Effects of Food Viscosity on Swallowing Velocity in Pharynx for Different Groups of Age and Gender

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Abstract

Dysphagia can be treated using methods such as direct food swallowing. However, the viscosity of food can be an obstacle to patients. To prepare appropriate food for patients, nutritionists need to understand the influence of food viscosity on the velocity of bolus transport in the pharynx. In the present study, the effects of the viscosity of shear-thinning food on bolus velocity are investigated. Food viscosity in the range of 95 to 1368 mPa·s (nectar to honey consistency) is tested. Thai volunteers were classified into 3 groups, namely young adult, adult, and elderly. Videofluorographic recording was performed and bolus velocity was calculated. The average tail bolus velocity of young adult volunteers while swallowing food with a nectar-honey consistency was about 99-125 mm/s for males and 77-90 mm/s for females. The values were 97-117 mm/s for males and 76-80 mm/s for females in the adult group, and 87 mm/s for males and 85 mm/s for females in the elderly group. Swallowing characteristic of male is developed in natural style, where velocity decreases with increasing viscosity. However, the swallowing characteristic of female is developed to a full performance, where swallowing power is at maximum regardless of viscosity. The velocity of food swallowing depends on food viscosity. A suitable swallowing velocity for healthy persons can be used for the design of food for dysphagic patients to yield similar velocity.

Keywords: Swallowing, Viscosity, Velocity, Pharynx, Dysphagia

1. Introduction

Swallowing is a complex human physiological mechanism. The process of food movement from mouth to stomach occurs in three phases. In the first phase, called the oral phase, food is chewed and mixed with saliva by teeth and tongue to form a bolus before it travels down to the pharynx. In the second phase, called the pharyngeal phase, the bolus is pushed from the mouth by the tongue while the soft palate is elevated to protect the nasopharynx. The palate then bends downwards to close the nasopharyngeal and oropharyngeal zones. The bolus is moved downwards to the pharyngeal zone during elevation of the hyoid bone with the epiglottis deformed to cover the laryngeal inlet and to convey the bolus to the upper esophageal sphincter (UES) while breathing is paused for a few seconds. Finally, in the esophageal phase, the UES is closed and the bolus is allowed to move forward to the stomach by peristaltic waves [1-3].

If any of these mechanisms is damaged or impaired, the swallowing system may suffer. Swallowing difficulties that result from damage are called dysphagia and aspiration [4-8]. There are many methods for treating dysphagia, such as surgery [9-11], chemotherapy [12], use of swallowing aid equipment [13], dietary changes for self swallowing [14-16], among others [17]. Self swallowing is advantageous as it is a non-intrusive alternative for healing, as well as curing, dysphagia effectively [16,17].

Several papers have reported the use of thickened liquid diets as a treatment method for dysphagia [17-19]. A few studies detailed factors affecting self swallowing. These include effects of volume and viscosity [20-26], head posture on bolus transport [27,28], and physical conditions such as age, gender, and body mass index (BMI) [21,24]. Viscosity has been found to have considerable effect on swallowing in many aspects, including pharyngeal response time, pharyngeal delay time, pharyngeal transient time of cricopharyngeal opening, and earlier airway closure relative to cricopharyngeal opening [26]. Studies of bolus movements have shown that increasing bolus viscosity results in slower transit times, higher amplitude of pharyngeal peristaltic waves, and larger UES opening [29-32].

The present study investigates the effects of the viscosity of shear thinning foods on swallowing physiology. The velocity of bolus transport in the pharyngeal of healthy Thai volunteers is studied. The results can be used in the simulation of food...
swallowing characteristics for healthy persons and could be employed as fundamentals to study food swallowing of dysphagic patients in the future.

2. Materials and methods

Several research works have used thickened liquids following the suggestion of the National Dysphagia Diet Task Force. Thickened liquids are classified according to their viscosity: the first consistency level, called “Thin” (1-50 mPa·s), which includes all unthickened supplements and beverages; the second consistency level called “Nectar” (51-350 mPa·s); the third consistency level called “Honey” (351-1750 mPa·s); and the fourth consistency level called “Spoon-thick” (more than 1750 mPa·s) [33]. Many researchers have studied the effects of viscosity at nectar-like and honey-like consistency levels and found these consistency levels to be appropriate for dysphagic foods [34-36].

In the present study, these two levels of food viscosity, nectar and honey levels (in the range of 95 to 1,368 mPa·s), are examined. Videofluoroscopy (VFS) is employed in the main analysis of swallowing physiology in the pharyngeal zone [37,38]. The effects of food viscosity on bolus transport during swallowing by subjects of different ages and genders are studied.

2.1 Subjects

Eighteen healthy volunteers (nine females and nine males) were selectively recruited to be the subjects of this study. These volunteers were in three age groups: young adult (18-25 years old, mean = 23 years, standard deviation (SD) = 2 years), adult (26-40 years old, mean = 32 years, SD = 5 years), and elderly (over 40 years old, mean = 46 years, SD = 1 year). Each group consisted of 3 volunteers. None of the subjects exhibited oropharyngeal symptoms at the time of the study.

2.2 Food preparation

Currently available foods for dysphagic patients are in powder form and tasteless. The foods used in this study were modified for easy swallowing and increased taste. The major component of the food used in the tests is a commercially available powder food (BLENDERA®). This was mixed with sodium carboxymethyl cellulose (SCMC), chocolate powder (Milo®), and hot water (70 °C).

The viscosity of the food was varied by varying the quantity of SCMC solution and hot water while the quantities of the powder food and the chocolate powder were fixed. Three recipes were used, as shown in Table 1. The viscosity was controlled by varying the quantity of SCMC solution and hot water while the quantities of the powder food and the chocolate powder were fixed. The concentration of SCMC was maintained at 1% w/v. The solution was then mixed with the remaining ingredients for 15 minutes.

The viscosity of all prepared food, shown in Table 2, was measured by a programmable viscometer (Brookfield, DV-II + ) The reference temperature for food viscosity determination provided by the American Dietetic Association is 25 °C [33]. In this study, the food temperature was controlled at 37 ± 0.1 °C. The main reason is that food prepared for patients in Thailand or other countries in tropical zones is served at temperature above the ambient temperature, which is usually in the range of 28-33 °C [39]. The temperature of food being served is then near body temperature (about 37 °C). Thus, the value of 37 °C was used as the food temperature during swallowing.

The viscometer measures the torque required to rotate an immersed cylindrical spindle in a fluid. The viscosity (\( \mu \)) can be calculated from the ratio of shear stress (\( \tau \)) and shear rate (\( \dot{\gamma} \)) on a spindle of the viscometer (Fig. 1):

\[
\mu = \frac{\tau}{\dot{\gamma}} \quad (1)
\]

where the shear stress of selected food can be estimated as:

\[
\tau = M(2\pi R_s^2L) \quad (2)
\]

and the shear rate can be determined as:

\[
\dot{\gamma} = 2\omega R_s^2 R_i^2 / (x^2(R_s^2 - R_i^2)) \quad (3)
\]

where \( M \) is the measured torque, \( \omega \) is the angular speed of the spindle, \( L \), \( R_s \), and \( R_i \) are the dimensional parameters of the spindle shown in Fig. 1, and \( x \) is the radial distance from the spindle centerline to the fluid at which the shear rate is calculated.

<table>
<thead>
<tr>
<th>Food</th>
<th>Consistency index ( K ) (Pa·s(^2))</th>
<th>Flow index ( n )</th>
<th>Apparent viscosity at shear rate of 50 s(^{-1}) ( \mu ) (mPa·s)</th>
<th>Consistency level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula 1</td>
<td>658</td>
<td>0.5053</td>
<td>95</td>
<td>Nectar</td>
</tr>
<tr>
<td>Formula 2</td>
<td>1934</td>
<td>0.6524</td>
<td>496</td>
<td>Honey</td>
</tr>
<tr>
<td>Formula 3</td>
<td>5683</td>
<td>0.6360</td>
<td>1368</td>
<td>Honey</td>
</tr>
</tbody>
</table>

Table 1. Ingredients of food used in experiments.

Table 2. Parameters in power-law equation of non-Newtonian fluid.

Figure 1. Dimensions of viscometer spindle.
Food behaves as a shear-thinning fluid, which can be described by the following power law equation:

$$\mu = K\gamma^{n-1}$$  \hspace{1cm} (4)

where the flow index($n$) can be obtained as:

$$n = \frac{d\ln(\tau)}{d\ln(\omega)}$$ \hspace{1cm} (5)

and $K$ is the consistency coefficient. These parameters, derived partially from curve fittings in Fig. 2, are shown in Table 2.

The food consistency levels are classified at the recommended shear rate of 50 s$^{-1}$, as suggested by the American Dietetic Association (ADA) [33,40-42]. The value of this fixed shear rate is used as a reference to determine the level of food viscosity. In this study, the food viscosity was measured for shear rates of 0 to 90 s$^{-1}$. The results of food viscosity shown in Fig. 2 indicate that the viscosity does not change significantly for higher shear rates.

The motion of a bolus in the throat can be visualized by the VFS method. Motions were recorded on an outer X-ray video recording system that comprised a video recorder (SVO-9550MDP, Sony, Japan) and a monitor (14-inch, 1280 × 800 resolution). They were also visualized by an inner X-ray monitor (Type 9807 751 52601, Philips Medical Systems, Japan) connected to an X-ray station (SUPER 80 MPA.S, Philips Medical Systems).

The videos were captured on an image capture station equipped with a personal computer (AMD Athlon™ XP2500+, 1.83-GHz CPU, 1.0 GB of DDR RAM, 320-GB hard disk) and a monitor (LG L194WT, 19-inch, 1440 × 900 resolution) at a rate of 25 frames/second. They were used to determine the pharyngeal length by digital image measurement employing a Computer-Aided Design (CAD) programming with an accuracy within 0.001 mm. The length was measured from the base of the tongue to the UES [38,43], as shown in Fig. 3. A coin was used to calibrate the length. The coin appeared as an oval because it was attached to the subject surface at an incline to the X-ray beam. The pharyngeal swallowing time was obtained by counting frames. Images of the bolus moving from the base of the tongue to the UES are shown in Fig. 4. The tail average bolus velocity can then be calculated [44].

In the VFS measurement, X-rays irradiate the upright left posterior of the subject. VFS has been previously used to record bolus motion during swallowing [44]. The subject stood with his left side facing the radiation. The subject was instructed to hold his head in a natural position. VFS recording was obtained at 90 keV with a 22.86-cm (9-inch) image intensifier mode and appropriate collimation so that a lateral image of the posterior mouth, pharynx, and pharyngoesophageal region was obtained. The total radiation exposure to the patient followed the standard procedures. In each measurement, a subject swallowed 5 ml of the food. Volunteers were asked to keep the food in their mouth until the measurement began. Complete swallowing was performed at
After three repetitions of the experiment with an identical food formula, the subject was allowed to drink 15 ml of water and to rest for 2 minutes before subsequent trials to avoid fatigue. The procedure used in the present study was approved by the ethics committee of the Faculty of Medicine, Prince of Songkla University. The subjects were informed about the procedure and the risk, and written consent was obtained prior to the experiment. The age and gender group analyses were conducted using the paired \( \chi^2 \) test and the t-test. Values are reported means and SDs unless stated otherwise.

3. Results

3.1 Group 1: Young adult (18-25 years old)

The effects of viscosity on the average bolus tail velocity are obviously different between genders in this group, as shown in Fig. 5. Swallowing by males is more natural, as the velocity decreased when the food viscosity increased [44]. The highest velocity for males was 125.1 mm/s (SD = 81 mm/s), obtained for a viscosity of 96 mPa·s, which is at the nectar consistency level. When the viscosity was increased to honey level, the velocity decreased rapidly until the viscosity reached 496 mPa·s. This reduction was then gradual up to a viscosity of 1,368 mPa·s, for which the velocity was 99.1 mm/s (SD = 43 mm/s). For females, the opposite results were obtained. The initial velocity was 77.2 mm/s (SD = 19 mm/s) at a viscosity of 96 mPa·s. This increased to 90.5 mm/s (SD = 5 mm/s) at a viscosity of 1,368 mPa·s. Male volunteers swallowed faster than female volunteers for any given recipe (\( \chi^2 = 4.298, p < 0.01 \)).

3.2 Group 2: Adult (26-40 years old)

The effects of food viscosity in this group are slightly different from those in the young adult group. The swallowing velocities for females only slightly changed over the entire viscosity range, as shown in Fig. 6. Swallowing by males is more natural, as the velocity decreased when the food viscosity increased [44]. The highest velocity for males was 96.7 mm/s (SD = 21 mm/s) at 96 mPa·s and decreased to 87.2 mm/s (SD = 15 mm/s) at 496 mPa·s. The bolus velocity increased to 116.8 mm/s (SD = 41 mm/s) at a viscosity of 1,368 mPa·s. Male volunteers can swallow faster than female volunteers for any given recipe (\( \chi^2 = 2.361, p < 0.01 \)).

3.3 Group 3: Elderly (over 40 years old)

Swallowing velocity for both genders in this group was rather constant. For the elderly, gender does not influence the swallowing mechanisms as the swallowing velocities for the two genders are virtually identical, with average values of 87.2 mm/s (SD = 6 mm/s) and 85.2 mm/s (SD = 23 mm/s) for males and females, respectively, as shown in Fig. 7. It can also be clearly seen that the average swallowing velocity of females is almost unchanged over the entire life period whereas that of males decreases with age. Male volunteers can swallow faster.
than female volunteers for any given recipe ($X^2 = 0.113, p < 0.01$). It is noted that standard deviations in the present study are lower than those reported in the aforementioned study [44].

4. Discussion

Food viscosity clearly affects the average bolus velocity. Bolus velocity decreases with increasing food viscosity because of higher resistance to motion. Swallowing muscles need to perform harder to drive highly viscous food [46]. However, in the present study, the swallowing velocity of the least viscous food (nectar-like consistency) for young adult females was low. This is because the female volunteers controlled the speed and the rhythm of swallowing. The control was not within the capacity of the researchers. This is a common and unique behavior for Thai ladies in this age group as most of them regard fast swallowing as inappropriate and they then swallow slowly as a habit. This is different from females in other countries, even in the same region. For adult males, the velocity increased when swallowing food with honey-like consistency. This is because the swallowing system of adults is fully developed and it can adjust bolus movement better than that of young adults.

Swallowing velocities of males and females are different. Food bolus velocity for males was greater than that of female in all cases, be it the age group or the viscosity. In general, males have larger and stronger muscles used in swallowing, allowing them to swallow faster. Swallowing for males is natural, where the velocity decreases with increasing viscosity. However, the swallowing of female is early-developed to a full performance swallowing in which the swallowing power is fully utilized, no matter how high the viscosity is.

Swallowing velocity for young adults is faster than that of the elderly for both genders ($p < 0.01$). This is consistent with several previous reports on swallowing delay time [29,47-50]. The bolus velocity in the elderly was found to be slower than those for younger subjects [44]. This is a result of the weakening of neuromuscular muscle when approaching old age [38,46]. A previous investigation [44] showed that the bolus velocity of young adults to adults (18-40 years old) is about 103 mm/s ($SD = 30$ mm/s). In the present study, the average bolus velocity for male young adults was from 125 to 99 mm/s, and that for female young adults was 77 to 90 mm/s. The elderly had an average bolus velocity of 87 mm/s for males and 85 mm/s for females. The values obtained here are near those previously reported though the conditions were different.

The obtained results can be used for the simulation of pharyngeal bolus transport to identify the swallowing characteristics of various food formulae. Future investigations on swallowing of dysphagic patients are necessary to identify appropriate food for treatment.

5. Conclusion

The average tail bolus velocities of young adult Thai volunteers when they swallowed food with nectar-honey consistency were about 125-99 mm/s for males and 77-90 mm/s for females, and those of the elderly were 87 mm/s for males and 85 mm/s for females. These results are consistent with a previous report that found an average tail bolus velocity of 103 mm/s ($SD = 30$ mm/s) for the young adults to adults (18-40 years) [44]. However, certain other characteristics are quite different, such as gender and influence of local behavior in female.

The swallowing of males is natural, where bolus velocity decreases with increasing food viscosity. On the other hand, the swallowing of female is early-developed to a full performance swallowing in which the swallowing power is fully utilized without regards to the viscosity.

Since swallowing velocity generally depends on food viscosity, knowledge of suitable swallowing velocity of healthy persons which corresponds to a specific viscosity can be used to design food for dysphagic patients to achieve a similar velocity.

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References


