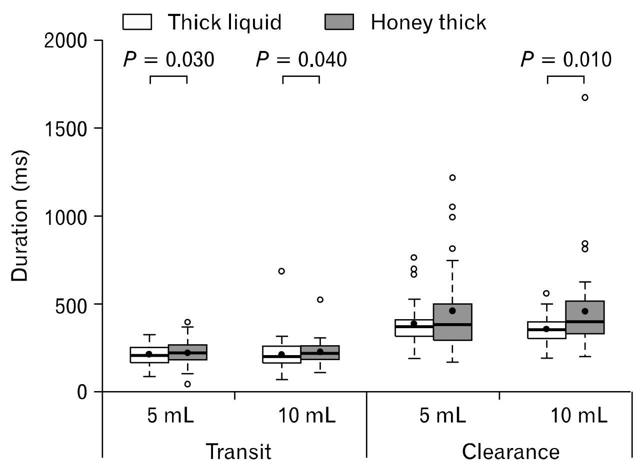

Figure 2. Pharyngeal transit duration and pharyngeal clearance duration after swallows of 5 mL and 10 mL of thick liquid and honey thick boluses in healthy subjects.

Table 3. Relation Between Pharyngeal Clearance Duration and Hyoid Movement Duration After Swallows of 5 mL and 10 mL of Thick Liquid and Honey Thick Boluses

	Thick liquid			Honey thick			P-value
	Mean (SD)	Median	Range	Mean (SD)	Median	Range	
5 mL	0.82 (0.35)	0.77	0.21-1.70	0.97 (0.58)	0.77	0.27-2.41	0.470
10 mL	0.84 (0.32)	0.80	0.19-1.69	0.92 (0.43)	0.77	0.31-2.24	0.520
P-value	0.440			0.640			

SD, standard deviation.

with a thick liquid and honey thick consistencies.

Swallowing a high-density liquid barium preparation causes a slower pharyngeal transit time and a longer UES opening duration than a low-density liquid barium preparation, showing that the density as well as viscosity has an influence on bolus transit time through the pharynx.[10,11]

Although there are differences in the UES transit with different bolus volumes and differences in pharyngeal transit with different bolus consistencies, the proportion between pharyngeal clearance and hyoid movement is the same. It is a demonstration of the precise control of the swallowing events, both in liquid and high viscous bolus.

Previous publications have already demonstrated that an increase in bolus volume causes an increase in UES opening duration and UES transit,[1,7-10,12,13] however, each investigation evaluated different bolus preparation. In this investigation, with the thick liquid and honey thick consistency, the effect of bolus volume was demonstrated and was the same at different bolus consistencies. The longer UES transit should be consequence of the increase of bolus length with the increase in bolus volume, in mouth and pharynx, with liquid and paste bolus'[1] which causes an early bolus arrival at the UES, early UES opening and longer UES flow.[12]

The longer pharyngeal transit with paste bolus compared with liquid bolus was seen in a previous publication with a bolus volume from 2 mL to 20 mL, without influence of bolus volume.[1] However, this previous investigation used low-viscosity liquid barium and a viscous barium paste with high viscosity.[1] With the smaller difference in consistency between thick liquid and honey thick bolus we used, increased viscosity was also demonstrated to be associated with a decrease in pharyngeal flow.

A possible explanation for longer UES transit with the increase of bolus volume and also for longer pharyngeal transit with increase in bolus viscosity is the modulation of the deglutitive inhibition in the skeletal muscle of the proximal esophagus, which is consequence of the inhibition of neuronal discharges in the brain stem.[14]

The results indicated that in the treatment of patients with impairment of UES opening the bolus volume of each swallow should be small, which causes a longer time to eat a meal, and patients who is unable to create enough pharyngeal pressure, essential for pharyngeal transit, should not swallow a viscous bolus, which need a higher pharyngeal pressure, compared with swallow of a liquid bolus.[1]

In conclusion, an increase in the swallowed bolus volume causes a longer UES opening duration, and an increase in bolus consistency causes a longer pharyngeal transit duration, however, the proportion between pharyngeal clearance and hyoid movement duration does not change with bolus volume or bolus consistency.

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