Correlation between the Drinkability of Beer and Gastric Emptying

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A subjective evaluation of beer drinkability and the degree of stomach fullness were found to correlate with the relaxed cross-sectional area of the pylorus antrum measured by real-time ultrasonography. Five kinds of beer with a different malt/adjuncts ratio and degree of attenuation were used. Each beer was given to 9 healthy volunteers at the rate of 3 ml/kg/15 min, and they each recorded the degree of stomach fullness, desire to drink and tastiness every 30 min. With increasing volume drunk, the degree of t astiness and desire to drink were lowered, and the degree of stomach fullness raised. The relaxed cross-sectional area of the pylorus antrum measured by an ultrasonic image analyzer every 30 min was highly correlated with the degree of stomach fullness, t astiness of the beer, and desire to drink (p = 0.0021, < 0.0001, 0.001). The beer giving the lowest degree of stomach fullness was appraised to be tasty and highly drinkable. These findings suggest that the rate of gastric emptying is one of the factors determining the drinkability of beer, and that measurement of the relaxed cross-sectional area of the pylorus antrum is useful to evaluate stomach fullness during beer drinking.

Key words: beer drinkability; gastric emptying; ultrasonography; pylorus antrum cross-section; subjective evaluation

Drinkability of beer refers to the characteristic of not making one tired of drinking beer even after drinking a lot, and allows the beer to be tasty to the last drop. Drinkability is an important factor for the evaluation of beer in Europe, including Germany. However, since no objective methods to determine drinkability have been developed, drinkability has not been analyzed in detail. Stomach fullness is well known to weaken the desire to drink beer. Periodical measurement of stomach fullness while drinking may help clarify the characteristics of drinkability, but there is no conveniently objective method to measure stomach fullness. Distention of the stomach wall caused by the gastric contents results in stomach fullness. The introduction of labeled compounds into the stomach through a catheter with subsequent collection of the contents and the combination of a radiopaque marker and X-ray radiography have often been used to measure the volume of the gastric contents. However, these methods have the disadvantage of causing stress to the subject. Another method is to administer radioisotopes and measure the movement of the gastric contents by scintigraphy, but this has the risk of exposing the subjects to radiation, and the use of such a method other than for medical treatment poses ethical problems.

Since the report by Bateman et al. (Br. J. Radiol., 1977) on the application of extracorporeal ultrasonography for evaluating gastro-duodenal motility, many workers have used this method for measuring gastric emptying. Yamanaka and Haruma have clarified by detailed experiments that measurement of the relaxed cross-sectional area of the pylorus antrum by a real-time ultrasonic echo image analysis can be used as an indicator of gastric volume, and they reported it to be as useful as the isotopic method for evaluating gastric emptying.

Gastric emptying of beer can be easily measured by this method without causing any discomfort to the subject, and can be used to evaluate the degree of stomach fullness. Therefore, in this study, we examined the correlation between relaxed cross-sectional area of the pylorus antrum measured while beer was being drunk and the drinkability of beer by using healthy volunteers.

Materials and Methods

Materials. Five kinds of beer (A, B, C, D and E) test-brewed by Kirin Brewery Co. Ltd. were used. They differed in the degree of attenuation and the ratio of malt and adjuncts that were used. Table 1 shows the alcohol concentration and sugar content of each beer. Beer F was a commercial canned beer, and was evaluated within one month of production.

Subjects. The subjects were 9 healthy volunteers (7 males and 2 females, average age of 25). According to the Declaration of Helsinki (1966, revised in 1989), we...
obtained written informed consent after explaining the details of the experiments, and any subject could drop out upon request. The subjects were ascertained not to be alcohol dependent or alcohol dehydrogenase deficient.

**Experiments on drinking beer.** The 9 subjects were fasted after finishing lunch at 1:00 p.m., and were not allowed to drink water after 4:00 p.m. The experiment started at 6:00 p.m., and was conducted with each subject sitting in a chair in a quiet room where the temperature was kept at 25°C. Conversation among the subjects was allowed, but the exchange of opinions on the evaluation of the test beer was prohibited. The subjects drank beer at a rate of 3 ml per 15 minutes per kg of body weight for 2 hours, the average volume of beer drunk in the 2 hours being 1432±94.6 ml (mean±SEM). According to Oshida, this amount of beer intake brings about an increase in blood ethanol level to 1.0 mg/ml, which seems to be within the range of harmless tipsiness. Each subject ate 25 g of pretzel (Beerpretz, Ezaki Glico Co., Osaka, Japan) during the 2 hours. They were instructed to urinate every 30 minutes and the urine volume was measured. Five subjects were randomly selected before the start of the experiment, and the relaxed cross-sectional area of the pylorus antrum was measured for each of these subjects just before and 15 minutes after the start of the experiment, and then after every 30 minutes, giving 8 times in total. We did not measure the relaxed cross-sectional area of the pylorus antrum for all the subjects because the measurement took a long time, enabling only 5 subjects to be measured. From 30 minutes after the start of the experiment, the urine volume was measured every 30 minutes for 3 hours.

This experiment was conducted 5 times so that every subject could drink each test beer once. No information on the test beer was given to the subjects.

Five times every 30 minutes during the experiment, all the subjects recorded the following items on a subjective scale of 5: tastiness, desire to drink, stomach fullness, bitterness, wateriness, and smoothness of throat passage. The maximum degree of tastiness, desire to drink, smooth throat passage, and stomach fullness were each ranked as 5, and the minimum as 1. The degree of stomach fullness at the start of the experiment was ranked as 1.

**Measurement of the cross-sectional area of the stomach.** The cross-sectional area of the stomach of a subject in a sitting position was analyzed with an extracorporeal ultrasonic echo-image analyzer (SSA-220A, Toshiba Co., Tokyo, Japan). On the echo-image simultaneously depicting both the aorta and superior mesenteric artery, the mucosal side of the pylorus antrum was traced with a calibrator built into the ultrasonic image analyzer, and the maximal relaxed cross-sectional area of the pylorus antrum was measured while naturally breathing. The measurement was conducted three times in succession, and the average of the three measurements was determined.

**Measurement of the urine volume.** Each subject was weighed with a precision digital scale (measurements in 10 g units, maximum weight of 100 kg; FW-100K, AND Co. Tokyo, Japan), and the difference between the values obtained before and after urination was regarded as the urine volume. The urine volume is presented as cumulative value during the experiment.

**Statistical analysis.** The correlation between the subjective evaluation of the beer and the relaxed cross-sectional area of the pylorus antrum was analyzed by Spearman’s ranked test. The time-course relationships for the change in subjective evaluation of each beer, the relaxed cross-sectional area of the pylorus antrum and cumulative urine volume were subjected to an analysis of variance (ANOVA).

**Results**

**Correlation between the gastric volume and relaxed cross-sectional area of the pylorus antrum**

The fasted subjects drank 100 ml of commercial beer F cooled to 10°C every 2 minutes, 5 times in total, and the change in relaxed cross-sectional area of the pylorus antrum was measured during this time. As shown in Fig. 1(b), a linear correlation was found between the volume of beer drunk and the relaxed cross-sectional area of the pylorus antrum. The inclination of the regression line for each subject was nearly the same. When water cooled to 10°C was given to the subjects, the same results were obtained (data not shown).

After drinking 350 ml of commercial beer F cooled to 10°C, the cross-sectional area had decreased with time along the curve shown in Fig. 2. Gastric emptying of beer F was 50% at 29 minutes.

**Subjective evaluation and relaxed cross-sectional area of the pylorus antrum**

Figure 3 shows time-course plots of the change in evaluation of tastiness, desire to drink, stomach fullness, bitterness, wateriness and smoothness of throat passage by the subjects given five kinds of beer, A, B, C, D and E. B was evaluated as the most tasty beer and D as the least tasty. B was evaluated to give the greatest desire to drink more beer and D the lowest. The ranking in smoothness in throat passage was lowest for D and A, and D also had the highest rank for stomach fullness. Final stomach fullness tended to be high for A.

The relaxed cross-sectional area of the pylorus antrum was greatest at 105 minutes, being largest for D.
and smallest for B. The relaxed cross-sectional area of the pylorus antrum measured 30 minutes after the end of beer drinking was also largest in the subjects who drank beer D (Fig. 4), which clearly shows that gastric emptying was slow for D. The relaxed cross-sectional area of the pylorus antrum was highly correlated with tastiness, the desire to drink, smoothness of throat passage and the degree of stomach fullness \((p<0.0001, \ p=0.0010, \ p=0.0035, \ p=0.0021, \text{ respectively})\).

**Urine volume**

The evaluation of urine volume revealed that urination tended to be the most rapid for B and slowest for D throughout the experimental period, but a statistically significant difference was observed only in the cumulative values up to 180 minutes after the start of the experiment.

**Discussion**

The various kinds of beer used in this experiment, except for commercial beer F, were brewed in a small-scale plant by Kirin Brewery Co. Ltd. The malt, yeast and hops used were the same for all the kinds of beer, but the degree of attenuation and the ratio of all the kinds of beer, but the degree of attenuation and the ratio of malt and adjuncts used were different. The final alcohol concentration was 4.7\% or 5.5\%, and there was no difference in the carbon dioxide content. After being brewed, the beer was bottled and immediately stored at 4°C.
Beer Drinkability and Gastric Emptying

Fig. 1(b). Correlation between the Relaxed Cross-sectional Area of the Pylorus Antrum and Gastric Volume.
After drinking each volume of beer F cooled to 10°C, the measurement was taken three times, and the average of three measurements was plotted. The relationship between the relaxed cross-sectional area of the pylorus antrum and gastric volume is expressed by the following formula:

\[ y = 4.348x + 238.095 \quad (r = 0.994) \]

where \( x \) is the volume of the gastric contents, and \( y \) is the relaxed cross-sectional area of the pylorus antrum.

Fig. 2. Change in the Relaxed Cross-sectional Area of the Pylorus Antrum after Drinking Beer.
After 350 ml of beer F cooled to 10°C had been drunk by a subject within 2 minutes, the relaxed cross-sectional area of the pylorus antrum was periodically measured by an ultrasonic echo-image analyzer. After 29 minutes, 50% of the beer had been emptied from the stomach.

Isotopes\(^7\) and pigments\(^9\) are generally used to measure the volume of the gastric contents. The transition of acetaminophen into the blood is sometimes measured to estimate emptying of the gastric contents,\(^{11}\) and gastric emptying has also been estimated from gastric motility.\(^{12,14}\) However, the disadvantage of each these methods is that it is stressful to the subject.

Fig. 3. Change in the Subjective Evaluation While Drinking Beer.
Each kind of beer was given to 9 subjects, and they recorded the subjective evaluation of (a) tastiness, (b) desire to drink, (c) throat passage, (d) bitterness, (e) wateriness, and (f) stomach fullness every 30 minutes. Each value is the average. 
\[ *3: B \text{ vs } E, p < 0.05; *4: A \text{ vs } E, B \text{ vs } D, p < 0.05; *5: B \text{ vs } D, p < 0.05; *6: D \text{ vs } E, p < 0.05; *7: B \text{ vs } D, D \text{ vs } E, p < 0.05; *8: A \text{ vs } C, B \text{ vs } D, C \text{ vs } D, D \text{ vs } E, p < 0.05; *9: B \text{ vs } E, p < 0.1; *10: B \text{ vs } D, p < 0.1. \]

A significant correlation was observed by Spearman's ranked test between the relaxed cross-sectional area of the pylorus antrum and the subjective degrees of tastiness, desire to drink, throat passage and stomach fullness \((p < 0.0001, p = 0.0010, 0.0035, 0.0021, \text{respectively})\).

Extracorporeal ultrasonography enables gastric motility to be evaluated in a short time, safely and non-invasively, and several investigators have reported the usefulness of this method for measuring gastric emptying.\(^5,8,10\) Yamanaka and Fujimura\(^7,8\) have reported a high positive correlation between the retention rate of test foods in the stomach that was estimated from the relaxed cross-sectional area of the pylorus antrum measured by an ultrasonic echo-image analyzer and that measured by the isotopic method, and confirmed ultrasonography to be as useful as the radio-isotopic method for evaluating gastric emptying. Ultrasonic
echo analysis can be used only for a liquid diet, which is a limiting factor for this method. However, this does not interfere with its suitability to observe the gastric retention of beer. The amount of beer given to the fasted subjects was in complete proportion to the relaxed cross-sectional area of the pylorus antrum (Fig. 1). The carbon dioxide generated from beer seems to remain in the upper portion of the stomach. Judging from Fig. 1, carbon dioxide had no effect on the relaxed cross-sectional area of the pylorus antrum. Furthermore, 25 g of pretzel given during the two-hour experimental period did not interfere with the measurement of cross-sectional area.

In the present experiment, the subjective evaluation of the degree of stomach fullness was closely correlated with the relaxed cross-sectional area of the pylorus antrum. This is in agreement with the result shown in Fig. 1 that the relaxed cross-sectional area of the pylorus antrum was completely in step with the gastric liquid volume. There have previously been no objective methods to evaluate stomach fullness, and measurement of the relaxed cross-sectional area of the pylorus antrum proved to be useful as an indicator of stomach fullness.

Interestingly, there was a significant negative correlation between the relaxed cross-sectional area of the pylorus antrum and such subjective evaluations as tastefulness, desire to drink and smooth throat passage (Fig. 3). This implies that a subject with a fully distended stomach has no desire to drink. When the stomach is fully distended, the tastiness of beer is lost and the smoothness of throat passage is also hindered.

It is wellknown that appetite is influenced by gastric distention. A gastric distention receptor has been reported to exist in the stomach, and the discomfort of stomach fullness and overeating is caused by the signal transmitted from the gastric distention receptor via the nervous vagus (parasympathetic nervous system). In the present experiment, rapid gastric emptying was found to have a strong effect on the drinkability of beer. Monitoring gastric distention may therefore be meaningful to evaluate beer drinkability.

In the experiments in which beer was given at a constant rate, gastric distention depended on the rate of gastric emptying, and the factors that have been pointed out to influence gastric emptying are sex, age, body weight, smoking, and drinking. In the present experiment, various kinds of beer containing 5.5% or 4.7% alcohol were used, but the rate of gastric emptying was not correlated with the alcohol content. Kaufman and Kaye (1979) have reported that the osmotic detector in the duodenum was not influenced by ethanol, and that the rate of gastric emptying of a solution containing alcohol substituted for equi-caloric dextrose was higher than that of the dextrose solution. Schwartz et al. have reported that, in an experiment using 99 mTc, gastric emptying of beer was more rapid than that of an equi-caloric sugar solution. These findings suggest that ethanol is not as important a factor as sugar in gastric emptying, which does not contradict the present findings. Furthermore, the concentration of carbon dioxide did not differ with the kind of beer used in the present experiment, and is not considered to be an important factor affecting gastric emptying. Gastric emptying has been reported to be lowered by smoking. However, since smoking was prohibited before and after the experimental period, it was not a factor here.

Gastric emptying of liquids is considered to be controlled by a chemical receptor existing in the duodenum that precisely measures the gastric contents. This evaluation has been reported to be influenced by the osmotic pressure of the solution, caloric density, fat content and other factors. Fatty acids retard gastric emptying markedly. Such control is reasonable because it keeps the transit of food in the small intestines from exceeding the available capacity of digestion and absorption.

However, the components of each beer used in the present experiment were not sufficiently different to affect the capacity of the small intestines. The various kinds of beer used in the present experiment had different alcohol and sugar contents, but they did not show any significant correlation with gastric distention, which supports the foregoing assumption. There may be some unknown factors influencing gastric motility and gastric emptying in beer, and a more detailed examination is thus necessary.

It is also conceivable that the sense of taste while drinking beer affects gastric emptying. Gastric motility is controlled not only by feedback from the duodenum but also by the central nervous system via the vagus nerve. Beattie et al. and Kabat et al. have reported the suppression of gastric motility by an electric stimulus given to the corpus mammillare in the hypothalamus. Changes in the gastrointestinal motility and induction of urination from an electrical stimulus given to the amygdala of the limbic system have also been observed. The control center related to taste, evaluation of
food and eating is located in the higher central nervous system. This supports the possibility that an evaluation of taste that follows a taste stimulus would affect gastric motility. With increasing amount drunk, the beer was evaluated as less tasty, and this may have delayed gastric emptying. There are many factors that lower the tastiness of beer, but after thirst has been satisfied by drinking beer, gross taste, poor balance of tastes, unpleasant smell and others may be intensified. It is uncertain whether the delay of gastric emptying or lowering of taste was the cause or the result, but a vicious circle of the two must arise when a subject drinks beer with low drinkability.

The rate of urination was slow in the subjects given beer D. This delay may have been caused by delayed gastric emptying.

In conclusion, the relaxed cross-sectional area of the pylorus antrum measured by an ultrasonic echo-image analysis was in proportion to the gastric volume, and is considered to be a good indicator of stomach fullness. The relaxed cross-sectional area of the pylorus antrum measured after drinking various kinds of beer was highly correlated with the subjective evaluation of drinkability, and the beer that was rapidly emptied from the stomach and that gave mild stomach fullness was suggested to be highly drinkable.

References