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The diaphragm as an anti-reflux barrier

A manometric, oesophagoscopic, and transmucosal potential study

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An infusion technique was used to measure pressures at the lower end of the oesophagus in normal patients and in those with hiatus hernia. These studies show a band of raised pressure at the lower end of the oesophagus in normal patients. This band was abnormally long in the majority of patients with hiatus hernia, but in others it resolved into two bands, particularly in patients with hiatus hernia and a short oesophagus.

When the distance between these two bands was compared with the length of the oesophagogastric junction above the hiatus radiologically and at oesophagoscopy, a significant correlation was found.

It, therefore, is postulated that one of these bands is produced by the inferior oesophageal sphincter and the other by the diaphragm, and thus it is demonstrated that the diaphragm must be included among the factors controlling reflux.

In the majority of instances, peptic oesophagitis is caused by reflux of acid from the stomach through an incompetent closing mechanism at the lower end of the oesophagus. The pressure in the stomach is always higher than in the oesophagus, and in certain manoeuvres this may further increase enormously, thus facilitating acid regurgitation (Dornhorst, Harrison, and Pierce, 1954; Atkinson *et al.*, 1961).

Many authors stress the importance of such factors as the inferior oesophageal sphincter, the intra-abdominal oesophageal segment, and the angle of entry of the oesophagus into the stomach, but it would appear that the diaphragmatic muscle is not accepted as having any influence on the control of reflux from the stomach to the oesophagus. Recent pressure studies of the lower end of the oesophagus have also failed to demonstrate the influence of the diaphragm (Dornhorst *et al.*, 1954; Fyke, Code, and Schlegel, 1956; Atkinson, Edwards, Honour, and Rowlands, 1957; Code, Kelley, Schlegel, and Olsen, 1962; Maclaurin, 1963; deNiord and Harris, 1967). The present study was carried out with constantly perfused catheters (Pope, 1967; Winans and Harris, 1967; Woodward, 1970) to determine if this technique helps in the greater appreciation of the factors involved in the control of gastric reflux and to establish the functional effect of the crural muscle of the diaphragm.

MATERIAL AND METHODS

Studies were carried out on 112 consecutive patients with symptomatic hiatus hernia. Of this total 73 were of the simple type and 39 had peptic structure in addition. Eleven people who had no radiological nor manometric evidence of hiatus hernia were included as controls. Of the above patients with hiatus hernia, 31 form a special group. These patients had a short oesophagus with permanent separation of the oesophagogastric junction from the hiatus. The findings in this group allowed a special study to be made of the separate pressure recordings at the hiatus and at the oesophagogastric junction. To record further the length of herniation (that is, the distance of the oesophagogastric junction above the hiatus) the radiographs of 27 patients were reviewed.

OESOPHAGEAL MOTILITY The study was carried out as previously described by Woodward (1970) with the patients supine. Intraluminal pressures were recorded from two polyvinyl open-tipped catheters (i.d. 1·4 mm) with openings 5 cm apart. The tubes were continuously perfused with water by a pump at the rate of 7 μl/sec. The catheters were first passed into the stomach and then were withdrawn 1 cm every 6 seconds approximately, while recording was continuous. In this way the resting pressure at the hiatus and oesophagogastric junction was recorded.

MEASUREMENT OF TRANSMUCOSAL POTENTIAL Simultaneous recordings of transmucosal potential were also made during the motility studies as described by

Helm, Schlegel, Code, and Summerskill (1965). The exploring electrode consisted of a catheter identical with the pressure-recording catheters. The electrode was filled with freshly prepared 3·5 molar KCl solution and was connected to a mercury half-cell. The reference electrode was similarly filled with 3·5 molar KCl solution and attached to the forearm. The potential difference across the two half-cells was then measured by a vibron electrometer (E.I.L. model 33B) and recorded. Normally the potential difference in the lumen of the stomach is negative and in the oesophagus it is positive. When an electrode traverses from the stomach into the oesophagus there is a sudden change in the polarity of the potential difference at the site of the oesophagogastric junction, and the transmucosal potential recordings thus help in siting this important junction.

OESOPHAGOSCOPY This was carried out as part of the routine assessment of hiatus hernia. Visualization of the oesophagus is a valuable method of investigation in assessing oesophagitis and in the evalution of symptoms of hiatus hernia, particularly when they are bizarre and atypical. The level of the oesophagogastric junction above the hiatus can also be measured. At oesophagoscopy the oesophagogastric junction was identified and its distance was measured from the lower incisor teeth. The distance to the diaphragmatic hiatus was taken as being the same as the distance from the tip of the xiphoid process to the lower incisor teeth with the head extended. This measurement has been made regularly at every oesophagoscopy for many years in this department by Professor Collis and has been found to be reliable. In order to check this, 22 patients with hiatus hernia were selected randomly to compare the levels produced at oesophagoscopy with those found using manometry.

DEFINITION OF TERMS USED IN THIS STUDY

CARDIA This is the anatomical junction between the lower end of the oesophagus and the stomach. It is generally presumed that at this anatomical junction the inferior oesophageal sphincter ends and gastric muscle begins, and also the squamous lining of the oesophagus changes to glandular epithelium of the stomach. There is considerable variation between individuals in the point at which mucosa and muscle change in their character. As a result of this statement it will be appreciated that the term 'cardia' is less exact in its meaning than the terms 'oesophagogastric junction' and 'inferior oesophageal sphincter'.

INFERIOR OESOPHAGEAL SPHINCTER This is a physiological term used to define a band of high pressure zone interposed between the oesophagus and the stomach and it usually lies at the cardia. It is a manometric term with no anatomical basis.

OESOPHAGOGASTRIC JUNCTION This is the junction where the squamous epithelium changes to cuboid epithelium. This usually occurs at the level of the cardia. In this study it was identified by transmucosal potential change and visually at oesophagoscopy.

POINT OF RESPIRATORY REVERSAL This is the point in manometric studies where positive pressure in the abdomen changes to negative thoracic pressure. This change from the dominance of the abdominal pressure to thoracic pressure ordinarily occurs at the diaphragm provided the hiatus is normal. In patients with hiatus hernia the point of respiratory reversal may not always synchronize with the position of the hiatus.

CRURAL PRESSURE BAND This is also a manometric term introduced in this paper to define a zone of elevated pressure found for a distance of 2–3 cm overlapping the inferior oesophageal sphincter in normal people. This overlapping makes identification difficult; certain conditions exist which will be demonstrated in this paper when the zones are separate.

The point of respiratory reversal is present at the upper end of this pressure band in normal people. The crural pressure band differs from the point of respiratory reversal because it has certain dimensions. The presence of a crural pressure band identifies the diaphragmatic hiatus with greater consistency than the point of respiratory reversal because in patients with hiatus hernia the point of respiratory reversal may not always synchronize. The term 'crural pressure band' is used in this paper instead of diaphragmatic pressure band to stress that the inferences are based on intraluminal pressure studies. It is assumed that the pressure exerted by the diaphragmatic crus over the oesophagogastric junction is through the contraction of the anatomical diaphragm. In these studies the crural pressure band could not be demonstrated in all patients with hiatus hernia, due to the wide and patulous hiatus. The possibility that the technique may not be sufficiently sensitive is remote.

RESULTS

HIATUS HERNIA AND SHORT OESOPHAGUS (Table 1) The catheters were withdrawn from the stomach through the hiatus into the oesophagus. Of 112 consecutive patients with hiatus hernia, 81 showed

an abnormally long band of raised pressure at the lower end of the oesophagus but in 31 patients this had resolved into two bands. These patients were studied in detail.

TABLE I

MEAN VALUES OF 31 PATIENTS WHO SHOWED 2 PRESSURE BANDS BECAUSE OF SEPARATION OF THE INFERIOR OESOPHAGEAL SPHINCTER FROM THE DIAPHRAGMATIC HIATUS

	Mean	SD
Diaphragm		
Inspiration (mmHg)	20	10·2
Expiration (mmHg)	4	5·1
Length (cm)	1·8	0·08
Mean length between two bands of raised pressure (distance of oesophagogastric junction above hiatus) (cm)	3	0·08
Inferior oesophageal sphincter		
Inspiration (mmHg)	5·6	7·2
Expiration (mmHg)	10·3	8·1
Length (cm)	1·2	0·07

The hiatus In this group of 31 patients, as the catheter tip was being withdrawn from the stomach into the herniated sac, a band of increased pressure was noticed at the level of the hiatus in the pressure record. The increase in pressure was more marked in the inspiratory phase than in the expiratory phase. This band of raised pressure finally disappeared when the catheter tip was withdrawn into the herniated sac. The proximal end of this band was usually associated with the point of change in the direction of the respiratory movement in the pressure record. Measurement of the transmucosal potential showed slight variations at the hiatus. It recorded a less negative stomach potential difference at the end of inspiration than at the end of expiration. This variation disappeared as the exploring electrode entered into the herniated sac in the chest (Fig. 1).

The mean length of the band of raised pressure was 1·8 cm (SD 0·08), the mean end-inspiratory pressure excess was 20 mmHg (SD 10·2), and the mean end-expiratory pressure excess was 4 mmHg (SD 5·1). However, there was no such end-expiratory pressure excess in 13 patients.

The herniated stomach In the pressure records of the same 31 patients this was identified as the distance between the two high pressure bands. The resting pressure in the herniated sac was

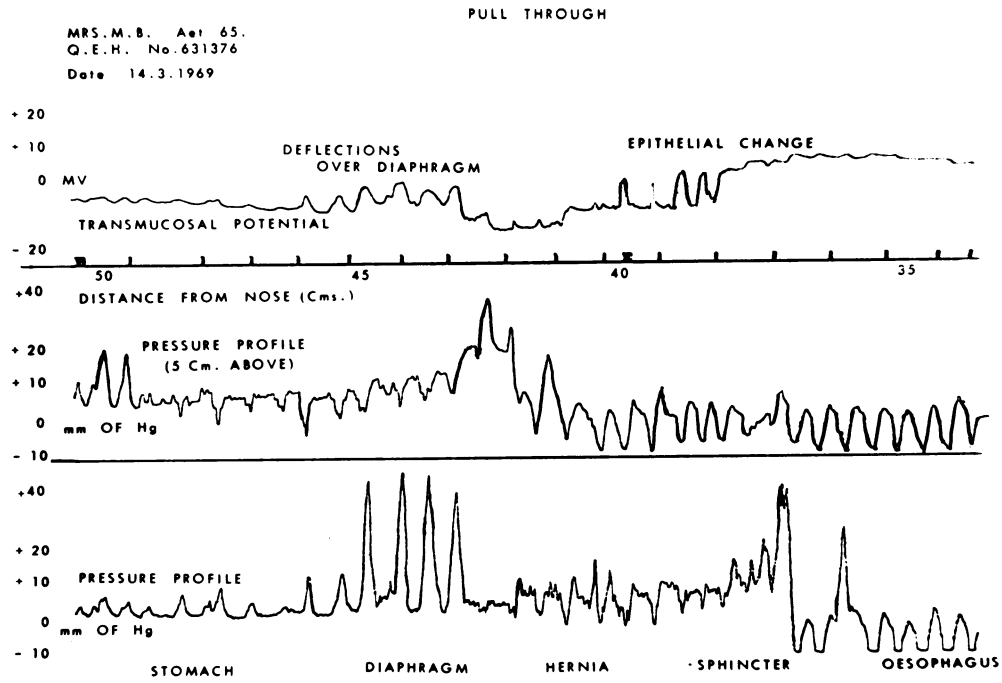


FIG. 1. *Resting pressure profile in a patient with hiatus hernia. Note the separation of the sphincter from the diaphragm. Note also the respiratory deflections over the recording of transmucosal potential.*

oesophageal in 26 patients, and in the others it was gastric. The transmucosal potential recorded negative gastric potential at this level. Measurement of the mean length of the herniated sac (the distance between the two bands) was 3 cm (SD 0·08).

Oesophagogastric junction and inferior oesophageal sphincter When the catheters were withdrawn from the herniated stomach into the oesophagus, a second band of raised pressure was noticed. This band had all the characteristics of the inferior oesophageal sphincter. The excess pressure in the band varied considerably from patient to patient. It was marginally raised in four patients; in two of these the fall in pressure with swallowing (relaxation) was 40%.

Measurement of the transmucosal potential showed the oesophagogastric junction at the same level as the sphincter in 25 patients. In the remaining six patients the junction was slightly proximal, which is normal. The mean length of this band of raised pressure was 1·2 cm (SD 0·07), the mean end-inspiratory pressure excess was 5·6 mmHg (SD 7·2), and the mean end-expiratory pressure excess was 10·3 mmHg (SD 8·1).

NORMALS (Fig. 2) Oesophageal pressure and transmucosal potential studies in normal people showed a band of raised pressure between the oesophagus and the stomach at the hiatus. Close study of the characteristics of the band of raised pressure showed that it had prominent inspiratory deflections at its distal end, and its proximal end was marked by elevation of the baseline. This means that this single band was in fact the sum of two bands—the sphincteric and the crural bands. The sphincteric band was identified as the length from the beginning to the end of the fall in pressure with swallowing (Kelley, Wilbur, Schlegel, and Code, 1960). To identify and to measure the length of the crural high pressure band, two criteria were used:

(*a*) the length over which the respiratory deflections were prominent and over which they could be increased by the patient's voluntary inspiratory efforts; and

(*b*) the length over which there was an absence

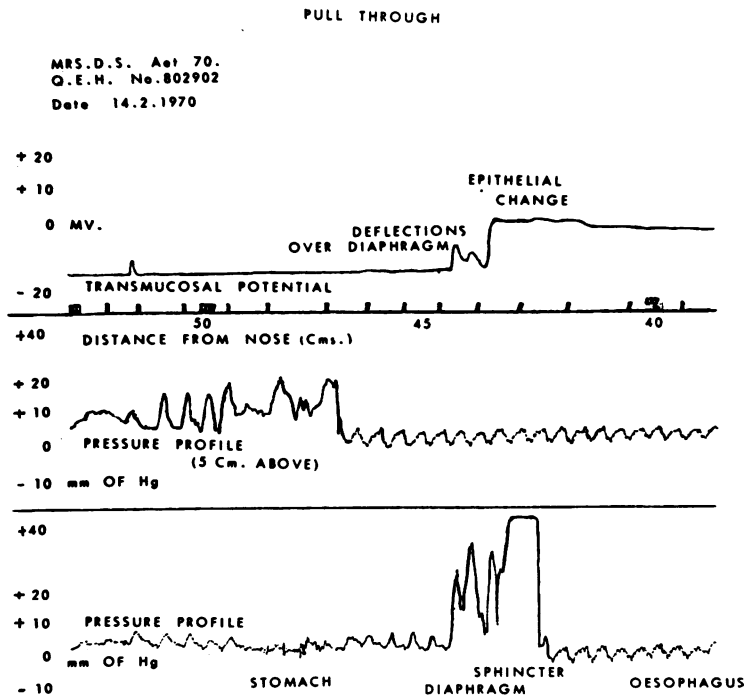


FIG. 2. *Resting pressure profile in a normal patient. Note a single high pressure zone made up of diaphragm and sphincter. Respiratory reversal was at the proximal end of the sphincter. Compare the resting pressures of the sphincter in both panels. The differences are due to variation in the tone of the sphincter.*

of fall in pressure (relaxation) ahead of a peristaltic wave.

Using the above criteria for measurement, the mean end-inspiratory crural pressure excess was 23·3 (SD 7·3) mmHg, the mean end-expiratory crural pressure excess was 6·0 (SD 3·3) mmHg, and the mean length of the crural pressure band was 1·9 (SD 0·36) cm. The mean end-inspiratory pressure excess at the sphincteric segment of the band was 21·8 (SD 9·1) mmHg, the mean end-expiratory pressure excess was 9·5 (SD 6·6) mmHg, and the mean length of the sphincter was 1·9 (SD 0·09) cm. The total band of the raised pressure produced by both the sphincter and crura was 3·5 (SD 3) cm (Table II).

TABLE II

MEAN VALUES OF 11 VOLUNTEERS (CONTROLS)

	Mean	SD
Mean total length of band of high pressure in normals (cm)	3·5	3·0
Diaphragm		
Inspiration (mmHg)	23·3	7·3
Expiration (mmHg)	6	3·3
Length (cm)	1·9	0·36
Inferior oesophageal sphincter		
Inspiration (mmHg)	21·8	9·1
Expiration (mmHg)	9·5	6·6
Length (cm)	1·9	0·09

MANOMETRIC DETAILS OF REMAINING HIATUS HERNIA PATIENTS (81 patients) (Figs 3, 4, and 5; Tables III and IV).

The diaphragm Using the criteria described, the crural pressure could be demonstrated in 26 patients. In eight patients the crural pressure was weak. In 47 patients no crural effect could be seen on the pressure tracing.

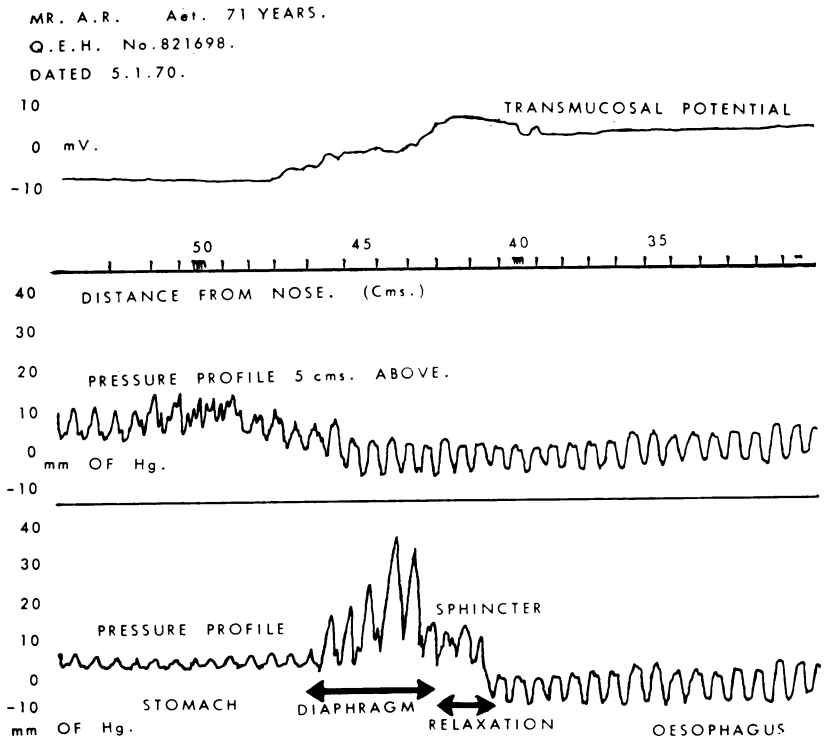


FIG. 3. *Patient with hiatus hernia, short oesophagus, and peptic stricture showing resolution of the band of raised pressure. Note the transmucosal potential change occurring at the proximal band of raised pressure (sphincteric band). As expected, the pressure in this band fell when patient swallowed.*

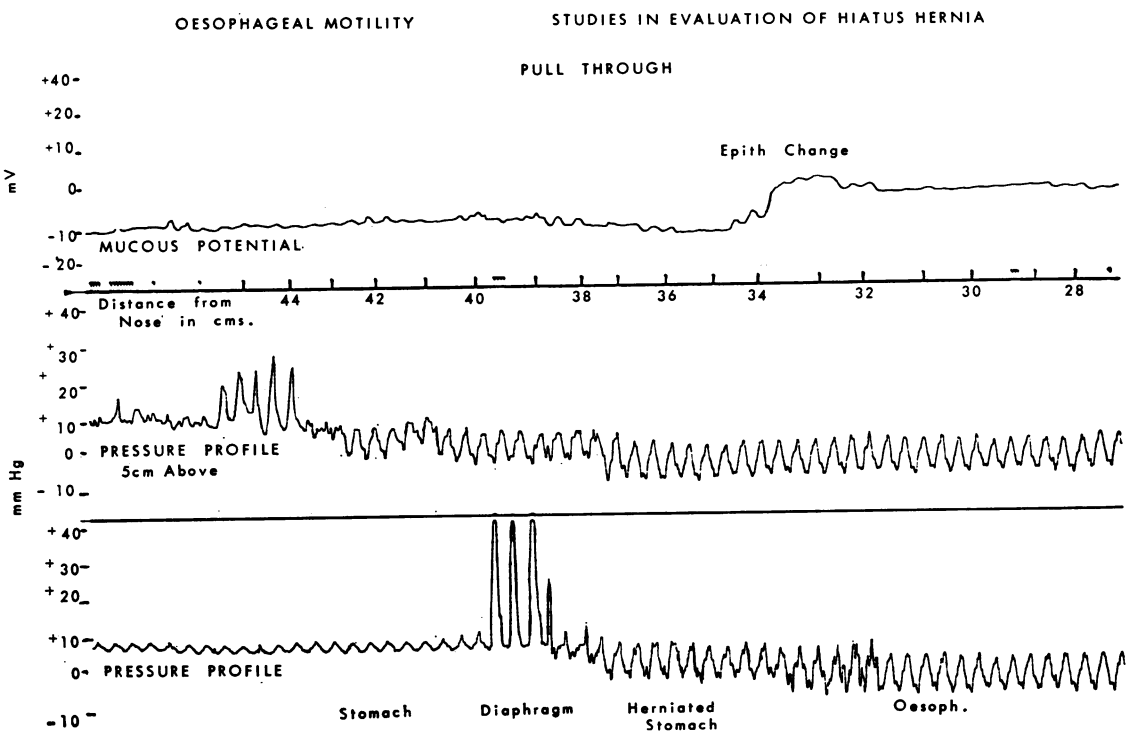


FIG. 4. *Patient with hiatus hernia, short oesophagus, and peptic stricture. Note the absence of sphincteric raised pressure band. The transmucosal potential study helped in the identification of the oesophagogastric junction which was at* 34 *cm. Note also the prominent diaphragmatic effect at the hiatus. Assessment of gastro-oesophageal reflux showed only moderate reflux.*

TABLE III

DETAILS OF ANTI-REFLUX BARRIER IN HIATUS HERNIA PATIENTS SHOWING ONLY ONE PRESSURE BAND

Diaphragm	Present	26
	Absent	47
Sphincter	Present	25
	Absent	57

TABLE IV

MEAN PRESSURES OF PATIENTS SHOWN IN TABLE III

	Mean	SD
Diaphragm (n=26)		
Mean inspiratory pressure (mmHg)	21·0	6·3
Mean expiratory pressure (mmHg)	4·2	4·3
Mean length (cm)	1·9	0·6
Sphincter (n=25)		
Mean inspiratory pressure (mmHg)	18·32	8·0
Mean expiratory pressure (mmHg)..	9·92	3·2
Mean length (cm)	1·76	0·6

(n=number of patients)

In 26 patients who had crural pressure at the hiatus, the mean end-inspiratory pressure excess was 21·1 mmHg (SD 6·3) and the mean end-expiratory pressure excess was 4·2 mmHg (SD 4·3). The length over which the crura were acting was 1·9 cm (SD 0·6). All these figures were not significantly different from the previous group.

Inferior oesophageal sphincter The inferior oesophageal sphincter recorded normal pressure in 25 patients. In five patients it was weak (less than 4 mmHg). In 51 patients the sphincter was non-existent. In 19 patients crural and sphincteric pressures were both present. The demarcation between these two pressure bands was not distinct because the separation of these previous bands was less than 2 cm. In 15 patients the crural pressure band was present and the sphincteric band was absent. On the other hand, 11 patients had a sphincteric but not crural pressure band. A total absence of anti-reflux barrier, either crural or sphincteric, was seen in 36 patients in this series.

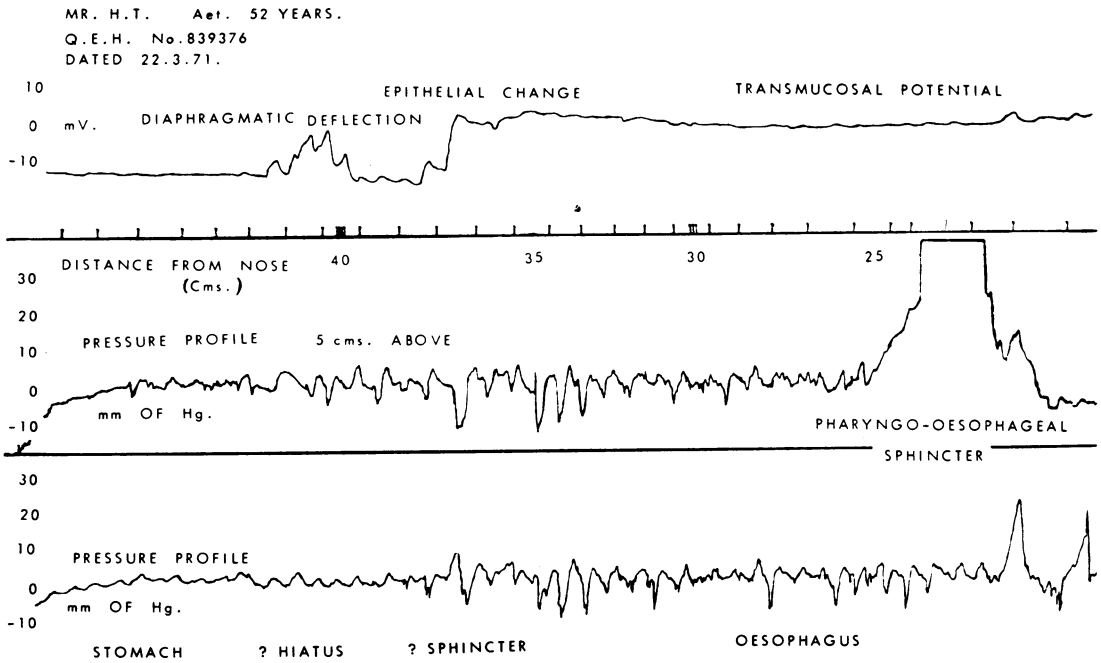


FIG. 5. *Patient with hiatus hernia and short oesophagus. No band of raised pressure could be demonstrated at the lower end of the oesophagus or at the hiatus. Identification of the level of the inferior oesophageal sphincter and the diaphragmatic hiatus would have been difficult in this tracing without simultaneous measurement of the transmucosal potential difference.*

Note the point of respiratory reversal occurring at the estimated level of the sphincter and not at the diaphragmatic hiatus. Note also the abnormally high pressure at the pharyngo-oesophageal sphincter in the right side of the middle panel. Radiological examination confirmed that the neck of the diaphragmatic hiatus was wide, and this explains the point of respiratory reversal at the displaced oesophagogastric junction rather than at the diaphragmatic hiatus. The abnormal tone in the pharyngo-oesophageal sphincter in hiatus hernia patients is also well known.

SUMMARY OF CORRELATIVE STUDIES

Between manometry and radiology (Table V) The mean displacement of the oesophagogastric junction upwards from the hiatus, as studied radiologically in 27 patients with hiatus hernia and short oesophagus, was 5·35 (SD 1·73) cm and the mean length as assessed by manometry (the distance between the two bands) was 3·8 (SD 1·51) cm ; this was highly significant ($r=0·8839$; $P<0·001$).

Between manometry and oesophagoscopy (Table VI) The mean distance of the oesophagogastric

TABLE V

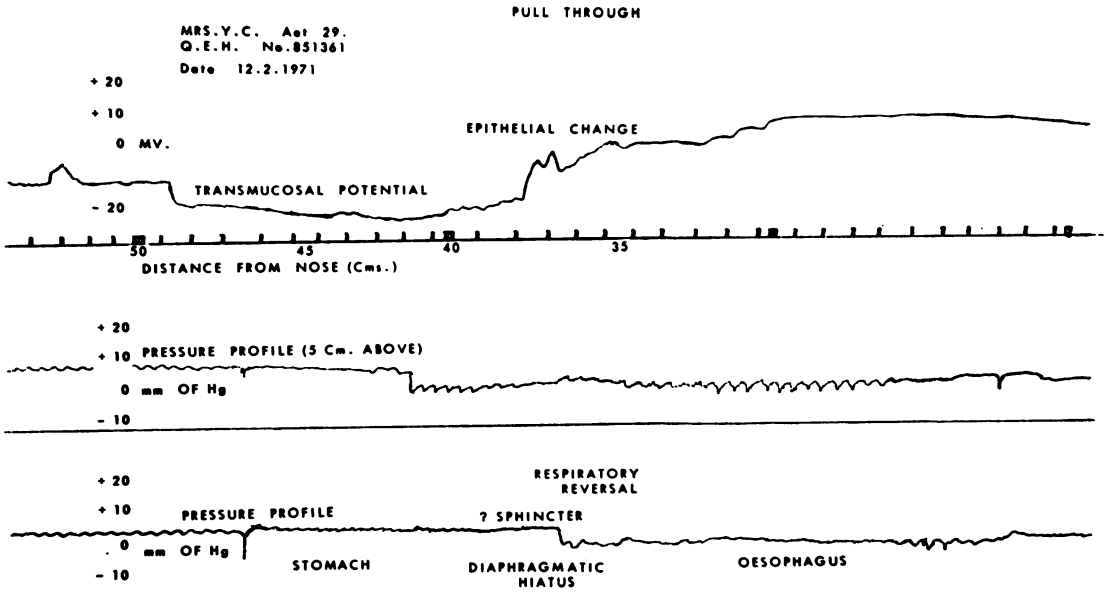
CORRELATION BETWEEN MANOMETRIC AND RADIOLOGICAL MEASUREMENTS IN 27 PATIENTS WITH HIATUS HERNIA AND SHORT OESOPHAGUS

Distance of Oesophagogastric Junction above Hiatus	Mean	SD	Significance
Radiological (cm)	5·35	1·73	$r=0·8839$;
Manometric (cm)	3·8	1·51	$P<0·001$

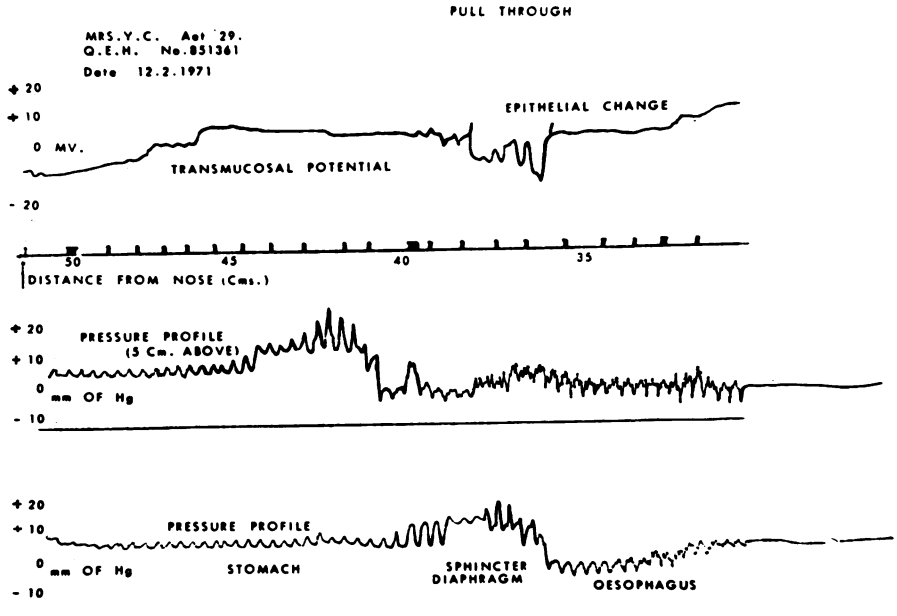
TABLE VI

CORRELATION OF MANOMETRIC FINDINGS WITH OESOPHAGOSCOPIC FINDINGS IN A RANDOM SELECTION OF 22 PATIENTS (n=22)

	Mean (cm)	SD	Significance of Correlation
Distance of oesophagogastric junction (cm)			
Oesophagoscopy (from lower incisor)	37	2·97	$r=0·6012$;
Manometry (from external nares)	41·8	3·27	$0·01>P>0·001$
Distance of the hiatus (cm)			
Oesophagoscopy (from lower incisor teeth to tip of xiphoid process)	39·9	2·67	$r=0·5015$;
Manometry (from external nares to point of respiratory reversal)	44·7	3·20	$0·02>P>0·01$
Estimated length of oesophagogastric junction above diaphragmatic hiatus (cm)			
Oesophagoscopy (oesophagogastric junction above xiphoid)	2·6	2·21	$r=0·8527$;
Manometry (oesophagogastric junction above point of respiratory reversal) ..	2·5	1·97	$P<0·001$



(*a*)



(*b*)

FIG. 6. (*a*) *Resting pressure profile in a patient with hiatus hernia, as determined by water-filled, non-infusion technique. No characteristic features of hiatus hernia were seen in the pressure tracings in the lower two panels.* (*b*) *The pressure profile in the same patient but with infusion technique. Note the slight separation of the sphincter from the diaphragm.*

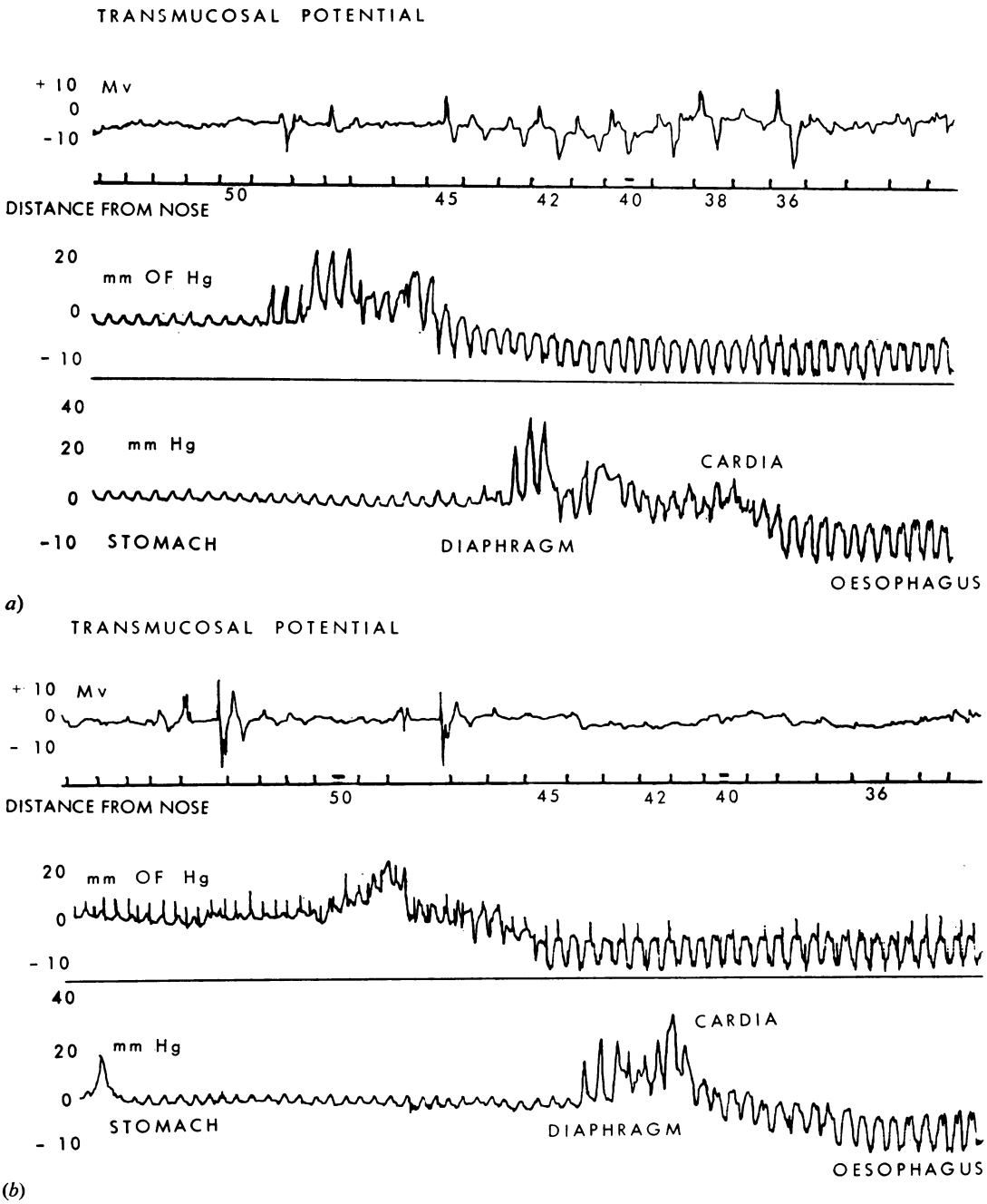


FIG. 7. *(a) Pressure tracing from a patient who had radiological evidence of sliding hiatus hernia. Note the level of the oesophagogastric junction at 38 cm from the nose; the hiatus as judged by the respiratory deflections and respiratory reversal is 42–43 cm from the nose. (b) Pressure tracings from the same patient. She was allowed to sit up for a while because of chest pain. The tracings were taken in the supine position. Note the inferior oesophageal sphincter has shifted toward the hiatus. The inferior oesophageal sphincter is at 42 cm and the hiatus at 43–44 cm. The transmucosal potential study was of little assistance in identifying the oesophagogastric junction in this particular patient. The inferior oesophageal sphincter was identified by the elevated end-expiratory pressure and its ability to relax with swallowing.*

junction from the lower incisor teeth, as assessed by oesophagoscopy, was 37 cm and its distance from the external nares as assessed manometrically was 41·8 cm. There was significant correlation between these observations ($r=0{\cdot}6012$; $0{\cdot}01>P>0{\cdot}001$). The mean distance of the diaphragmatic hiatus as assessed by external measurement at oesophagoscopy (xiphoid process from lower incisor) was 39·9 cm, and by manometry (distance of point of respiratory reversal and upper border of crural pressure band from external nares) was 44·7 cm. A significant correlation was found between these observations ($r=0{\cdot}5015$; $0{\cdot}02>P>0{\cdot}01$). The distance of the oesophagogastric junction above the diaphragm as assessed by oesophagoscopy was 2·6 cm and by manometry 2·5 cm. This was highly significant ($r=0{\cdot}8527$; $P<0{\cdot}001$).

DISCUSSION

The inferior oesophageal sphincter is important in the control of gastro-oesophageal reflux (Hoag, Kiriluk, and Merendino, 1954; Ingram, Respess, and Muller, 1959; Atkinson *et al.*, 1957; Wankling, Warrian, and Lind, 1965; Cohen and Harris, 1971). These authors could not demonstrate the effect of the diaphragm in contributing to a band of raised pressure at the lower end of the oesophagus. This is because uninfused, open-ended catheters were not sufficiently sensitive. Figure 6a and b compares manometric studies with and without infusion. Two bands of raised pressure in hiatus hernia have also been demonstrated previously by Edwards (1961) and Kelley (1966) using water-filled balloons.

The control of reflux by the diaphragm has not been universally accepted (Marchand, 1955; Atkinson *et al.*, 1957; Atkinson, 1962). The anatomy of the crural muscle (Collis, Kelly, and Wiley, 1954) suggests that when the diaphragm contracts in inspiration the hiatus would constrict the oesophagus. Johnstone (1955) and Berridge, Friedland, and Tagart (1966) have observed the constriction radiologically. The present study shows that the diaphragm acts over the oesophagus in all phases of respiration and specifically in inspiration. These studies do not suggest a direct pinch-cock action by the diaphragm as with such an action the point of respiratory reversal would be at the distal end of the band of raised pressure rather than at an observed position at the proximal end.

The crural pressure band was also observed by Code *et al.* (1962) and they suggested that it may be produced by the upward movement of the stomach in the hiatus. This is not likely in the present study. Any significant displacement at the hiatus would also change the level of the inferior oesophageal sphincter and this can be detected by manometry and by radiology (Fig. 7a and b). Not all patients with hiatus hernia have demonstrated a crural pressure band in this study. This is because these patients had a wide hiatus. In this situation the pressure recording catheters were unable to record any raised pressures.

This study was carried out with infusion of fluid through the catheters. This may itself give false recordings, but the infusion is too slow and too small to effect any significant changes (Pope, 1967; Edwards, 1971). Studies on correlation with radiology and oesophagoscopy have further confirmed the validity of the manometric results.

CONCLUSION

In the present study the diaphragm appears to play a definite role in the control of reflux by maintaining a band of high pressure at the oesophagogastric region in normal individuals, and this action is more pronounced during inspiration when pressure is always two to three times higher than gastric pressure. This observation is in agreement with the radiological findings of Johnstone (1959) and Creamer, Harrison, and Pierce (1959).

I am grateful to Professor J. Leigh Collis for his encouragement to undertake this study, for his invaluable criticism, and for providing excellent facilities to study the patients under his care; to Mr. Tom Dee, clinical photographer of the Department of Medical Illustration for the figures; to Mr. D. H. Berer for statistical help and advice; and to Miss Mary T. Isherwood for secretarial help.

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