Pressure Profile of Esophageal Peristalsis in Normal Humans as Measured by Direct Intraesophageal Transducers

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The pressure profile of esophageal peristalsis was studied in healthy young adult males using an intraesophageal transducer assembly. The amplitude of peristaltic contractions following wet swallows was determined at intervals along the esophagus from the lower esophageal sphincter (LES) to the upper esophageal sphincter (UES). The amplitude profile revealed a trough of significantly decreased ($P < 0.05$) *amplitude at 17.5–20.0 cm above the LES. The change in pressure per unit time* (dp/dt) *produced a profile also with a significant decrease* ($P < 0.01$) *in the upper esophagus, having good correlation* ($r = 0.91$, $P < 0.001$) *with the amplitude profile. Mean velocity of the peristaltic wave in the upper esophagus varied from 2.92 ± 0.19 (±SEM) to 3.29 ± 0.36 cm/sec. In the distal esophagus, mean velocity increased significantly* ($P < 0.01$) *to 4.98 ± 0.38 cm/sec at 7.5 cm above the LES, and then fell significantly* ($P < 0.05$) *to 2.15 ± 0.27 cm/sec at 2.5 cm above the LES. This report establishes amplitude and velocity profiles in the human esophagus. The profile of the first derivative of the primary peristaltic wave* (dp/dt) *is also described, and its possible importance discussed.*

Studies of peristaltic amplitude and velocity profiles in the human esophagus have produced results with a wide range of variation (1–6). The methods employed in these studies included single transducers (1, 4), water-filled, noninfused catheters (2, 3, 5), and infused catheters (6). The merits of an infused, water-filled catheter system have been discussed (7, 8), but recent evidence suggests that such a system is itself subject to variables that decrease recording accuracy (9, 10). Miniature intraluminal strain gauges have been shown to achieve a high degree of accuracy in human esophageal studies (9, 10). In this paper, intraluminal transducers were employed to establish amplitude and velocity profiles for the primary peristaltic wave in normal humans.

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MATERIALS AND METHODS

Subjects. Ten healthy male subjects having a mean age of 22 years (range 19–28 years) formed the study group. None of the subjects had a history of esophageal disease or chronic heartburn. All studies were performed following an overnight fast after informed consent had been obtained.

Esophageal Manometry. Recordings were made using a direct intraluminal transducer system consisting of a flexible tube containing three small (5 mm in diameter) pressure transducers with lateral openings spaced 5 cm apart (Honeywell Inc., Model 31 Probe). These transducers

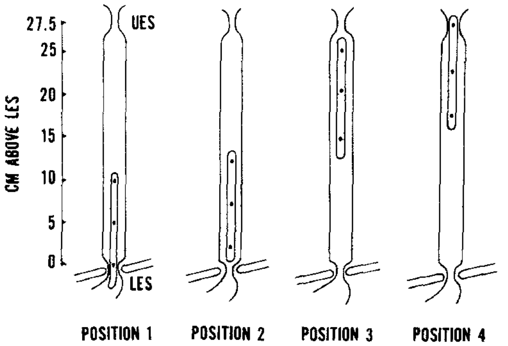

Fig 1. Diagrammatic representation of recording positions. Position 1 shows the assembly with the distal transducer in the LES. The assembly was then withdrawn in three successive steps as shown in positions 2–4.

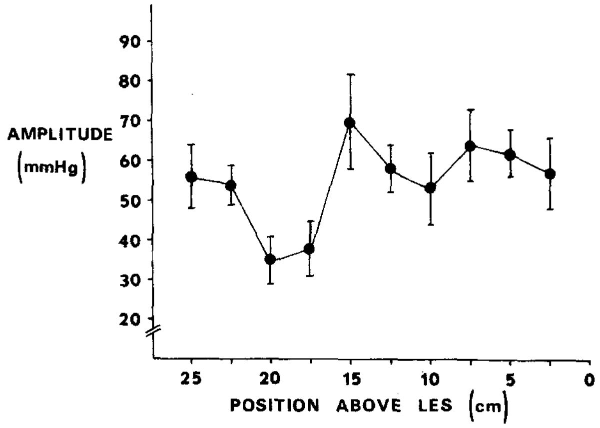

Fig 2. Mean amplitude of esophageal contractions in mm Hg at 2.5-cm intervals along the human esophagus reveal a significant ($P < 0.05$) decrease in mean amplitude at 17.5–20.0 cm above the LES. Vertical lines indicate ±SEM.

have a frequency response rated as flat to approximately 5000 Hz. Pressures were graphed on a multichannel direct-writing recorder. With the subjects supine, a belt pneumograph was placed over the larynx to record swallowing. Four positions within the esophagus were used (Figure 1). The transducer assembly was initially positioned with the distal transducer in the lower esophageal sphincter (LES), and with the middle and proximal transducers recording at 5 and 10 cm, respectively, above the LES. The assembly was then withdrawn successively 2.5, 15.0, and 17.5 cm above the LES, thus obtaining recordings at 2.5-cm intervals from the LES to the upper esophageal sphincter (UES). At each position, a series of 20 wet swallows (5-cc water bolus) were recorded, allowing a 30-sec interval between each swallow (10-min study period).

Measurements and Analysis. Amplitude was determined by subtracting mean resting esophageal pressure from the peak of the pressure wave. The first derivatives (*dp/dt*) or slopes of the pressure complexes were measured directly from the tracings. Velocity of peristalsis was calculated from the time between peristaltic wave peaks from adjacent transducers. It was measured over seven intervals of 5.0 cm each in the body of the esophagus. For statistical analysis, Student's *t* tests for paired samples and correlation coefficients were used. Each individual value for each subject represents the mean of the values for the 20 repetitive swallows. Group means for the 10 subjects thus represent the mean of the individual means.

RESULTS

Figure 2 illustrates the amplitude profile of the human esophagus. A trough of low amplitude was noted at 17.5–20.0 cm above the LES. The mean

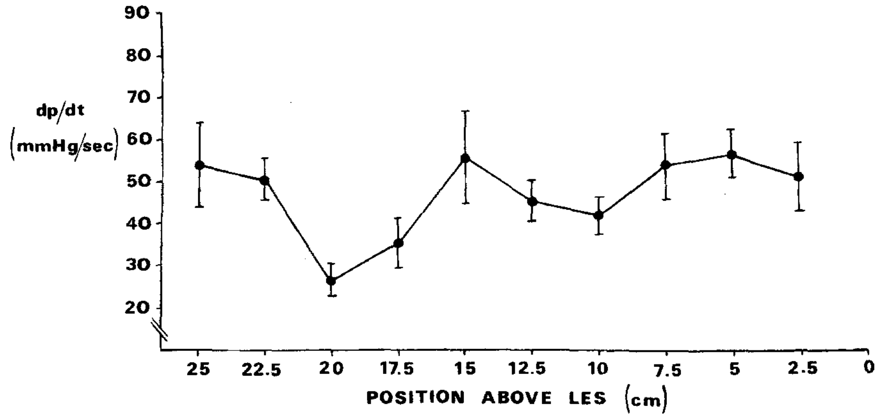

Fig 3. Mean values for the first derivative of the peristaltic wave (*dp/dt*) at 2.5-cm intervals along the human esophagus showing a significant ($P < 0.05$) decrease in mean *dp/dt* at 17.5–20.0 cm above the LES.

amplitude varied insignificantly from 53.4 ± 9.0 (±SEM) to 69.5 ± 12.1 mm Hg in the lower two thirds of the esophagus. However, in the pressure trough, the mean amplitude decreased significantly ($P < 0.05$) to 35.0 ± 6.4 mm Hg.

The profile of the first derivative of the primary peristaltic wave is shown in Figure 3. The change in pressure per unit of time (*dp/dt*) also demonstrated a zone of significantly lower values in the upper esophagus, 17.5–20 cm above the LES. The mean *dp/dt* varied insignificantly from 51.0 ± 8.3 to 56.4 ± 6.0 mm Hg in the lower two thirds of the esophagus, but fell significantly ($P < 0.05$) to 26.6 ± 4.5 mm Hg in the *dp/dt* trough. As shown in Figure 4, comparison of *dp/dt* values with pressure amplitudes over the entire length of the esophagus revealed excellent correlation ($r = +0.91$, $P < 0.001$).

The velocity of the primary peristaltic wave was studied over seven intervals of 5.0 cm each in order to produce a profile in the same manner as the two already presented. This is demonstrated in Figure 5. Mean velocity in the upper esophagus varied insignificantly from 2.92 ± 0.19 to 3.29 ± 0.36 cm/sec. However, in the distal esophagus, mean velocity increased significantly ($P < 0.01$) to 4.98 ± 0.38 cm/sec at 7.5 cm above the LES, and then fell significantly ($P < 0.05$) to 2.15 ± 0.27 cm/sec at 2.5 cm above the LES.

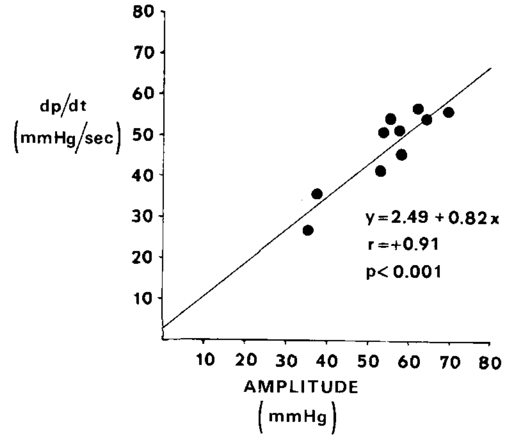

Fig 4. Comparison of mean amplitude and mean *dp/dt* of esophageal contractions at 10 positions along the human esophagus.

DISCUSSION

Recent studies (9, 10) have suggested that the direct intraesophageal transducer assembly is the most accurate method currently available for the manometric study of the human esophagus. In our study, this method was used to establish normal profiles of several physiological parameters in the human esophagus.

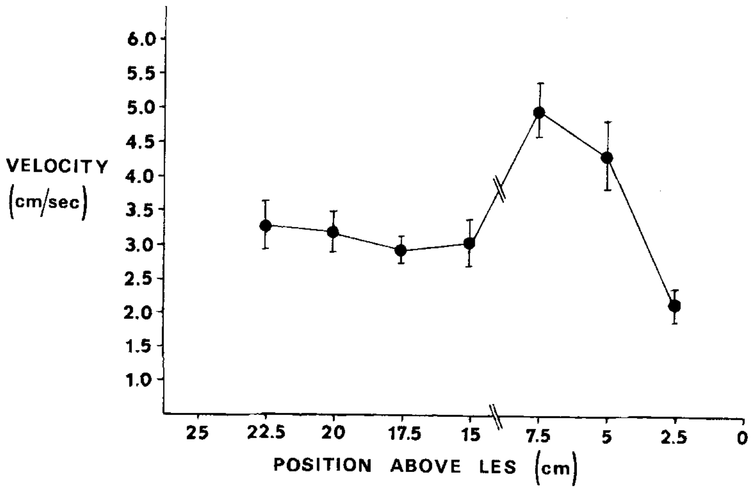

Fig 5. Mean velocity of esophageal peristalsis in the human esophagus showing a significant ($P < 0.01$) increase in the lower third of the esophagus followed by a sharp significant ($P < 0.05$) decrease abruptly above the LES. No determination was possible with the method used at the most proximal transducer in each position (25.0, 12.5, 10.0).

The amplitude or "squeeze" of peristalsis in human subjects has been frequently studied. Early reports revealed amplitude ranges of approximately 40–100 mm Hg with extremes of 10 and 140 mm Hg (1–3, 5). Pope used a water-filled, infused system (infusion rate: 40 μl/sec) to study amplitude at 2-cm intervals over the length of the esophagus (6). The range of amplitude of this "squeeze" profile was 15–110 mm Hg. Although not reaching statistical significance, a pronounced dip in "squeeze" values was noted in the upper third of the esophagus. Amplitude tended to be maximal in the lower third of the esophagus. Hollis and Castell (9), using a direct intraesophageal transducer assembly, reported the widest range of maximal amplitude values to date, 58–219 mm Hg in the distal 10 cm of the normal human esophagus. Our study, using intraesophageal transducers, supports the findings obtained by Pope with an infused system in that the amplitude profile presented also shows a pressure trough in the upper third of the esophagus. However, in our data the pressure trough achieves statistical significance, probably reflecting much less scatter. Marked variation of amplitude values with repetitive wet swallows at the same level in the esophagus did not occur. Perhaps this difference can be attributed to the greater accuracy of the transducer assembly. The occurrence of the pressure trough is probably best explained by variation in muscle response at the transition zone from striated muscle to smooth muscle located in this area of the human esophagus.

Unlike peristaltic amplitude, the profile of the first derivative of the primary peristaltic wave has received little attention in the literature. In a recent study employing eight wet swallows at each of five levels in the esophagus in five subjects, Stef et al (10) reported a mean *dp/dt* of 85 ± 5 (SEM) and 74 ± 3 mm Hg/sec in the lower third, with a drop to 51 ± 7 mm Hg/sec in the upper third. In our study, we calculated *dp/dt* at more frequent intervals to form a first derivative or slope profile. Although our values are somewhat lower, they are similar to those of Stef et al. A significant trough of low values occurs in the upper third of the esophagus and correlates well with the amplitude profile discussed above.

It is interesting to speculate upon the possible diagnostic value of *dp/dt* in the early detection of diseases of the esophagus. This parameter can be easily obtained during a standard esophageal motility study at no added discomfort or expense to the patient. An important advance in the study of myocardial contractility was the development of a method to accurately measure the rate of rise of ventricular pressure (11). Further research has proven that this factor alone is limited as an assessment of ventricular contractility, since *dp/dt* is a complex function dependent on many variables besides myocardial contractility (12). Recently, esophageal muscle mechanics have been studied in the opossum under regulated conditions similar to those used to study cardiac muscle function (13). Although this study employed *in vitro* methods, the authors suggest that the simple measurement of the amplitude of peristalsis may not provide an adequate assessment of esophageal function. Pope and Horton (14) designed an intraluminal force transducer that recorded a force profile of the normal human esophagus. Force values were lowest in the upper third of the esophagus, in close parallel to the *dp/dt* profile developed in our study. Although these parameters are unrelated, Pope's study and ours indicate that a nadir in esophageal contractility occurs in the upper third of the organ. Considering the above, it would appear that *dp/dt* may indeed be a parameter, easily obtained, that will give a more complete assessment of esophageal muscle contractility.

The velocity of esophageal peristalsis elicited as much interest as amplitude in early studies. Most authors report a velocity of 2–4 cm/sec (1–5). However, there is some difference of opinion with regard to events in the distal esophagus. Some studies suggest a slowing of the peristaltic wave as it approaches the LES (2, 3, 15, 17), while the opposite effect has also been stated (16). Our data may clarify these differing views. Mean velocity in the upper two thirds of the esophagus is within the range that has been reported. In the distal third, however, the velocity increases significantly prior to decreasing significantly abruptly above the LES.

We have presented data that establishes normal profiles for three parameters of human esophageal peristalsis: amplitude, *dp/dt*, and velocity. In addition, the possibility is discussed that *dp/dt* may be a useful parameter in the more complete evaluation of normal and abnormal muscle function. Studies are presently in progress to determine the usefulness of this measurement in disease states.

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REFERENCES

1. Butin JW, Olson AM, Moersch HJ, Code CF: A study of esophageal pressures in normal persons and patients with cardiospasm. Gastroenterology 23:278–293, 1953
2. Sanchez GC, Kramer P, Ingelfinger FJ: Motor mechanism of the esophagus, particularly of its distal portion. Gastroenterology 25:321–332, 1953
3. Kornhorst AC, Harrison K, Pierce JW: Observations on the normal oesophagus and cardia. Lancet 1:695–698, 1954
4. Fyke FE Jr, Code CF: Resting and deglutition pressures in the pharyngoesophageal region. Gastroenterology 29:24–34, 1955
5. Nagler R, Spiro HM: Serial esophageal motility studies in asymptomatic young subjects. Gastroenterology 41:371–479, 1961
6. Pope CE II: Effect of infusion on force of closure measurements in the human esophagus. Gastroenterology 58:616–624, 1970
7. Winans CS, Harris LD: Quantitation of lower esophageal sphincter competence. Gastroenterology 52:773–778, 1967
8. Pope CE II: A dynamic test of sphincter strength: Its application to the lower esophageal sphincter. Gastroenterology 52:779–786, 1967
9. Hollis JB, Castell DO: Amplitude of esophageal peristalsis as determined by rapid infusion. Gastroenterology 63:417–422, 1972
10. Stef JJ, Dodds WJ, Hogan WJ, Linehan HJ, Stewart ET: Intraluminal esophageal manometry: An analysis of variable affecting recording fidelity of peristaltic pressures. Gastroenterology 67:221–230, 1974
11. Gleason WL, Braunwald E: Studies on the first derivative of the ventricular pressure pulse in man. J Clin Invest 41:80–91, 1962
12. Mason DT, Spann JF, Zelis R: Quantification of the contractile state of the intact human heart. Am J Cardiol 26:248–257, 1970
13. Cohen S, Green FE: The mechanics of esophageal muscle contraction. J Clin Invest 52:2029–2049, 1973
14. Pope CE II, Horton PF: Intraluminal force transducer measurements of human oesophageal peristalsis. Gut 13:464–470, 1972
15. Ingelfinger FJ: Esophageal motility. Physiol Rev 38:533–584, 1958
16. Code CF: Handbook of Physiology, Volume IV, Motility. Baltimore, Waverly Press, 1968, Section 6, pp 1827–1856
17. Mukhopadhyay AK, Weisbrodt NW: Neural organization of esophageal peristalsis: Role of vagus nerve. Gastroenterology 68:444–447, 1975