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Pressure profile along the oesophagus during eructation in sheep

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Summary — The pressure profile along the oesophagus was recorded simultaneously with the flow rate of eructated gas in sheep to evaluate the oesophageal motor events leading to the relief of gas. All the eructation sequences started by a rise followed by a plateau of oesophageal pressure. The passage of gas at the tracheal level occurred during this plateau and not during the consecutive transient lowering of the oesophageal pressure. All eructation sequences ended by a peristaltic contraction of the oesophagus. The flow rate pattern of gas during eructation was affected by head position leading to different tensions of the oesophagus. We conclude that, despite the large volume of eructated gases, the eructation process is not significantly different in sheep compared to other animals. Therefore, by virtue of its unique physiological particularity, the sheep might be used as an experimental model for the evaluation of lower oesophageal sphincter (LOS) competence.

sheep / oesophagus / eructation / lower oesophageal sphincter

Résumé — Profil manométrique de l'œsophage au cours de l'éructation chez le mouton. *Le profil manométrique de l'œsophage et le débit des gaz éructés sont enregistrés simultanément chez le mouton afin d'évaluer les événements conduisant à la libération des gaz. Toutes les expulsions pharyngées de gaz sont précédées par une augmentation phasique puis tonique de la pression intra-œsophagienne Le passage des gaz au niveau de la trachée survient lorsque la pression intra-œsophagienne atteint un plateau et non après ce dernier, durant la chute transitoire de la pression œsophagienne. Toute les éructations se terminent par une contraction péristaltique de l'œsophage. Le débit aérien au cours de l'éructation dépend de la position de la tête qui modifie la tension de la paroi de l'œsophage. En conclusion, en dépit des importants volumes de gaz éructés, les événements conduisant à l'éructation chez le mouton ne diffèrent pas fondamentalement de ceux observés chez d'autres espèces animales.*

mouton / œsophage / éructation / sphincter œsophagien inférieur

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INTRODUCTION

Gastro-oesophageal reflux episodes occur in man most often during transient relaxation of the lower oesophageal sphincter (LOS) or when the basal pressure of the LOS does not differ significantly from intragastric pressure (Dent *et al,* 1988). The competence of the LOS to prevent reflux of gastric acidic chyme or gas into the oesophagus is clinically evaluated by measurement of its basal pressure (Patriokios *et al,* 1986; Mittal *et al,* 1990) whereas the flow of liquid and/or gas through the LOS is its true indicator. Gas flow was not used in clinical practice as an indicator of sphincter competence because it cannot be directly measured without altering the motor activity of the oesophagus.

In ruminant animals, due to the particularities of the eructative sequence (Dougherty *et al,* 1962), a simultaneous assessment of oesophageal pressure and gas flow rate is possible without inducing oesophageal motor disturbances. Gases produced by fermentative digestion of roughage do not escape directly into the atmosphere (Dougherty *et al,* 1962). Eructated gases enter the trachea at pressures equal to those occurring in the oesophagus during the expulsive phase of eructation as the glottis remains open during eructation (Ali and Singleton, 1979). Therefore, using a special X-shaped tracheal cannula (Stevens and Sellers, 1960), the eructated gas flow rate could be measured simultaneously with the pressure events occurring within the oesophagus (Arndorfer *et al,* 1977).

The purpose of this study was to evaluate the pressure flow relationships occurring within the oesophagus during eructation.

MATERIALS AND METHODS

Surgery

Tracheostomy was performed under general anaesthesia (pentobarbital sodium 20 mg.kg^{-1} IV) and aseptic conditions in order to insert a 10-cm long straight silicon cannula (ID = 1 cm) in 4 adult Romanov ewes (43 ± 4.3 kg) A ruminal cannula (ID = 1 cm) was fixed on the dorsal sac of the rumen to insufflate gas into the forestomach.

Recordings

Oesophageal pressure profile was monitored by a multiple perfused side-holes manometric assembly. The catheter assembly (ED = 4 mm, PVC made) consisted of a series of 5 side-holes and was inserted into the oesophagus through a nostril. The distances between the distal (gastric) tip of the assembly and the side-holes were: 0.5, 2, 4, 12 and 17 cm. The first side-hole in the manometric assembly was located in the stomach. The LOS was localized by a constant speed pull-through achieved by a motor retrieving the manometric assembly at 1 mm.s^{-1}. The catheter assembly was secured in recording position when the second side-hole sensed a basal pressure 5 mm Hg above the third, fourth and fifth one (Calleja *et al,* 1987). Catheters continuously perfused with degassed distilled water using a low compliance pneumo-hydraulic capillary infusion system (IP 8000, Gould) at a flow rate of 0.6 ml/min. The proximal end of each catheter was connected to a pressure transducer (Gould PX23). Pressure was continuously displayed on an electrostatic high frequency response recorder (ES 2000, Gould) and digitalized at 10 Hz frequency using a multiple channels A/D card (NB-MIO-16, National Instruments) plugged into a micro-computer (Macintosh II, Apple Computer). The data were continuously stored on hard drive for further analysis.

About 2 h before the beginning of the experiment, the straight cannula was replaced by an

X-shaped cannula through which animals could breathe and eructated gas could be collected separately (fig 1). The proximal end of this cannula was connected to a pneumotachograph (Lilly type, MediSoft) attached to a differential pressure transducer in order to obtain an analogic value of the flow rate. A microcontroller (SAB 80515, Siemens) calculated the eructated volume by measuring the area under the flow rate curve. Flow rate and eructated volume of gas were plotted and digitalized together with pressure signals.

Experimental procedure

Sheep were allowed to recover for 2 weeks after surgery. The tracheostomy was temporarily closed by a straight cannula during the interval between the experiments. The animals were fasted 12 h before the onset of the experiment which was repeated 4 times for each subject. During the experiment, forestomach insufflation was performed 3 times by nitrogen gas flowing at 1 $l.min^{-1}$ through the ruminal cannula. Nitrogen insufflation lasted 3 min and a rest period of 30 min was allowed between 2 consecutive insufflations. The catheter assembly was withdrawn during the rest period. Relationships between flow rate and oesophageal pressure were

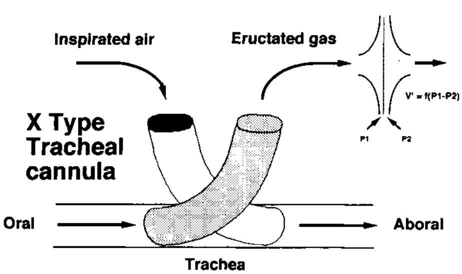

Fig 1. Experimental set-up showing the design of the tracheal X type cannula allowing simultaneous breathing and sampling of the eructated gas. The proximal end of the cannula is connected to a pneumatograph, an airflow measuring device based on the use of the Venturi principle. The flow of air is proportional to the pressure difference on both side of a capillary grid which induces a small resistance.

assessed under 2 different experimental conditions depending on the position of the head relative to the neck: normal position, *ie* an angle of about 30° between the head and the neck; fully extended position, *ie* an angle of less than 10° between the head and the neck.

Data analysis

Duration and velocity of pressure waves were calculated off-line with the eructated volume of gas and the maximal peak flow rate. All data are presented as mean ± SE.

RESULTS

The volume of gas evacuated during each eructation sequence ranged from 75 to 480 ml. The average volume was 255 ml and the flow rate 267 $ml.s^{-1}$. When the head was in a normal position, the passage of gas through the pneumotachograph occurred in a single bolus manner without any blackflow (fig 2). The flow rate of gas rapidly reached a plateau which lasted for 1.9 ± 0.3 s. When the head was in a fully extended position, numerous (4–10) passages of gas through the pneumotachograph were detected during a single eructation sequence (fig 3). The shape of these passages of gas was triangular and each single bolus last for 0.14 ± 0.03 s. The volume of eructated gas per bolus was 6.5 ± 2.32 ml.

Irrespective of head position, gas evacuation was consistently preceded by a rapid increase in basal pressure. This pressure increase amounted to 312% in the upper and to 576% in the lower oesophagus with the head in the normal position (table I). The increase in pressure was first observed at the distal end of the oesophagus and moved in retrograde manner towards the proximal oesophageal body. The gradual shift of baseline lasted about

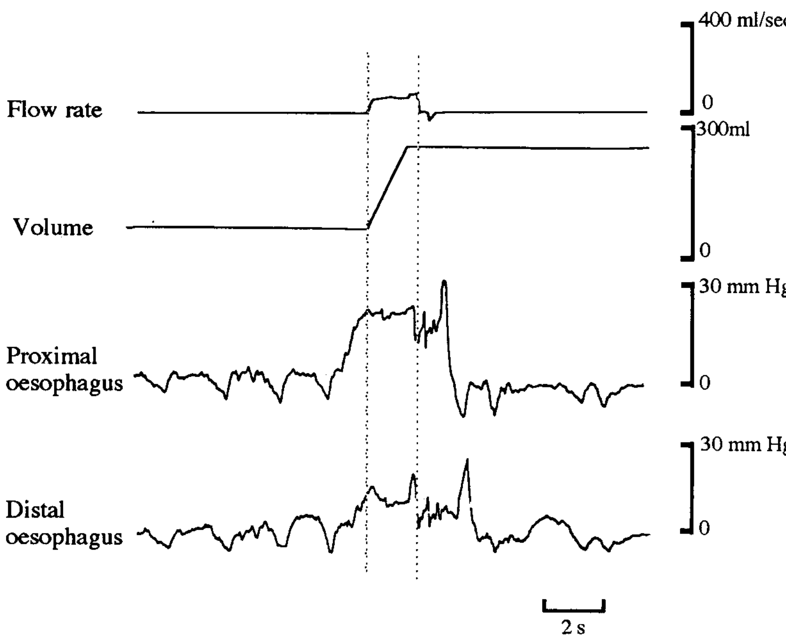

Fig 2. Oesophageal motor events associated with eructation and simultaneous assessment of the flow rate and volume of the eructated gas. The volume of gas expelled during each eructation sequence is calculated from the area under the curve; the volume trace is cumulative. The vertical greyish lines show the onset and the end of the eructation. The angle between the head and the neck was about 30°.

1 s and was followed by a pressure plateau for 1.9 ± 0.2 s which moved orally at 146 ± 37.5 cm.s^{-1}. The passage of gas through the pneumotachograph occurred during the pressure plateau. When the flow rate was again nullified, a slight decrease (3 ± 1 mmHg) in oesophageal pressure was observed. A peristaltic oesophageal pressure wave moving caudally was consistently observed after the eructation sequence (table II). Immediately before the pressure plateau, thirty percent of the eructation sequences (105/350) showed a decrease in pressure in the proximal oesophagus. These periods of low oesophageal pressure were multiple, corresponding to numerous passages of gas when the head was in a fully extended position (fig 3). Conversely, a single decrease in oesophageal pressure was noticed with the head in the normal position.

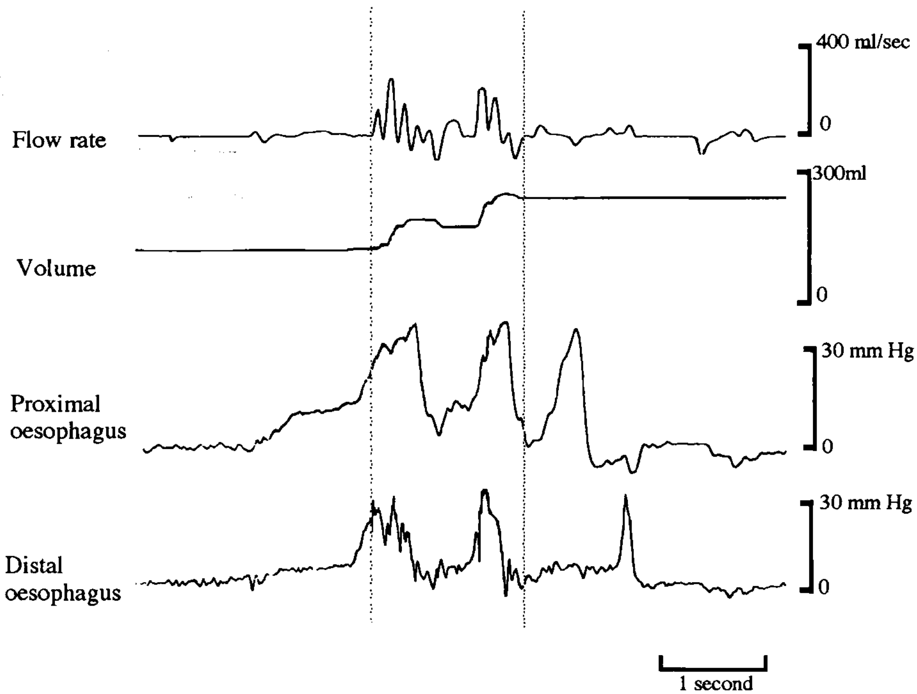

Fig 3. Oesophageal motor events associated with eructation and simultaneous assessment of the flow rate and volume of the eructated gas. The angle between the head and the neck was about 10°. Note the pulsatile type of the eructation process which occurred in successive flow pulses rather than single bolus of gas.

Table I. Pressure profile of the oesophagus during eructation in sheep.

Pressure (cm Hg)	*LOS (15 cm)*	*LOS (10 cm)*	*LOS (2 cm)*
Basal pressure	–0.4 ± 0.35	– 0.1 ± 0.30	1.4 ± 0.37
Filling pressure	1.0 ± 0.26	0.8 ± 0.25	2.1 ± 0.27
Clearing pressure	2.3 ± 0.46	2.5 ± 0.62	4.2 ± 0.78

Mean ± SE of the mean (n = 15 eructative sequences). Basal pressure refers to the mean oesophageal pressure in the absence of phasic motor event (end insipiratory phase). Filling pressure represents the value of the pressure plateau which occurs immediately before eructation. Clearing pressure corresponds to the peristaltic wave which occurs after eructation. Measurement was made with the head of the subjects in a normal position.

Tableau II. Duration, amplitude, and speed of sequential activation of pressure waves at 10 cm above the LOS.

	Duration (s)	*Amplitude (cm Hg)*	*Sequential activation speed (cm.s^{-1})*
Retrograde	4.0 ± 0.23	1.3 ± 0.02	146.5 ± 37.58
Anterograde	0.8 ± 0.20	2.7 ± 0.52	33.2 ± 1.64

Mean + SE of the mean (*n* = 34 eructative sequences). Retrograde refers to the filling pressure plateau and anterograde to the clearing pressure wave.

DISCUSSION

Manometry of the oesophagus showed that eructation in sheep was associated with a complex sequence of motor events. They were characterized by: i), before relief of gas, a rise in basal pressure which moved cranially and was followed by a pressure plateau; ii), after the relief of gas, a high amplitude pressure event which was propagated caudally.

Most of the studies performed to evaluate the manometric profile of the sheep oesophagus have been carried out using either balloon probes (Dougherty *et al*, 1962) or perfused high compliance catheters (Carr *et al*, 1979, 1983). These systems are known to underestimate the amplitude and to overestimate the duration of pressure wave (Calleja *et al*, 1987). The need for low compliance perfusion pumps designed specifically for manometry has been well demonstrated (Arndorfer *et al*, 1977). Continuous recording of intraluminal oesophageal pressure by a low compliance side-hole manometric assembly perfusion system shows that the pressure events related to eructation did not differ significantly from those recorded in man or in dog during gaseous distension of the stomach (Patriokios *et al*, 1986; Dent *et al*, 1988). The major difference was the amplitude of the pressure plateau which was almost similar to that of the caudally propagated peristaltic wave, whereas in man the amplitude of the pressure plateau was about 1/10 that of the caudally propagated peristaltic wave (Dent *et al*, 1988; Holloway *et al*, 1989).

The pressure events occurring in a retrograde manner and followed by eructation have been interpreted by former authors (Dougherty *et al*, 1962, 1971; Heywood and Wood, 1985) as an aborally propagated contraction of the oesophagus. This interpretation is unlikely because of the quasi-immediate pressure rise occurring alongside the oesophagus and the decrease in pressure recorded simultaneously within the entire oesophagus when a bolus of gas was relieved. Therefore, it could be suspected that the increase of oesophageal pressure preceding the pharyngeal expulsion of gas was similar to the so-called "common cavity" phenomenon described in dogs (Patriokios *et al*, 1986) and humans (Mittal *et al*, 1990) and was not related to oesophageal muscle contraction. However, because the method used can only accurately record lumen occlusive wall motion, non-occlusive wall motion of the oesophagus might occur during the expulsive phase of eructation. The functional efficacy of such non occlusive wall motion is, however, limited (Brasseur and Dodds, 1991).

A striking feature of this study was the change in the pattern of flow rate of eructated gas depending on the relative position of the head and the neck. When the angle formed by the head and the neck was widely open, eructated gas flowed down to the lungs in successive flow pulses rather than the hitherto accepted notion of a single bolus of gas. Because gas flow pattern was altered only by changes in head position, it might be that the higher tension exerted on the oesophagus and the resulting lower compliance would lead to a multiple flow pulses rather than an ejection of a single bolus of gas.

In conclusion, the manometric pattern involved in eructation did not differ in sheep compared to other non-ruminant species. Due to its unique physiological particularity, *ie* passage of eructated gas through the airway, the sheep might be a valuable animal model for analyzing the relation between the flow rate of gas and the relaxation of the lower oesophageal sphincter area.

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