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Relationships between air swallowing, intragastric air, belching and gastro-oesophageal reflux

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Abstract *Background: With each swallow a certain amount of air is transported to the stomach. The stomach protects itself against excessive distention by swallowed air through belching (gas reflux). The mechanism of belching (transient lower oesophageal sphincter relaxation) is also one of the mechanisms underlying gastro-oesophageal reflux.*
Aim: To investigate whether swallowing of air leads to an increase in size of the intragastric air bubble and to gastro-oesophageal reflux.
Methods: Multichannel intraluminal impedance measurement was used to quantify the incidence of swallowing of air in 20 healthy volunteers before and after a meal. Radiography was used to measure the size of the intragastric air bubble. Gastro-oesophageal reflux was assessed by concurrent impedance and pH measurement.
Results: The rate of air swallowing was correlated to the size of the intragastric air bubble postprandially and to the rate of gaseous gastro-oesophageal reflux. The number of air swallows and the size of the intragastric air bubble did not correlate with the number of liquid acid and non-acid reflux episodes.
Conclusions: In healthy subjects, air swallowing promotes belching but does not facilitate acid reflux.

Keywords *electrical impedance, gastro-oesophageal reflux, oesophageal motility, swallowing.*

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INTRODUCTION

Belching, the passage of gaseous material from the stomach to the mouth, is a physiological phenomenon. A study using ultra-fast computer tomography showed that with each liquid swallow a certain volume of air was ingested simultaneously.[1] Several studies have shown that distention of the proximal stomach induced by inflation with air triggers transient relaxations of the lower oesophageal sphincter (TLOSRs).[2–5] By means of these TLOSRs ingested air can be vented. It has been shown that TLOSRs are also the most important mechanism through which non-gaseous gastric contents can enter the oesophagus.[6,7]

The mechanisms enabling belching (gas reflux) are of particular interest since they bear great resemblance to the mechanisms underlying gastro-oesophageal reflux.[8] Almost 50% of patients with gastro-oesophageal reflux disease (GORD) complain of a certain degree of excessive belching[9] and belching is also common in patients with functional dyspepsia.[10]

Recently, multiple intraluminal electrical impedance monitoring was introduced as a novel technique for investigation of bolus transport in luminal organs.[11] This technique makes it possible to distinguish movements of even small volumes of gas through the oesophagus in oral and in aboral direction.[12] Using impedance monitoring we aimed to investigate whether swallowing of air leads to an increase in size of the intragastric air bubble and whether it promotes gastro-oesophageal reflux.

MATERIALS AND METHODS

Subjects

We studied 20 healthy volunteers (14 males and six females: mean age 28 years, range 19–46 years). Subjects were free of gastrointestinal symptoms and were not taking any medication. Written informed consent

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was obtained from all subjects and the protocol was approved by the Medical Ethics Committee of the University Medical Center Utrecht. This study was carried out according to the standards set by the declaration of Helsinki.

Validation study

In three healthy subjects determination of air swallowing was assessed on both fluoroscopy and impedance monitoring. This validation study was performed on another day as the other part of the study. After insertion of the impedance catheter, 10 20-mL swallows of a fluid barium suspension were monitored with concurrent fluoroscopy and impedance. Framing speed for fluoroscopic pictures was 10 s^{-1}. For each swallow, the amount of swallowed air was determined on the fluoroscopic picture using millimetre blocked paper. For this measurement, the picture was used that was taken when the bolus head reached the radio-opaque electrodes of impedance channel 5 on the impedance catheter (see below). On the impedance tracings, the maximum amplitude caused by the swallowed air was determined with respect to baseline impedance.

Study protocol

After an overnight fast radiographic images of the upper abdomen were obtained in anteroposterior and lateral direction with the subject in upright position (Fig. 1). Thereafter, routine oesophageal manometry was performed to determine the distance from the nostrils to the lower oesophageal sphincter (LOS). The impedance catheter and the pH catheter were introduced transnasally and positioned based on the manometric findings (see below). After an adaptation period of at least 10 min recording was started and subjects were asked to minimize head movements and to breathe normally. After 45 min of continuous recording the subjects took a standardized meal consisting of one hamburger (McDonald's Quarter Pounder), 20 g of fresh onions, 44 g of potato chips and 475 mL of orange juice (in total 967 kCal). This meal was used to provoke reflux in a previous study by our group.[13] The meal had to be finished in 30 min. Immediately after ingestion of the meal, recording was continued for another 90 min. Forty-five min after the meal radiographic images in anteroposterior and lateral position were obtained. Subjects remained seated for the duration of the study.

Impedance and pH monitoring

For impedance monitoring a 7-channel impedance catheter was used (Aachen University of Technology, FEMU, Aachen, Germany). This catheter (outer diameter 2.3 mm) enabled recording from seven segments, each recording segment being 2 cm long. The recording segments were located with electrodes at 0–2, 2–4, 4–6, 8–10, 10–12, 14–16 and 17–19 cm above the upper border of the manometrically localized LOS (Fig. 2). Impedance signals were stored in a digital system (Aachen University of Technology, FEMU) using a sample frequency of 1000 Hz. Intraluminal pH monitoring was performed with a catheter with a glass pH electrode (Ingold A.G., Urdorf, Switzerland) and data were stored in a digital datalogger (Orion, MMS, Enschede, The Netherlands) using a sampling frequency of 2 Hz. A cable connects the pH datalogger with the impedance datalogger. pH data are thus stored on both dataloggers and can be visualized together with the impedance tracings. The pH glass catheter was positioned 5 cm above the manometrically upper border of the LOS.

Data analysis

The size of the gastric air bubble projection was measured from the anteroposterior and lateral radiographic images using transparent millimetre blocked paper. The projection of the impedance catheter was used as a reference for actual size. Previously established criteria were used to identify swallows, gas reflux, liquid reflux and mixed gas–liquid reflux in the impedance signals.[14–16] We also identified air-containing swallows (air swallows) as swallows that were preceded by an impedance peak of more than 1000 Ω above baseline that was recognizable in the most distal impedance segment.[17] We chose a threshold of 1000 Ω because this was found to be well above the amplitude of baseline noise. Furthermore, using the pH tracings, liquid reflux, mixed gas–liquid reflux and gas reflux events were classified as acidic or non-acidic, using a threshold of $pH < 4$. Total acid reflux events and percentage of time with $pH < 4$ were also assessed. In

			10 min	45 min	30 min	45 min		45 min
X-ray	Manometry	Insertion pH and imp catheters	Adaptation	Recording	Meal	Recording	X-ray	Recording

Figure 1 Study protocol.

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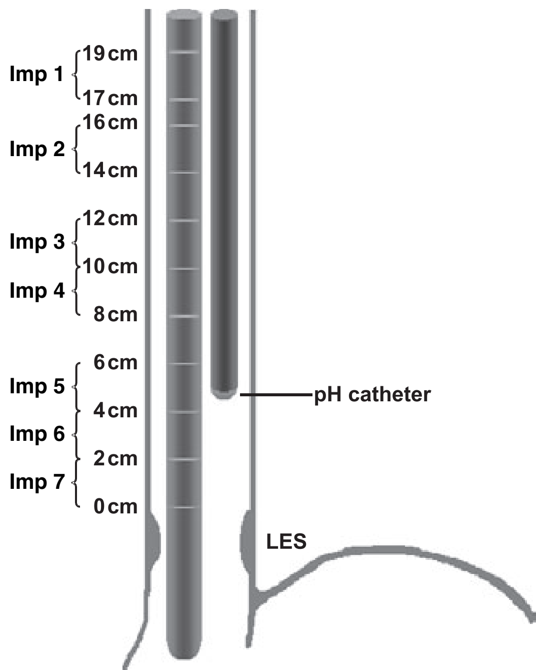

Figure 2 Schematic representation of positioning of the recording catheters. The impedance catheter included seven measuring segments. The numbers indicate the distance above the manometric upper border of the LOS. Impedance was measured between the electrodes at 0 and 2, 2 and 4, 4 and 6, 8 and 10, 10 and 12, 14 and 16, and 17 and 19 cm above the upper border of the LOS.

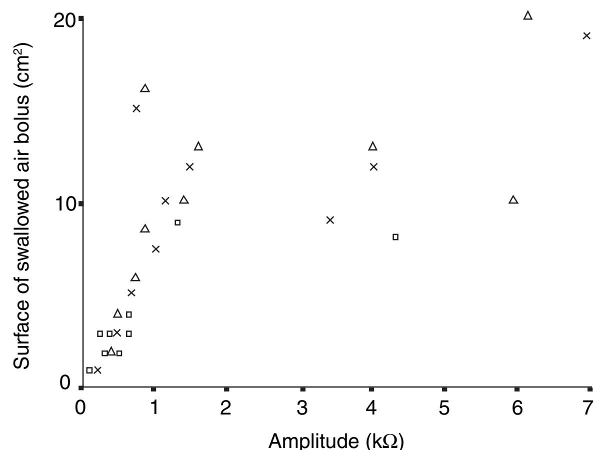

Figure 3 Relationship between the surface of swallowed air bolus determined with radiography and the peak in impedance caused by the passage of the bolus in the in the validation study. Different markers are used for the three healthy subjects.

the analysis, the period of meal consumption was disregarded.

Statistical analysis and presentation of data

Pearson's correlation coefficient was calculated to explore the relation between gastric air bubble size before and after the meal and the relation between gastric air bubble size in anteroposterior and lateral direction. Spearman's correlation calculations were performed for all other data. Repeated measures ANOVA and Friedman's test were used to perform comparisons for repeated measures of parametric and non-parametric data, respectively. Analysis of the data is performed on per subject values. Significance level was set to 0.05. Throughout the manuscript data are presented as mean ± SEM.

RESULTS

In the validation study a strong and statistically significant correlation ($P < 0.01$) was found between the amplitude of the air-induced increase in impedance on the tracings and the size of the swallowed air as assessed with fluoroscopy for each of the three subjects, with the Spearman correlation coefficients varying between 0.78 and 0.89 (Fig. 3). Often the air bolus moved in front of the barium but not infrequently a vertical air–fluid interface was observed in the distal oesophagus.

In the main study gastric air bubble size measured radiographically in anterior and lateral projection correlated extremely well, both before ($r = 0.978$, $P < 0.001$) and after the meal ($r = 0.856$, $P < 0.001$). No significant correlation was found between pre- and postprandial gastric bubble size in anterior ($r = 0.388$, $P = 0.124$) and lateral projections ($r = 0.351$, $P = 0.151$).

The hourly rate of swallows, air swallows, or gas reflux episodes did not differ significantly between the pre- and postprandial recording period. In contrast, the incidence of liquid and mixed reflux increased significantly immediately after the meal (Table 1). Postprandially, liquid and mixed reflux events were acidic in 66.7 and 49.2%, respectively, while gas reflux was never acidic (Fig. 4).

A statistically significant correlation was found between the number of air swallows and the number of gas reflux events, both before ($r = 0.40$, $P < 0.05$) and after ($r = 0.48$, $P < 0.05$, first 45 min, $r = 0.54$, $P < 0.05$, second 45 min) the meal (Fig. 5), whereas the total number of swallows did not correlate significantly with the occurrence of gas reflux events. Correlation of air swallowing with liquid or mixed reflux events was not statistically significant, nor was the correlation of air swallows with the time with pH < 4 or the total number of acid reflux events.

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Table 1 Gastric air bubble size, swallows, air swallows, and reflux parameters

	Preprandial period	First 45-min period postprandial	Second 45-min period postprandial	*P*-value
Gastric air bubble size AP (cm^2)	11.3 ± 1.4	12.0 ± 1.6		NS
Gastric air bubble size L (cm^2)	9.8 ± 3.5	11.0 ± 1.4		NS
Swallows (h^{-1})	79.4 ± 8.6	68.5 ± 5.5	62.1 ± 5.9	NS
Air swallows (h^{-1})	21.3 ± 3.7	26.1 ± 2.3	23.6 ± 3.5	NS
Liquid reflux events (h^{-1})	0.6 ± 0.6	2.1 ± 0.5	1.4 ± 0.4	≤0.05
Gas reflux events (h^{-1})	4.6 ± 1.0	3.4 ± 0.9	3.3 ± 0.4	NS
Mixed reflux events (h^{-1})	0.5 ± 0.2	3.9 ± 0.6	3.9 ± 0.4	≤0.05
Acid reflux events (h^{-1})	0.5 ± 0.1	3.0 ± 1.4	4.2 ± 1.2	≤0.05
% Time with pH < 4	0.8 ± 0.5	3.9 ± 1.4	8.1 ± 2.2	≤0.05

AP, anteroposterior; L, lateral projections.
Repeated measures ANOVA was used to perform comparisons for repeated measures of % of time with pH < 4, Friedman's test was used for comparison of all other data.

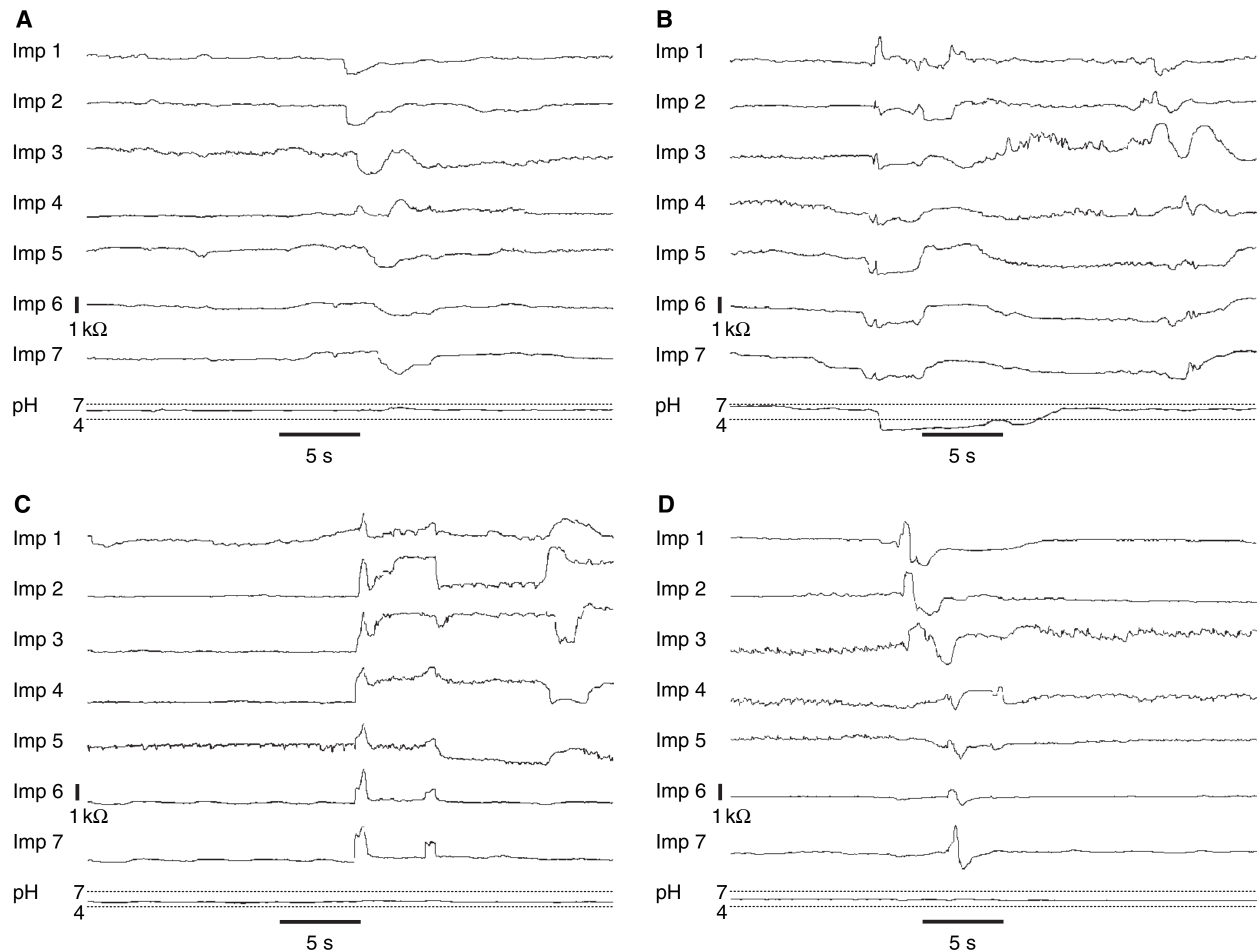

Figure 4 Oesophageal impedance and pH signals. (A) Regular dry swallow. The decrease in impedance during 'dry' swallows is most likely due to swallowed saliva (B) Mixed gas–liquid reflux. After the initial decrease in impedance, indicating liquid reflux, a rapid increase in impedance occurs. pH falls below 4. (C) Gas reflux without change in pH. (D) Air swallow. An increase in impedance followed by a decrease moving in aboral direction, representing air being pushed forward in front of a liquid bolus.

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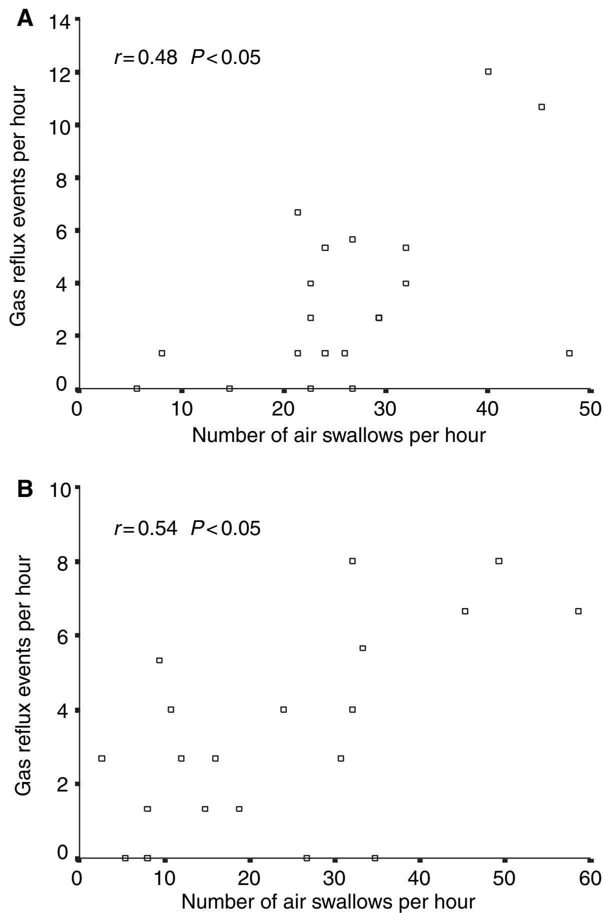

Figure 5 Relationship between frequency of air swallows and gas reflux events in the first 45 min after the meal (A) and the second 45 min after the meal (B).

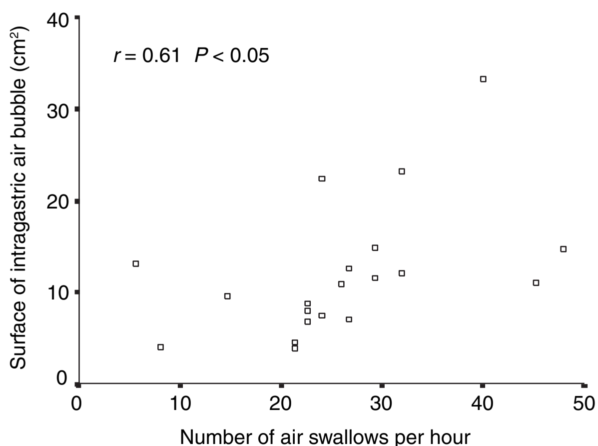

Figure 6 Relationship between frequency of air swallows in the first postprandial 45 min and surface of the intragastric air bubble on radiography after the meal.

Correlation between the number of air swallows after the meal in the period before the radiograph and the size of the postprandial gastric air bubble was significant for both anterior ($r = 0.61$, $P < 0.05$) (Fig. 6) and lateral projections ($r = 0.60$, $P < 0.05$) but correlation between the total number of swallows and postprandial gastric air bubble size was not. In addition, no significant correlation was found between the size of the gastric air bubble and the occurrence of reflux of any kind (gas, liquid or mixed). There was no relation between the size of the gastric air bubble and the time with pH < 4 or the total number of acid reflux episodes.

DISCUSSION

Previous studies have shown that the presence of a large volume of air in the proximal stomach triggers stretch receptors in the gastric cardia and leads to an increase in the rate of TLOSRs.[2,5,8,18,19] These TLOSRs are the most important mechanisms through which acidic gastro-oesophageal reflux can occur.[6,7] It was, therefore, hypothesized that an increase of intragastric air volume, for example after swallowing of air, would lead to acid reflux.[3,4] However, thus far the relation between swallowing of air, gastric air volume and acid reflux had remained uninvestigated.

Multiple intraluminal impedance monitoring makes it possible to detect transport of air and liquids in the oesophagus, both in oral and in aboral direction. Reflux of air and liquids and swallowing of liquids have already been investigated using impedance monitoring but this is the first study that uses impedance monitoring for the quantification of air swallowing. Our validation study shows that the increase in impedance that precedes the decrease in impedance caused by swallowed liquids is dependent on the amount of air swallowed and the correlation between impedance amplitude and size of the air swallow was better for smaller air swallows than for larger air swallows. We thus quantified air swallowing in this study using a threshold for the amplitude of air swallows of 1000 Ω above baseline impedance.

Thus far, swallowing of air was only studied using radiography and computerized tomography. The exposure of subjects to radiation restricts the duration of the period during which air swallowing is monitored with these techniques. We show that impedance is also capable of monitoring air swallowing. This will create opportunities to study air swallowing in conditions where swallowed gastric air is believed to play a role such as the gas-bloat syndrome after fundoplication, GORD and functional dyspepsia. In aerophagia, repetitive belching does not originate from regular air

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swallowing and gas reflux as described in this paper, but instead a different air transport pattern is seen as can be observed with impedance monitoring.[17]

With the use of impedance monitoring and radiography, we were able to show that the size of the gastric air bubble is related to the frequency with which air is swallowed. We also found a significant correlation between gas reflux and air swallowing. Air swallowing did not provoke reflux of liquid or mixed gas–liquid gastric contents in these healthy volunteers. Apparently venting decreases the volume of swallowed air in the gastric fundus, without affecting gastro-oesophageal sphincter continence for acid and non-acid liquids. A study in dogs showed that filling of the stomach with liquid leads to a distention of the cardia that is different from that resulting from filling of the stomach with both liquid and gas.[20] Perhaps the gastric receptors that are triggered by gaseous distention differ from those that are triggered by distention by liquid, resulting in the ability of the stomach to differentiate between gaseous and liquid filling and to react differently. The concept that intragastric air does not facilitate the reflux of liquids is supported by a study by Sifrim *et al.* showing that in mixed reflux events liquid often precedes gas reflux.[12] They furthermore observed that in only a minority of acid reflux episodes, gas occurred as the primary event. Their conclusion was that belching can precipitate acid reflux, but that most acid reflux occurs as a primary event. Another finding of our study was that after a meal both liquid and mixed reflux increased considerably, but gas reflux did not. This observation supports the hypothesis that gas and liquid reflux are provoked by different mechanisms.

In the current study no relation was found between the size of the gastric air bubble and the different reflux parameters, while other studies showed that distention of the stomach with a barostat balloon increases the rate of TLOSRs. It should be noted however, that although TLOSRs are the most important mechanisms by which reflux occurs, other mechanisms also play a role. Furthermore, not every TLOSR is followed by reflux. Another explanation for the seemingly discrepant results of our study as compared with the studies using barostat and manometry is that distention of the stomach with an balloon filled with air is quite a different stimulus than the physiological distention of the stomach by ingested air.

A possible limitation of this study is the short measurement period during which recordings were made. Impedance and pH were monitored during a short pre- and postprandial period. Twenty-four hour data would possible render more information. However, reproducibility of reflux monitoring with impedance monitoring of even a short postprandial period was found to be very acceptable and intra-subject variability was considered much smaller than inter-subject variability.[21]

The relations found in this study between postprandial air swallowing and gas reflux were statistically significant but not very strong with calculated r values of 0.480 and 0.539. The same can be said for the relation between air swallowing and the size of the gastric air bubble ($r = 0.611$ for anterior images and $r = 0.603$ for lateral images). In part, this can be attributed to the fact that the events air swallowing and gas reflux were scored as either present or absent, while volumes of air transport associated with air swallows and gas reflux episodes were not measured. Other factors such as duodenal gas escape may play a role. However, studies in normal subjects in whom gas was inflated into the stomach have shown that only moderate amounts of gas leave the stomach via the duodenum and most of the gas escapes by belching.[2,22] Our observation that a correlation between air swallowing and gastric air bubble size is absent before the meal but appears to be present postprandially suggests that in the fed state air escapes the stomach through the duodenum less easily and is stored in the fundus instead. It is known that a meal rich in lipids, as used in this study, slows intestinal gas transit and provokes gastric distention.[23,24]

It is important to stress that this study was performed in healthy subjects and that the conclusions drawn from it are, therefore, not necessarily applicable to patients with GORD. It would be most interesting to investigate whether the mechanisms that enable venting of gas without occurrence of acid reflux are preserved in patients with GORD. It has been shown that GORD patients have an abnormal intragastric distribution of acid after a meal.[25,26] It is possible that this abnormality compromises the competence of the stomach to vent gas without the occurrence of liquid reflux.

In conclusion, we showed that multiple intraluminal impedance monitoring is a useful tool to study gas transport in the human oesophagus. In healthy subjects, liquid and mixed gastro-oesophageal reflux events are largely related to feeding, but gas reflux is related to air swallowing. Swallowing of air and accumulation of air in the stomach do not lead to acid reflux in healthy volunteers.

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DISCLOSURE

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