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The Esophageal Propulsive Force: Esophageal Response to Acute Obstruction *

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Abstract. The response of the normal human esophagus to an obstructing intraluminal bolus was investigated and compared to the response evoked by transient intraluminal distention. A balloon, immobilized within the esophagus by external attachment to a force transducer, was inflated with from 3 to 25 ml of air for from 3 to 210 sec. Pressure phenomena occurring in the esophagus were simultaneously recorded from the body of the esophagus above and below the balloon.

Transient distention (5 sec or less) with small volumes (5 ml or less) often evoked a secondary peristaltic wave in the esophagus distal to the balloon, but infrequently resulted in the registration of any force exerted upon the balloon to drive it downward. Conversely, distentions of longer duration and with greater volume elicited an esophageal propulsive force exerted upon the balloon oriented to propel it aborally, and much less often evoked a propagated wave of secondary peristalsis. The propulsive force, obviously resulting from esophageal muscular contraction, occurred promptly, and once initiated, was sustained until deflation of the balloon. It varied widely in magnitude, from 4 to 200 g, and was associated with no motor phenomena recorded from the body of the esophagus proximal or distal to the balloon which could account for its presence, onset, magnitude, or duration. The force was inhibited by deglutition, but arrival of the primary peristaltic wave at the bolus resulted in augmentataion of the force. When the obstructing balloon was freed from its attachment, the persistent, stationary force was converted to a propagated one that propelled the balloon before it. It the balloon was arrested before entering the stomach, the moving contraction was also arrested and the persistent propulsive force acting upon the balloon was maintained. The velocity of the moving contraction wave was determined in great part by the resistance offered by the bolus. Unrestrained, the balloon was propelled aborally at 4–8 cm/sec by the esophageal propulsive force; when restrained by 50 g, the rate of passage was reduced to 0.2–0.8 cm/sec.

The esophageal response to intraluminal distention is thus not limited to the uninterrupted wave of secondary peristalsis but is versatile and is determined by the nature of the distending bolus. Transient distention by a mobile or collapsible bolus elicits the propagated secondary peristaltic wave.

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An acutely obstructing bolus, on the other hand, evokes a persistent, often rather powerful muscular contraction, presumably localized to the proximal margin of the bolus, oriented to propel the bolus aborally, and serving to transport the obstructing morsel to the stomach.

Introduction

In the normal esophagus the act of swallowing initiates a muscular contraction wave which progresses in an aboral direction (primary peristalsis). This contraction wave progresses in much the same manner whether a "dry" swallow is performed or whether the swallowed bolus consists of water, or a sausage tied to a string (1). A second stimulus, for the initiation of the muscular contraction wave is intraluminal distention of the esophagus (secondary peristalsis) (2). Thus a morsel of food or quantity of fluid, left behind by the primary peristalsis wave or regurgitated from the stomach, will be transported to the stomach by the secondary wave.

With few exceptions, the investigations concerned with the esophageal motor response to distention have utilized either a mobile or a collapsible bolus. In fact, Fleshler, Hendrix, Kramer, and Ingelfinger, studying secondary peristalsis evoked by inflation of a fixed intraluminal balloon, found the progressive wave to be related to balloon deflation rather than distention per se (3).

Far less is known about the esophageal response to a fixed, obstructing intraluminal bolus. Hwang, Essex, and Mann stated that when an inflated balloon was restrained from moving in the canine esophagus, a forceful pull was registered on an attached spring balance which they ascribed to the pull of repeated waves of secondary peristalsis (4). On the other hand, Creamer and Schlegel (5) and Fleshler et al. (3) recorded repetitive contractions in the human esophagus proximal to a fixed distending balloon.

Since the esophagus is occasionally called upon to transport a bolus which tends to obstruct its lumen, the nature of the propulsive effort is clearly of physiologic importance. This report describes the response of the human esophagus to an obstructing intraluminal bolus and compares this response to that evoked by transient distention.

The results show that a sustained force is exerted upon the obstructing bolus, invariably oriented to drive the bolus into the stomach. We have termed this the esophageal propulsive force (EPF).

Methods

11 persons, including two women, were studied. They were healthy adult volunteers, aged 23–40 yr, without evidence of esophageal disease.

Techniques (Fig. 1)

A triple-lumen, water-filled, polyvinyl tube was introduced through the nose into the esophagus. The three tubes each measured 1.8 mm in internal diameter and were fused longitudinally with their open tips 5 cm apart. Radiopaque mercury markers were adjacent to each tip. Pressure changes were transmitted to Sanborn pressure transducers (Sanborn Division, Hewlett Packard Company, Waltham, Mass.) and registered on a multichannel, direct writing Sanborn recorder.

A thick-walled rubber balloon attached to a separate polyvinyl tube was inserted through the mouth into the esophagus. A radiopaque marker was placed at the at-

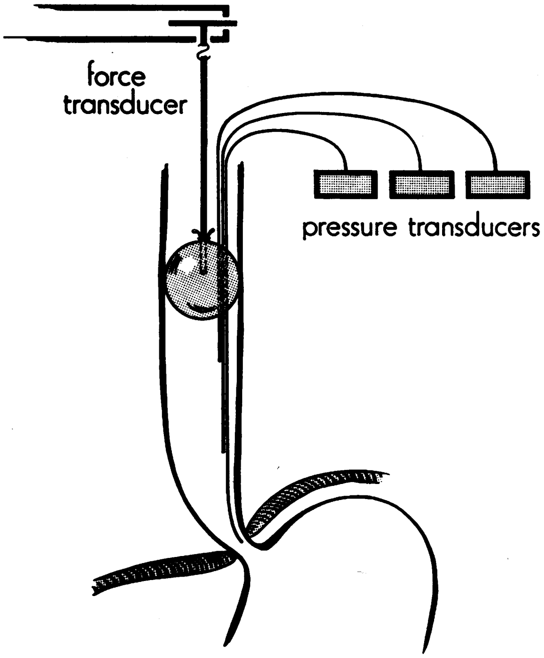

FIG. 1. DIAGRAM OF BALLOON FORCE TRANSDUCER AND PRESSURE TIP–PRESSURE TRANSDUCER ASSEMBLIES. Balloon and pressure tips may be independently positioned within the esophagus.

tachment of the balloon to the tube. Distention of the balloon with 3–25 cc of air resulted in a bolus about 1.5–4.0 cm in transverse diameter. The thick wall rendered the distended balloon firm when distended with these volumes. Externally, the balloon tube was attached by an inelastic heavy-gauge cotton thread to the spring level of a Grass force transducer (Grass Medical Instruments, Quincy, Mass.). Calibration was accomplished by suspension of precision weights from the horizontal spring lever. This transducer was situated dirictly above the mouth of the supine subject and connected to a fourth recording channel. No slack was permitted between force transducer and balloon. The balloon tube was about 40 cm long; it stretched by 3% of its length for each 100 g applied, up to 500 g. Maximum displacement of the spring lever of the force transducer was 2 mm. The balloon was, therefore, essentially immobilized within the esophagus.

To demonstrate propulsion of the balloon by the force exerted upon it, we used an additional connection between balloon and transducer in some studies. The thread between the balloon tube and the force transducer was connected to the hook of the spring lever in two or three places (Fig. 2, *A*). The pull exerted upon the balloon was thus transmitted to the force transducer through the shortest connection. When this connection was cut (Fig. 2, *B*), the balloon was allowed to move, only to be arrested by the attachment of the second connection to the force transducer and the registration of the pull was reestablished (Fig. 2, *C*). This sequence could be repeated with a third connection, or the balloon could be completely freed from any attachment. The length of thread between connections equalled the distance travelled by the balloon. Thus the time recorded between cutting of the connection and reestablishment of the pull permitted calculation of the speed at which the balloon moved downward within the esophagus.

To assess the ability of the esophagus to propel the balloon against a known resistance, we tied another thread to the proximal end of the balloon tube, led it over a low-friction supporting rod, and attached it to a weight resting on a platform (Fig. 2, *D*). Just enough slack was allowed in this thread so that no force was applied to the weight until the first connection was cut (Fig. 2, *E*). Then, movement of the balloon down the esophagus could occur only by lifting the weight off the platform (Fig. 2, *F*). When the balloon was arrested by the second loop, the force registered by the force transducer was thus in addition to that which held the weight suspended. Weights of up to 100 g were used.

A pneumographic belt around the chest of the subject identified respiratory excursions on a fifth recording channel; another belt about the neck registered deglutition on the same channel.

Balloon and recording tips were positioned in the esophagus under fluoroscopic control. Repeated, sudden inflation of the balloon with a 3–25 ml of air were performed for periods varying from 3 to 210 sec. All subjects felt the distending balloon at each volume of distention. The balloon was distended in the middle third and the distal third of the esophagus in all subjects.

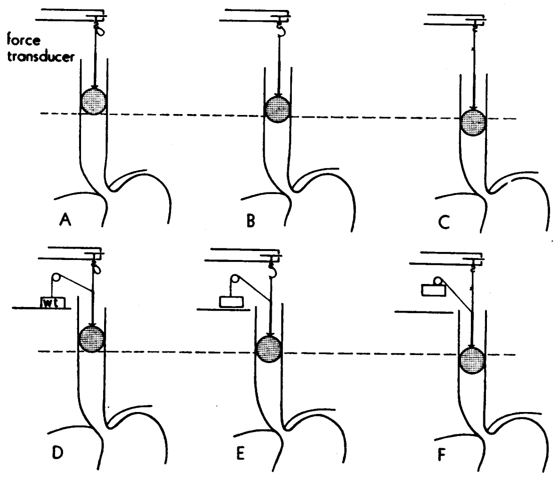

FIG. 2. DIAGRAM OF BALLOON FORCE TRANSDUCER ASSEMBLY TO DEMONSTRATE PROPULSION OF THE BALLOON. The angle between thread attaching balloon to transducer and thread attaching balloon to weights was < 15 degrees.

When the balloon was in the middle third of the esophagus, the recording tips were in the distal third and vice versa. During four individual distentions, however, the balloon was situated between the proximal and middle recording tips. With all distentions during which the balloon was allowed to move, initial position of the balloon was proximal to or at the level of the proximal recording tip.

The effect of buccal and pharyngeal friction upon the balloon tube was disregarded.

Statistical analysis of frequency of response was performed by chi-square contingency analysis; significance of mean differences were calculated according to Student's *t* test (6).

Results

The esophageal propulsive force (*EPF*) (*Table I*)

In the 11 subjects, the balloon was distended 411 times and evoked an aborally directed force upon the distending balloon 194 times. Typically, the force commenced from 0 to 30 sec (mean 2.5 sec) after the balloon was distended, increased rapidly to its maximum level, and persisted at that level with minor variations until deflation of the balloon caused its abrupt termination (Fig. 3). The force varied from subject to subject, and from distention to distention in the same subject; it ranged from 4 to 200 g. The greatest duration re-

TABLE I

Results of balloon distention in 11 subjects

Subject	Age	Sex	Primary peri-stalsis	Secondary peri-stalsis	Number of dis-tentions	Number of EPF	Mean magnitude of EPF (range)	Longest sustained EPF
							g	*sec*
Normals								
EW	23	M	P*	P	43	23	24 (7–58)	195
MM	24	F	P	P	48	34	28 (8–70)	60
AC	24	M	P	P	57	17	26 (6–184)	116
JP	23	M	P	NP‡	24	14	19 (8–52)	105
TS	25	M	P	P	46	16	34 (10–58)	137
BM	25	M	P	P	41	23	43 (8–184)	150
HS	29	M	P	P	32	31	28 (8–96)	105
HP	40	M	P	P	22	7	38 (5–200)	145
SW	25	F	P	P	22	8	10 (4–20)	28
WW	26	M	P	P	33	13	15 (4–26)	70
NB	24	M	P	P	43	8	25 (6–54)	210

* P, present.
‡ NP, not present.

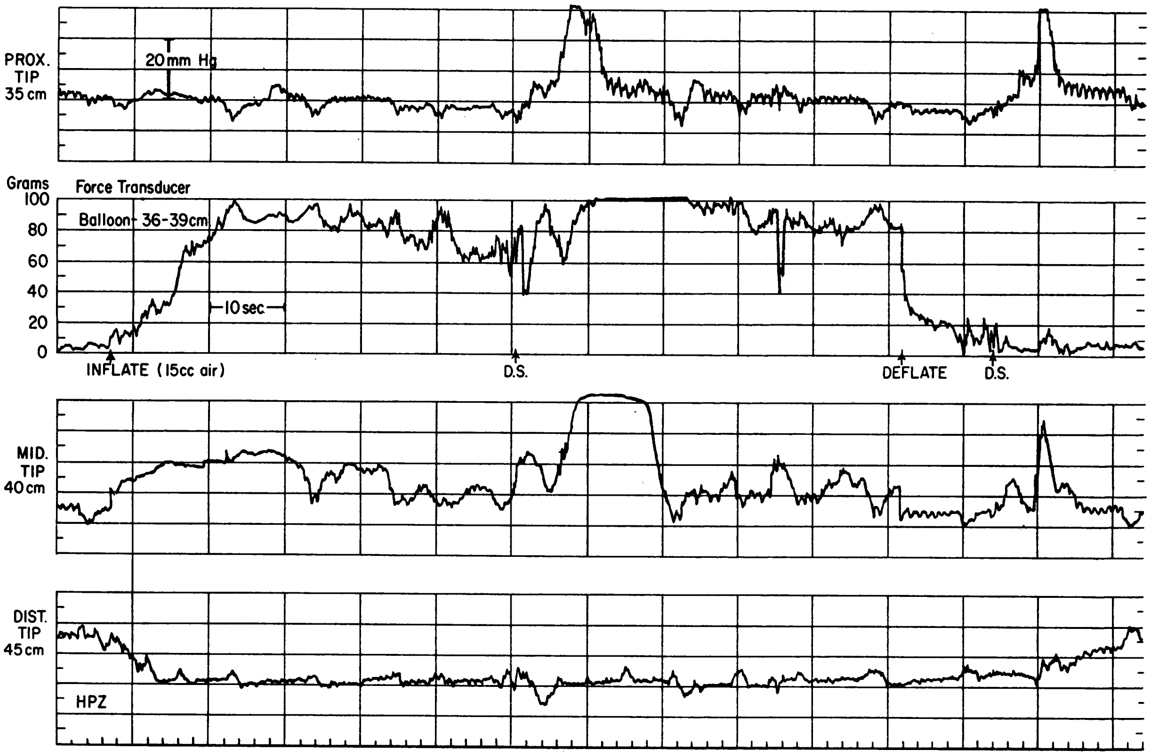

FIG. 3. THE ESOPHAGEAL PROPULSIVE FORCE (EPF). Balloon is situated between proximal and middle pressure tips. Upon balloon inflation, a propulsive force exerted upon the balloon is registered from the force transducer. No pressure phenomena occur above or below the balloon to account for the EPF. After dry swallow (*D.S.*), a monophasic wave appears in the proximal tip and progresses to the balloon. As the wave reaches the balloon the EPF attains a higher level; the EPF persists until balloon deflation. The distal tip is positioned in the inferior esophageal high pressure zone (*HPZ*). Resting pressure decreases upon balloon distention, remains depressed until after D.S. following deflation. There is no secondary peristaltic wave. Paper speed 2.5 mm/sec.

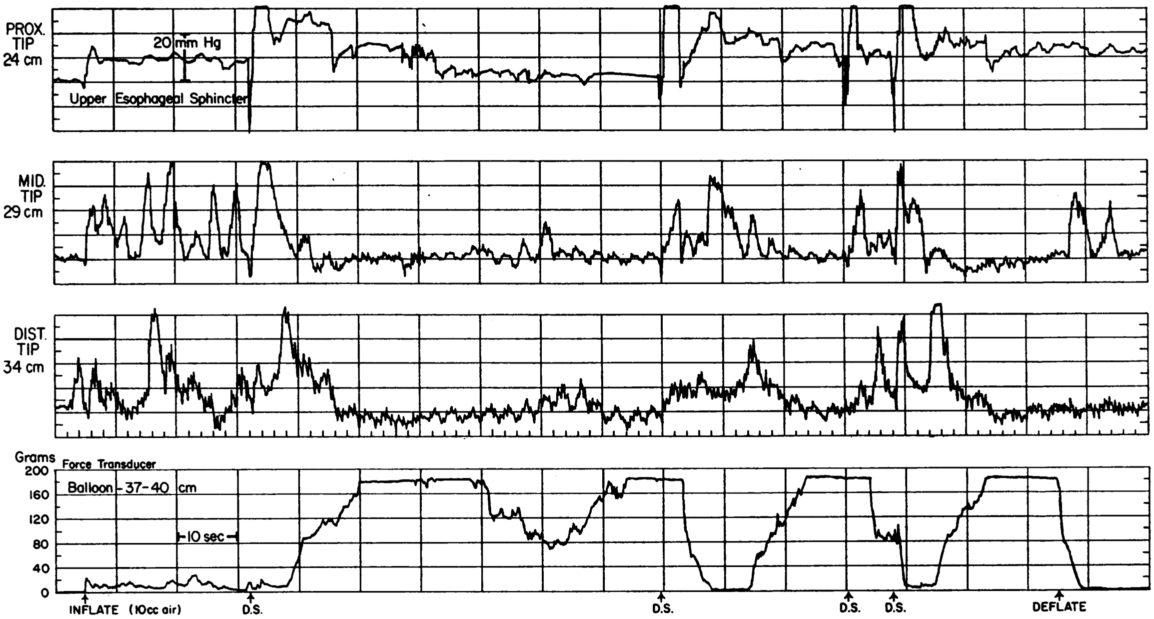

FIG. 4. THE EPF. The proximal pressure recording tip is in the upper esophageal sphincter; the balloon is distal to all recording tips. Balloon distention evokes repetitive waves proximally and a small, persistent EPF. After dry swallow (*D.S.*) the EPF increases sharply, repetitive waves cease proximal to balloon. Subsequent dry swallows are followed by relaxation of the EPF, which then returns to its prior level. Deflation terminates the EPF, and evokes no secondary peristalsis. Paper speed 2.5 mm/sec.

corded of any EPF equalled the longest duration of balloon distention.

The balloon was in the middle third of the esophagus and proximal to the recording tips during 314 distentions. An EPF alone was recorded during 125 of these distentions. Both an EPF and secondary peristalsis were registered 3 times, the secondary peristaltic wave always following balloon deflation and cessation of the EPF. Secondary peristalsis alone occurred 75 times; 5 times during the distention and the remaining 70 upon deflation. No motor response accompanied 111 distentions. In one subject (JP) an EPF was registered with 14 of 24 distentions but no secondary peristalsis was recorded.

The response of the inferior esophageal high-pressure zone was assessed during 170 distentions. A prompt fall in resting pressure of this zone accompanied all but five of the distentions, and in 163 instances this decrease in pressure was maintained throughout the distention. Upon balloon deflation, the pressure promptly returned to its resting level (Fig. 3).

When the balloon was in the distal third of the esophagus with recording tips proximal, an EPF was registered 66 times during 97 distentions. Progressive pressure waves unaccompanied by swallows were never identified proximal to the balloon.

Nonperistaltic contractions, both single and repetitive, occurred occasionally either above or below the inflated balloon, but their presence or absence had no consistent relationship to presence, onset, magnitude, or duration of the EPF (Figs. 3 and 4). The balloon was never propelled orad.

Relation between EPF and secondary peristalsis

1) Effect of duration of distention (Table II). The incidence of the EPF increased with increasing duration of balloon distention in the middle third of the esophagus ($P < 0.001$), but the incidence of secondary peristalsis decreased ($P < 0.001$). This inverse relationship between the EPF and secondary peristalsis as a function of duration of distention is highly significant (≤ 5 sec, $P < 0.025$; ≥ 10 sec, $P < 0.001$).

TABLE II

Effect of duration of balloon distention upon esophageal motor response

Duration of distention	Number of distentions	Secondary peristalsis	EPF	Mean magnitude of EPF
sec		%	%	*g ± 1* SD
Balloon in middle third of esophagus; pressure tips below				
≤ 5	188	34	21	14 ± 6
≥10	126	11	71	34 ± 39
Balloon in distal third of esophagus; pressure tips above				
≤ 5	55	*	49	17 ± 12
≥10	42	*	93	34 ± 19

* Secondary peristalsis was never identified proximal to the balloon. This does not preclude its presence below the balloon.

The mean magnitude of the EPF was significantly greater with increased duration of distention, whether the balloon was in the mid-third ($P < 0.005$) or distal third ($P < 0.001$) of the esophagus.

2) *Effect of distending volume (Table III).* When the balloon was in the mid-esophagus, distention with larger volumes more frequently initiated the EPF than did small volume distentions ($P < 0.001$). The mean magnitude of the EPF in this location was not significantly influenced by changes in volume, however ($P > 0.200$). In the distal third of the esophagus, differences in distending volume did not influence frequency of the EPF ($P > 0.250$). The mean magnitude of the EPF in the distal third, however, was significantly greater with large than with small distending volumes ($P < 0.025$). The volume of air used to distend the balloon had no consistent influence upon the incidence of secondary peristalsis ($P > 0.100$).

TABLE III

Effect of volume of distending balloon upon esophageal motor response

Distending volume	Number of distentions	Secondary peristalsis	EPF	Mean magnitude of EPF
ml		%	%	*g ± 1* SD
Balloon in middle third of esophagus; pressure tips below				
≤5	85	32	19	17 ± 12
≥7.5	229	22	49	29 ± 36
Balloon in distal third of esophagus; pressure tips above				
≤5	30	*	77	20 ± 13
≥7.5	67	*	64	31 ± 20

* See Table II, footnote.

3) *Combined effect of duration and volume of distention.* The duration of balloon distention and distending volume each appeared to influence the esophageal response to distention. The influence of different durations of a uniform distending volume upon esophageal response was examined further as well as the influence of different distending volumes on constant duration of distention. A plot of the volume data showed that the incidence of the EPF was low at distending volumes below 6 ml, and increased sharply with distentions of more than 9 ml. Data from distentions with volumes between 5 and 10 ml were thus excluded from this tabulation.

From this analysis the following conclusions may be drawn (Table IV):

TABLE IV

Combined effects of duration and distending volume upon esophageal motor response

Duration of distention	Distending volume	Number of distentions	Secondary peristalsis	EPF
sec	*ml*		%	%
Balloon in middle third of esophagus; pressure tips below				
≤ 5	≤ 5	60	40	7
≥10	≥10	97	12	74
≤ 5	≥10	110	33	30
≥10	≤ 5	25	12	48

(*a*) Secondary peristalsis occurred most often with ≤ 5-sec and ≤ 5-ml distentions, whereas the EPF was least likely to be evoked at this short duration and small volume ($P < 0.005$).

(*b*) The EPF was most likely to occur with distentions of ≥ 10 sec and ≥ 10 ml, but this duration and volume least often elicited secondary peristalsis ($P < 0.005$).

(*c*) The incidence of secondary peristalsis was influenced primarily by duration of distention and varied inversely with it ($P < 0.005$). Distending volume was less important, but the decrease in incidence of secondary peristalsis effected by increasing duration was enhanced by increasing volume.

(*d*) The incidence of the EPF increased primarily with increasing duration of the distention ($P < 0.005$). Increasing volume of distention contributed to the effect.

Effect of deglutition upon EPF

Deglutition during prolonged balloon distention (> 10 sec) usually evoked a complex set of phenomena. If an EPF was already present, its force usually diminished sharply upon the act of swallowing. When the primary peristaltic wave arrived at the balloon, the EPF was regenerated to its former level or to even greater magnitude. The EPF was then sustained until either deflation of the balloon or repetition of the swallow occurred (Fig. 4).

Deglutition was recorded 115 times while an EPF was present and on 92 occasions the EPF decreased. With only four exceptions the EPF promptly returned to its prior level or attained a magnitude greater than that which had been present before the swallow. With 19 swallows, the EPF did not decrease on deglutition but increased in magnitude upon arrival of the peristaltic wave from above. The mean force generated after deglutition was significantly greater than that registered before swallowing [78 ± 56 g (± 1 SD) vs. 31 ± 29 g (± 1 SD); $P < 0.05$].

An additional 39 swallows were recorded when balloon distention had not evoked an EPF. In each case an EPF was generated subsequent to the deglutition (Fig. 5). The force then persisted until the balloon was deflated or swallowing was repeated.

Propulsion of the distending bolus

The ability of the EPF to actually propel the bolus aborally was studied in the first six subjects listed in Table I. Using the balloon-transducer assembly shown in Fig. 2 (*A–C*), we inflated the balloon with 10 or 15 ml of air. In each subject

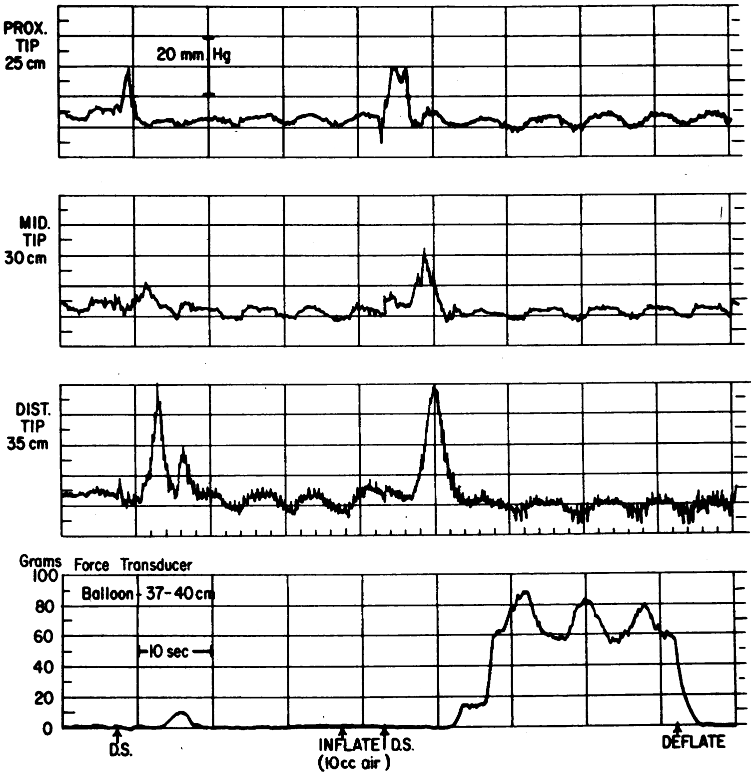

FIG. 5. THE EPF. The balloon is distal to all pressure tips. Distention elicits no response. Dry swallow (*D.S.*) during distention evokes a primary peristaltic wave which progresses down the esophagus, generating an EPF upon its arrival at the balloon. The EPF then persists until balloon deflation about 30 sec later. On the left, dry swallow is followed by a primary peristaltic wave which passes over the deflated balloon, producing a brief, 10 g tug upon the balloon. Paper speed 2.5 mm/sec.

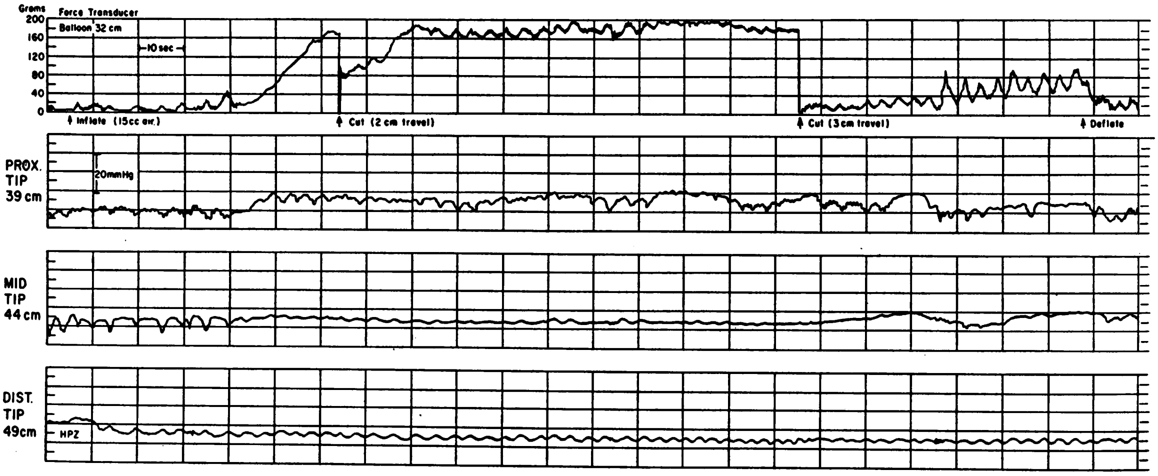

FIG. 6. PROPULSION OF THE BOLUS. The balloon is proximal to the recording tips. Distention evokes an EPF which eventually reaches 175 g. The attachment of balloon to force transducer is severed, the balloon moves aborally, is rearrested, and the EPF maintained. After the second release of the balloon, it travels 3 cm, is rearrested, but the EPF then generated is less. No pressure wave traverses the esophagus distal to the balloon. Paper speed 2.5 mm/sec.

four distentions were selected in which the EPF registered at least 25 g. After establishment of the EPF, the first connection was severed, freeing the balloon to move to 2–4 cm. In these 24 trials the balloon was propelled distally 22 times and the EPF was reestablished promptly with arrest of the balloon (Fig. 6). A second connection was cut in 14 instances. In all, the balloon was propelled further. The balloon was freed entirely 4 times and each time it progressed into the stomach. In the remaining 10, the moving bolus was arrested a second time and the EPF reappeared (Fig. 6). The mean speed of propulsion was 6.5 cm/sec (range 4–8 cm/sec).

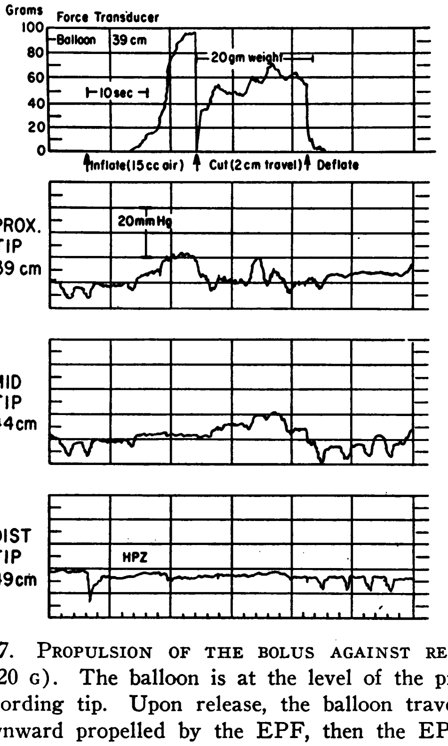

FIG. 7. PROPULSION OF THE BOLUS AGAINST RESISTANCE (20 G). The balloon is at the level of the proximal recording tip. Upon release, the balloon travels 2 cm downward propelled by the EPF, then the EPF is regenerated. Speed of propulsion is 2 cm/sec. No pressure wave traverses the esophagus distal to the balloon. Paper speed 2.5 mm/sec.

In 30 instances in which the balloon was arrested after being propelled by the EPF, at least one pressure recording tip was positioned in the body of the esophagus distal to the point of arrest. In no case was a monophasic wave registered beyond the point of arrest; thus the contraction did not continue in the esophagus distal to the arrested balloon.

Fig. 2 (*D–F*) shows the assembly used in further studies in five of these six subjects. Weights of 20, 50, or 100 g were used, depending upon the magnitude of the EPF just before their attachment. A 20 g weight was used in all subjects, 50 and 100 g in three subjects. The ability of the EPF to propel the bolus while restrained by the weight was evaluated 21 times. In each instance after the EPF was established, the first connection was severed, permitting the bolus to move.

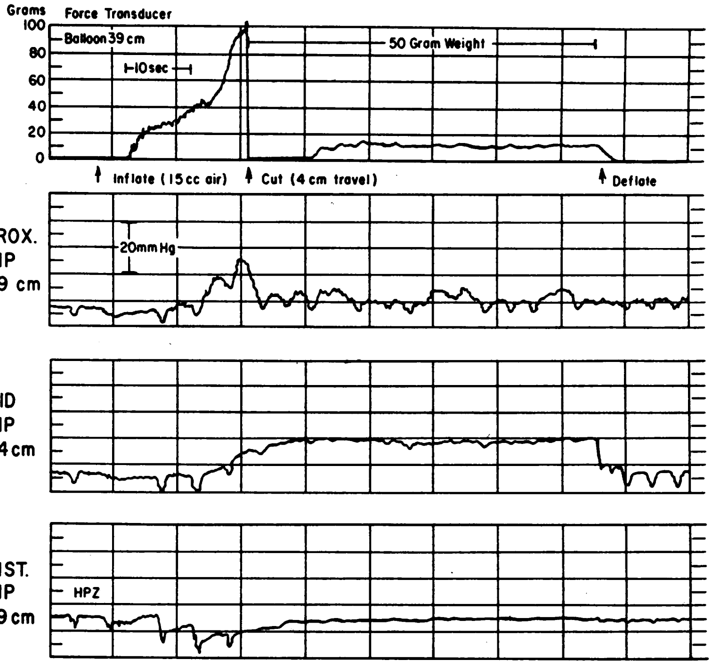

FIG. 8. PROPULSION OF THE BOLUS AGAINST RESISTANCE (50 G). After an EPF of nearly 100 g is generated, the balloon is freed to travel 4 cm aborally. This requires 10 sec (0.4 cm/sec) then the balloon is rearrested and a smaller EPF established. Paper speed 2.5 mm/sec.

To propel the bolus down the esophagus the EPF was required to lift the weight vertically until the balloon was rearrested by the second loop (Figs. 7 and 8). This propulsion was accomplished in 8 of 10 trials with 20 g, in 5 of 8 with 50 g, and in none of 3 trials with 100 g. In the remainder, the weight was lifted at least 1 cm above the platform except in the three instances in which a 100 g weight was not lifted.

The sum of the weight lifted and the force registered while the weight was suspended was always slightly less than that recorded prior to cutting the connection. The reason for this difference is not apparent.

The heavier the weights the less was the speed of propulsion (Figs. 6–8). When opposed by 20 g the mean speed of the bolus was 1.8 cm/sec (range 1–3 cm/sec). With 50 g the speed was 0.4 cm/sec (range 0.2–0.8 cm/sec).

As before, no contraction was registered in the body of the esophagus below the arrested balloon in any instance. This lack of contraction indicated that the muscular contraction which had moved the balloon was also arrested.

In each instance in which the balloon was allowed to move past a recording tip a monophasic pressure wave of large magnitude was registered from the tip. No effort was made to analyze these waves further, however, since the contributions of bolus and muscular contraction could not be separated.

Discussion

The esophageal response to intraluminal distention is clearly influenced by the nature of the distending bolus. When the bolus is liquid or an easily transported solid (2), the resultant secondary peristaltic wave neatly carries it to the stomach. These conditions may be simulated by a fixed intraluminal balloon which transiently distends the esophagus. According to Fleshler et al. (3) the critical event initiating the progressive contraction wave of secondary peristalsis is almost always collapse or deflation of the distending balloon. The results of the present study confirm this view.

When a bolus obstructs the esophagus, however, the response is considerably altered. Within a few seconds of the onset of obstruction, provided in this study by sudden distention of a fixed balloon, a force is exerted which is invariably oriented to drive the balloon into the stomach. Once established, this EPF persists until the balloon is deflated. With rare exception it does not occur in conjunction with a secondary peristaltic wave. In fact, it occurs with greatest frequency under those conditions which are least likely to evoke secondary peristalsis, that is increasing volume and duration of distention of the bolus.

The EPF is not in itself a peristaltic wave, since it may persist locally for long periods and not progress down the esophagus. Nor is it the result of repeated waves of secondary peristalsis impinging on the obstructing bolus, as proposed by Hwang (4). We recorded no repeated waves of secondary peristalsis in the esophagus above or below the balloon. Finally, the EPF is not the result of repetitive, foreceful esophageal contractions above the balloon as asserted by Creamer and Schlegel (5). Such contractions were seen to exist at times, but they had no relationship to presence, onset, magnitude, or duration of the EPF.

The motor phenomenon that produces the EPF is presumably a localized muscular contraction involving a short segment of the esophageal wall enveloping the proximal aspect of the balloon. The stimulus for this contraction is obviously the stretch of smooth muscle fibers invoked by the distending bolus. The orientation of the force thus generated is in accord with the "law of the intestine," formulated by Bayliss and Starling for the small and large intestine (7) and suggested by Creamer and Schlegel to apply to the esophagus as well (5).

After generation of the EPF, release of the bolus from its attachment results in its transport toward the stomach. The stationary propulsive force is probably converted into a moving one which sweeps the balloon before it. When the bolus is arrested, the contraction maintains its relationship to the bolus and continues to exert an uninterrupted propulsive force upon it. An alternate possibility is that the bolus is "squirted" downstream by the force of the stationary EPF and a new EPF is generated at its new distal location. This possibility cannot be excluded but seems less likely since the EPF is registered immediately upon arrest of the balloon, whereas a mean lag time of 2.5 sec precedes the generation of the EPF when the balloon is first inflated at any site.

The speed with which the EPF propels the bolus down the esophagus is influenced by the degree of resistance encountered. Thus when the balloon was unrestrained, the speed of propulsion was 6–8 cm/sec. When opposed by 50 g, it traveled at only 0.2–0.8 cm/sec. Furthermore, once initiated, the contraction is not committed to uninterrupted travel down the esophagus.

The effects of deglutition, superimposed upon the EPF, demonstrate integration of the complex mechanisms of bolus propulsion. Relaxation of the EPF immediately upon swallowing is evidence that reflex inhibition precedes the contraction of primary peristalsis in the body of the esophagus. This relaxation persists until arrival of the peristaltic wave from above, when the EPF is then regenerated to a force often greater than that originally attained. This inhibitory phenomenon is similar to that observed in the inferior esophageal sphincter. In that location, the intraluminal resting tone also falls immediately upon swallowing (or distention of the balloon in the body of the esophagus) (1).

The propulsive forces observed in the present investigation are considerably higher than those previously reported in the human esophagus. Schreiber (8) investigated the propulsive force of esophageal peristalsis in subjects who swallowed a bolus counterpoised by weights. The weights were attached to the bolus by a string over a pulley. They were lifted vertically by the force of the peristaltic wave. With the help of many swallows, the bolus could negotiate the esophagus, while restrained by only 5–10 g. A weight of 15 g proved insurmountable and the bolus stuck in the mid-esophagus. By contrast, the retentive force of the esophagus proved much greater. The weight necessary for pulling a bolus out of the esophagus was reported as up to 200, 50, and 350 g in the upper, middle, and lower thirds of the esophagus, respectively. The retentive force was never converted to a propulsive one, however, even when smaller weights were used.

The investigative technique in the studies of Schreiber and those of the present investigation differ greatly and comparison of results is difficult. The important fact is that the propulsive force of the human esophagus is much greater than previously measured.

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