FURTHER OBSERVATIONS ON THE GASTRO-OESOPHAGEAL JUNCTION

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This paper is an attempt to clarify the anatomy and function of the gastro-oesophageal junction by correlating *x*-ray appearances with landmarks established by pressure recordings and observations made at operation. The essential finding is that a short segment of gullet lies within the abdominal cavity.

NOTE ON TERMINOLOGY

Much confusion has arisen from the many terms applied to this area. Because of this we have chosen the term "gullet" as opposed to "oesophagus" to cover that part of the foregut which may normally appear as a tube, irrespective of its mucosal lining or site in the body cavities (Barrett, 1957). The point at which the gullet (tube) enters the fundus of the stomach (sac) is referred to as the "cardiac orifice." The term "sphincteric area" indicates a zone of increased resting pressure which can only be determined by manometry and has no exact radiological counterpart. Within this "sphincteric area" is a sharply localized point where the pressure swing with inspiration changes from an abdominal to a thoracic pattern and this is termed the "pressure barrier." It is important to realize that the "pressure barrier" is not synonymous with the "sphincteric area."

REVIEW OF RECENT WORK

Evidence has been presented of two mechanisms at work in the gastro-oesophageal junction. Dornhorst, Harrison, and Pierce (1954) showed that the junction had the properties of a valve, i.e., very small resistance to forward passage and the ability to resist retrograde flow in the face of large inverse pressures.

More recently Fyke, Code, and Schlegel (1956) and Atkinson, Edwards, Honour, and Rowlands (1957a) have demonstrated a sphincteric mechanism

by pressure measurements. There exists a zone about 3 cm. in length in which the resting pressure at certain phases of respiration is higher than either the gastric or oesophageal pressures, and where swallowing is followed by a fall in pressure before the arrival of the peristaltic wave. This is interpreted as a tonic contraction of the sphincteric area with reflex relaxation on swallowing. The pressure barrier is usually situated near the middle of the sphincteric area, although there is considerable individual variation (Fyke and others, 1956).

Correlation of pressure measurements and cineradiology has shown that the point of hold-up of barium in the lower gullet coincides with the pressure barrier rather than the upper end of the sphincteric area (Creamer and Pierce, 1957). It is clear, therefore, that the tonic contraction of that part of the sphincteric area which is exposed to intrathoracic pressure is easily overcome and forms no resistance.

The present observations were designed to answer the questions, (1) What is the anatomical location of the pressure barrier; (2) What is the mechanism by which barium is held up at the pressure barrier; and (3) Does this "hold-up" mechanism also play a part in the anti-reflux mechanism of the gastro-oesophageal junction?

METHODS

Ten normal volunteers have been investigated by combined cineradiology and pressure measurements as described previously (Creamer and Pierce, 1957). In addition two patients have been similarly investigated in whom radio-opaque markers had been placed at thoracotomy, two posteriorly on the edges of the crus forming the diaphragmatic hiatus and one on the anterior limit of the hiatus, and two other markers of different shape on the lower gullet at the level of

FIG. 1.—Conventional radiographs taken in the erect position, showing the inspiratory hold up of barium in the two patients with radio-opaque markers: clips on the diaphragmatic hiatus and shot on the peritoneal reflexion. A pressure recording tube filled with mercury distal to the recording hole has been placed at the level of the pressure barrier in each case. Note that the markers lie well above the visible cupola of the diaphragm in one case and coincide with it in the other.

the reflection of the peritoneum from the gullet on to the diaphragm. Observations were made at operation on 24 cases of hiatus hernia to determine the level of the change of mucosal lining relative to the point of peritoneal reflection. These cases had no peri-oesophageal inflammation.

RESULTS

LOCATION OF PRESSURE BARRIER IN RELATION TO DIAPHRAGMATIC HIATUS.—This was investigated in the two patients in whom markers had been placed on

FIG. 2.—Cine frames from a patient with radio-opaque markers, placed as in Fig. 1, during a barium swallow in the supine position: (1) During expiration; (2) during inspiration. The lumen of the abdominal gullet is closing at the level of the diaphragmatic hiatus leaving the remainder filled with barium. (In Figs. 2, 3, 5, and 6 the shadow of the synchronizing marker appears on the right-hand side of each frame.)

the oesophageal hiatus of the diaphragm. In both instances the point of reversal of inspiratory pressure swing (the pressure barrier) was found to coincide closely with the level of the markers on the hiatus. On swallowing single mouthfuls, erect and supine, barium was arrested at this level and this was also the level at which the intermittent hold-up with inspiration occurred both with swallowing and continuous drinking (Figs. 1 and 2). In these two patients the markers at the point of reflection of the peritoneum from the gullet to diaphragm coincided closely with the markers on the diaphragmatic hiatus (Figs. 1 and 2).

DEMONSTRATION OF ABDOMINAL SEGMENT OF GULLET.

Both these sets of markers lay well above the opening of the gullet into the fundus of the stomach, clearly demonstrating that there is a segment of gullet below the diaphragm and within the peritoneal cavity. Within this segment the respiratory pressure swing is of the abdominal pattern. When barium is flowing into the stomach this segment is indistinguishable by purely radiological means from the gullet lying above the hiatus, but when barium is held up at the pressure barrier the abdominal gullet usually empties, forming the "empty segment."

The length of the abdominal gullet was measured in five normal subjects and in the two patients. A pressure recording tube, filled with mercury distal to the recording orifice, was placed so that the orifice was at the pressure barrier with the subject supine and the fundus outlined with barium. The length of the opaque tube projecting from the fundus measured the length of the abdominal segment; the mean length was 2.5 cm. with a range of 1.4 to 3.3 cm. The length was also measured by using the "empty segment," the distance between the point of hold-up of barium and the fundus of the stomach during inspiration;

FIG. 3.—Cine frames from a barium swallow in a normal subject, supine position. (1) At the moment of swallowing, fundus outlined with barium and mercury-filled tube projecting out to pressure barrier; (2) barium held up at the pressure barrier; (3) barium flowing through abdominal gullet; (4) abdominal gullet fully dilated showing funnel shape.

the mean length by this method was 2.0 cm. with a range of 1.4 to 3.2 cm.

MUCOSAL LINING OF THE ABDOMINAL SEGMENT.—One of us (G.K.H.) has opened the gullet at the level of the peritoneal reflection during the repair of a hiatus hernia in 24 cases. In 21 instances the junction of gastric and oesophageal mucosae was within 1 cm. of the apex of the peritoneal fold. This suggests that the abdominal gullet is normally lined with gastric mucosa.

BEHAVIOUR OF THE ABDOMINAL GULLET.—The opening of the lower part of the gullet during swallowing and drinking in the erect posture has been previously described (Creamer and Pierce, 1957). The term "abdominal gullet" was not used in this communication, but changes in the lumen below the pressure barrier refer to this.

This was further investigated in the supine position with the fundus outlined with barium. As barium arrived in the lower oesophagus it was

FIG. 4.—Conventional radiographs during a barium meal showing abdominal gullet dilated and closed.

usually arrested at the pressure barrier for a short pause before flowing through into the stomach. When barium was flowing through the abdominal gullet the lumen gradually widened, particularly at the gastric end ("cardiac orifice") so that when the lumen had reached its maximum width the tube was frequently funnel-shaped and it was no longer possible to recognize any point of demarcation between gullet and fundus (Figs. 3 and 4).

In some subjects, during the interval between the act of swallowing and the forward flow of barium through the abdominal gullet, barium flowed retrogradely from the fundus into the abdominal gullet forming a triangular projection from the fundus. This retrograde flow never went proximal to the pressure barrier (Fig. 5).

When barium was flowing through the abdominal gullet inspiration suddenly arrested it at the level of the pressure barrier (Fig. 6). In the erect position the whole of the abdominal gullet was obliterated while in the supine position the closure was frequently localized to the area of the

pressure barrier leaving the rest of the abdominal gullet filled with barium (Figs. 1 and 2). This closing of the abdominal gullet and its subsequent opening during expiration happened with extreme rapidity. This was measured in five subjects during a barium swallow in the erect posture. The speed of closing when the lumen of the gullet was already maximally dilated and again the speed of opening to the maximal diameter was observed in 12 instances. The speed was remarkably constant; in nine out of the 12 instances the opening and closing was each completed in $\frac{1}{8}$ sec., in one instance $\frac{3}{16}$ sec., and in two instances $\frac{1}{16}$ sec.

The opening and closing were associated in every instance but one with a change in the relative pressures in the stomach and oesophagus. Opening did not take place until there had been an increase in oesophageal pressure to levels above intragastric pressure and, in closing, the reverse held true. The pressure gradient at opening and closing of the abdominal gullet was always the same in any one experiment.

FIG. 5.—Cine frames from a barium swallow in a normal subject, supine position: (1) At the moment of swallowing, fundus outlined with barium and mercury-filled tube projecting out to pressure barrier; (2) after swallowing, barium beginning to flow retrogradely into abdominal gullet; (3) immediately before barium flows from the oesophagus into the abdominal gullet.

FIG. 6.—Consecutive cine frames taken at 16 frames per sec. of a barium swallow in the erect position during expiration. A mercury-filled tube has been placed at the pressure barrier. The first frame shows the abdominal gullet closed and the last shows it fully open.

The diaphragm could be seen moving throughout inspiration and expiration, but the actual movement during the brief period of opening and closing was minimal and no more than during a similar period at other parts of the cycle.

DISCUSSION

Previous observations have indicated that the pressure barrier is a point of physiological importance, for not only is it the point of change from intra-abdominal to intrathoracic pressures but it is the point where barium is held up in the lower oesophagus. In order to learn more about the pressure barrier, three questions were posed.

(1) **LOCATION OF THE PRESSURE BARRIER.**—In two patients this has been shown to coincide with the level of the diaphragmatic hiatus. This was unequivocal and it seems reasonable to accept the evidence of two cases as a general finding. On this assumption it has been shown that a short segment of gullet, some 2 cm. in length, lies within the abdominal cavity and is subjected to intra-

abdominal pressure. It is partially covered with peritoneum up to the level of the diaphragmatic hiatus and is usually lined with gastric mucosa. Radiologically it may be indistinguishable from oesophagus above or it may funnel out into the fundus below without a hint of its boundary. Whether it should be regarded as stomach or oesophagus appears to be a matter of definition.

(2) **THE MECHANISM OF HOLD-UP OF BARIUM.**—This is most clearly seen during respiration. Our experiments show that the opening and closing of the abdominal gullet have the characteristics of a valve; the opening and closing are closely associated with changes in the pressure gradient between the oesophagus and stomach; the act of opening and closing occurs with great rapidity and the timing of this is constant. We suggest that a flaccid tube running from a chamber of lower to a chamber of higher pressure would have these characteristics and that the part of the tube subjected to higher pressure would collapse as a “flap valve” and only open to allow forward

FIG. 7.—Diagrammatic representations of the gastro-oesophageal junction: (1) Oesophagus, empty; (2) oesophagus full, during inspiration, with abdominal gullet closed; (3) oesophagus full, during inspiration, with abdominal gullet dilated.

flow when the pressure gradient has been overcome.

The rapidity of opening and closing and the constant timing virtually exclude a squeezing action of the crus forming the diaphragmatic hiatus or active contraction and relaxation of gut smooth muscle.

(3) RELATION OF HOLD-UP MECHANISM TO ANTI-REFLUX MECHANISM.—It is necessary, here, to distinguish between the threat to the competence of the gastro-oesophageal junction by a rise in intra-abdominal pressure and by a rise in intragastric pressure. A collapsible segment in the abdomen will clearly act against reflux when there is a general rise in intra-abdominal pressure, and we suggest that this valvular action of the abdominal gullet is an important part of the anti-reflux mechanism. However, a rise in intragastric above intra-abdominal pressure would overcome this mechanism unless the sphincteric area contracted as part of the stomach.

If the whole of the abdominal gullet closes the "empty segment" is formed, while if the lumen is obliterated only at the level of the hiatus the rest of the abdominal gullet remains filled and funnels out into the fundus. One of the actions of the sphincteric area would appear to be to convert this wide, funnel-shaped area into a narrow tube. The mucosal folds then effectively plug the cardiac orifice so that this now becomes a part of the anti-reflux mechanism (Botha, 1958).

Radiologically the sphincteric area cannot be detected above the diaphragmatic hiatus. It seems most likely that here the weak tone of the sphincteric area is overcome by the negative

intrathoracic pressure while below the diaphragm its tone is unopposed and augments the flap valve.

This concept of the closing mechanism of the gastro-oesophageal junction gives an explanation for the incompetence that occurs in hiatus hernias; if the abdominal gullet is herniated into the chest the valvular action is lost. Competence will then depend upon the ability of the sphincteric area to allow the mucosal folds to plug the cardiac orifice, and a good correlation between sphincteric tone and oesophagitis in hiatus hernias has been demonstrated by Atkinson and others (1957b).

CORRELATION OF TERMINOLOGY

Fig. 7 shows how some of the many terms applied to parts of the gastro-oesophageal junction fit in with the present observations.

SUMMARY

Observations on the gastro-oesophageal junction have been made in 12 subjects using simultaneous pressure measurements and cineradiography. The point of reversal of inspiratory pressure swing ("the pressure barrier") coincides with the level of the diaphragmatic hiatus. Below this a segment of gullet, about 2 cm. in length, lies within the abdomen. This segment has a valvular action which is responsible for the hold-up of barium and also for the prevention of reflux.

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