ORIGINAL ARTICLE

X-ray examination of the stomach bubble after frequent experimental swallowing of saliva: the mechanism of aerophagia

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BACKGROUND: While the mechanism of aerophagia remains unclear, the frequency of clenching has been reported to be increased when under stress. We hypothesized that, via the swallowing reflex, chronic air swallowing was induced through a "learned habit" of the oral cavity, which was acquired through psychological factors. This study examined whether the habitual repeated swallowing in the oral cavity was a process of aerophagia.

METHODS: After continuous experimental saliva swallowing, changes in the stomach bubble were examined by abdominal X-rays in a standing position. The subjects included 9 males and 10 females aged 20 to 36 years that were without organic disease in the pharynx and nasal cavity. X-ray images were digitized, and the area of the stomach bubble was measured by tracing.

RESULTS: A close correlation was revealed in the stomach bubble area between posteroanterior and lateral views in six males (p < 0.001, r = 0.910). In 3 males and 10 females, the area of the stomach bubble by posteroanterior view after 30 swallows was significantly increased compared with that before swallowing (p = 0.004). CONCLUSIONS: In the present study, abdominal X-rays confirmed that frequent saliva swallowing expanded the stomach bubble.

Key words: aerophagia, air swallowing, belching, stomach bubble

Introduction

Air swallowing occurs unconsciously while eating and drinking and in daily activities1. Double contrast radiography of the esophagus utilizes the fact that drinking a large amount of liquid in one gulp results in swallowing a large amount of air. According to Romall, “Aerophagia is an unusual presenting complaint. It refers to a repetitive pattern of swallowing or ingesting air and belching. It is an unconscious act unrelated to meals, and is presumably a learned habit.” This definition suggests the involvement of psychological factors. Aerophagia has been reported to be caused by stress and mental strain2, but the mechanism of aerophagia has not been clarified. Swallowing occurs by the swallowing reflex. We hypothesized that chronic air swallowing is a learned habit acquired with psychological factors. The purpose of this study was to evaluate whether habitual repeated swallowing in the oral cavity is a process of aerophagia by radiographic observation of experimental continuous saliva swallowing (dry swallowing).
Methods

Subjects
The subjects were 19 healthy volunteers, consisting of 9 males and 10 females, aged 20-36 years (mean, 28.0 years). All subjects had neither organic diseases in the pharynx and nasal cavity nor anamnesis of surgical treatment, and had complete tooth alignment or deficiency of a small number of teeth without dentures. This study was carried out according to the principles of the Declaration of Helsinki and approved by the ethics committee. The subjects were informed of the experimental methods, the exposure dose, and safety according to the ethical regulations, and gave consent.

Experimental protocol
The following 2 experiments were performed.
1. Evaluation of the area of stomach bubbles imaged in different projections
To examine the amount of stomach bubbles by two-dimensional imaging, 6 males underwent plain abdomen radiography in the standing position. The radiography was performed in the posteroanterior (PA) and lateral (LAT) projections. The subjects performed saliva swallowing 10 times continuously, and underwent radiography under the same conditions as above. Immediately after 10 more actions of saliva swallowing, radiography was performed under the same conditions as above. The subjects were requested not to belch during the experiment period.

2. Changes in stomach bubbles by saliva swallowing
The subjects in this experiment consisted of 3 males and 10 females, and underwent plain abdomen radiography in the PA projection. The subjects performed saliva swallowing 30 times continuously, and immediately underwent radiography under the same conditions as above. The subjects were requested not to belch until the completion of imaging.

Radiographs were converted into digital images using a scanner (ES-2200, Epson) and transmitted to an IBM PC. The periphery of stomach bubbles was traced using a Photoshop Elements 2.0 (Adobe Systems, Japan). The traced areas were measured using a Scion Image Beta 4.02 (Scion Corporation, USA) (Figure 1).

Statistical analysis
Statistical analysis was performed using the Statcel2 program (OMS publishing Inc., Japan). Since the distribution of the area of stomach bubbles was skewed, it was normalized by logarithmic conversion of

1. Evaluation of the area of stomach bubbles imaged in different projections

Subjects: 6 males

Before

Saliva swallowing 10 times continuously

The radiography was performed in the posteroanterior (PA) and lateral (LAT) projections.

Saliva swallowing 10 times continuously

2. Changes in stomach bubbles by saliva swallowing

Subjects: 3 males and 10 females

Before

Saliva swallowing 30 times continuously

The radiography was performed in the PA projection.

Fig. 1. Experimental protocol

Results
1. The markers indicate the results of individual subjects. There was a close correlation (0.910) of the fluctuations in individual subjects between the PA and LAT images within the subject.

2. A value of $p<0.05$ obtained by the paired t test was regarded as significant.

1. Analysis of covariance (ANCOVA) was used to determine the variations between the PA and LAT images within the subject.

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2. A value of $p<0.05$ obtained by the paired t test was regarded as significant.

Results

1. The markers indicate the results of individual subjects. There was a close correlation (0.910) of the fluctuations in individual subjects between the PA and LAT projections ($p<0.001$) (Figure 2).

2. The horizontal lines indicate the geometric means. On the images taken in the PA projection, the area of stomach bubbles after 30 times of saliva swallowing was significantly larger than that before saliva swallowing ($p=0.004$) (Figure 3).
There have been various studies on the amount and components of bowel gas. In several studies, the quantity of bowel gas was examined in patients with abdominal symptoms of Irritable Bowel Syndrome and control subjects. It was reported that the quantity of bowel gas observed by abdominal radiography was significantly larger in the patient group than in the control group\(^5,6\), and that there was no difference in the quantity of gas observed by CT between the patient and control groups\(^7\). Among factors causing symptoms, location of bowel gas was reported to be more important than the amount of gas\(^8\).

Among studies on gas in the upper digestive tract, Pouderoux P et al. examined the swallowing function in the esophagus by ultrafast CT after swallowing of 10 ml liquid contrast medium in the supine position, and found that 8-32 ml air was taken by the swallowing\(^9\). Bredenoord AJ et al. reported that there was a close correlation of the area of stomach bubbles observed by abdominal radiography between the anteroposterior and lateral projections\(^10\). A similar result was obtained by saliva swallowing in our study. They measured impedance by fixing several manometers, and found that supragastric belches were the gas not from the stomach but from the esophagus\(^10\). However, in their study, there were no significant differences in the area of stomach bubbles between the aerophagia and control groups and between before and after eating. In our study, habitual swallowing unrelated to meals was examined. Originally, aerophagia was considered to be involved in gas-related symptoms, such as belching, abdominal swelling, and flatulence. In the criteria of aerophagia according to Roma\(II\), belching repeats troublesomely and observation of air swallowing is important\(^2\). Therefore, aerophagia may be limited to supragastric belches. We considered that air swallowing is important from the viewpoint of a learned habit in the oral cavity. This disease model includes gastrocardiac syndrome and intestinal flatulence in addition to supragastric belches. Since the subjects were healthy adults, swallowed air was sent into the stomach from the esophagus in our experiments. In this study, to minimize changes in stomach bubbles and movement of gas to the outside of the stomach by its motion, the subjects performed saliva swallowing continuously. Several reports described that the interval between the consecutive 2 actions of swallowing slightly increased with increases in the numbers of swallowings because of muscular fatigue and elevation of the threshold of swallowing reflex expression by shortage of saliva caused by repetition of saliva swallowing\(^11,12\). A similar tendency was observed in this study. Some subjects belched during the experiment period, and the

**Discussion**

There have been various studies on the amount and components of bowel gas. In several studies, the
amount of stomach bubbles decreased in 2 of the 13 subjects in experiment 2. Although we did not attempted to measure the exact amount of air in this study, it was confirmed that stomach bubbles were expanded by air taken by frequent saliva swallowing unrelated to drinking and eating. Experiment 1 revealed a correlation between PA and LAT, and suggested that the area of stomach bubbles slightly increased with the number of swallowing. Therefore, to simplify the experimental methods and to reduce the exposure to radiation, Experiment 2 was performed using PA alone.

Organic factors of aerophagia have been reported to be nasal obstruction in experimental animals, post-nasal drip, airway obstruction, hiatus hernia, and some neurological disorders, and other factors are bad habits in the oral cavity and ill-fitting dentures and braces. With regard to the function of nasopharyngeal closure, Fujiki T et al. reported that movement of rear part of dorsal tongue was slower, and nasopharyngeal closure was earlier during swallowing in 10 subjects with anterior open bite, aged 15-24 years, than normal adults. Such swallowing is considered to be likely to cause air swallowing. Stress and mental strain are considered to cause aerophagia, but the mechanism remains unclarified. Swallowing is considered to be repeated under mental strain to remove discomfort in the oropharynx caused by dryness of the mouth, but this hypothesis lacks anatomicophysiological evaluation. In adults, there is a freeway space of 1-2 mm between the dental arches at rest. In normal swallowing in adults, momentary tooth contact occurs at the time of swallowing, and it is very difficult to swallow without contact. Hidaka O et al. reported that weak but long mental stress changed hemodynamics of the masseteric muscle and increased electromyographic activity of the temporalis muscle, and Tsai CM et al. reported that stress increased masticatory muscle EMG activity, and persistent stress increased the frequency of tooth contact. Rosales Vp et al. reported that emotional stress in rats significantly increased braxism-like masseteric activity. This may easily maintain the oral cavity in the same position as the oral stage of swallowing in individuals under stress or mental strain. Tooth contact itself does not affect the secretion of saliva. However, when teeth are in contact, oral mucosa, soft palate, palatal uvula, dorsal tongue surface, and faucial pillars are likely to anatomically contact each other. Stimulation of these oral regions induces increases in the secretion of saliva and swallowing reflex. With regard to the relationship between stress and the secretion of saliva, Gemba et al. reported that the saliva flow rate was changed by emotional state, Queiroz CS et al. found that it was decreased under stressful situations, and Bergdahl M et al. showed that stress induced subjective dry mouth feeling. These changes in the salivary flow rate and subjective dry mouth feeling increase actions inducing saliva swallowing and swallowing reflex. Based on these findings, our experiments showed a potential mechanism of aerophagia, and Oral conditions related to psychological and physiological factors are likely to induce swallowing reflex, leading to air swallowing. In future studies, it is necessary to perform additional experiments under stressful situations. At the time of belching, the soft palate is elevated without the superior pharyngeal muscle adduction, and air is retained in the esophagus if belching is repressed, resulting in aggravation of belching. If action for the suppression of belching makes the oral condition likely to induce swallowing reflex, aerophagia may be more persistent.

Conclusions

In this study, expansion of stomach bubbles by frequent saliva swallowing was confirmed by abdominal radiography. It was suggested that besides the change in salivary flow rate, oral conditions in tooth contact were likely to induce swallowing reflex and lead to air swallowing.

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References