Normal Esophageal Body Function: A Study Using Ambulatory Esophageal Manometry

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Objective: The objective of this study was to establish normative ambulatory manometric data for contractions and contraction propagation in three levels of the esophagus. Methods: Twenty-five healthy volunteers underwent simultaneous ambulatory 24 h manometry. Concomitant 24 h pH studies were performed to exclude the presence of increased esophageal acid exposure. Pressures were recorded over a complete circadian cycle while patients continued with their normal lifestyles including eating and sleeping. Data were analyzed with a software program that was previously modified and validated and that enables quantitation of contractions in terms of efficacy. Results: The frequency of contractions was lowest during sleep, was increased when awake, and was highest during meals. Contraction amplitude increased during meals, providing a greater propulsive force for bolus transport. Similarly, the prevalence of peristaltic waves varied according to different physiologic states, i.e., while eating, upright, awake, and sleeping. An increased amplitude and prevalence of peristalsis resulted in an increase in manometric efficacy during meals. Conclusions: This study provides normative data for ambulatory manometry for comparison when studying patients with disease. (Am J Gastroenterol 1998;93: 183-187. © 1998 by Am. Coll. of Gastroenterology)

INTRODUCTION

Ambulatory esophageal manometry is increasing in popularity, both as a research tool and as a clinical diagnostic device. Early development was limited by the lack of comprehensive software for automated analysis of the large amount of data acquired from the 24 h record. Unlike pH monitoring, pressure monitoring requires data to be stored from three or more levels of the esophagus at a frequency 32 times that required for pH data. Complex software is required to analyze the amplitude, duration, and morphology of contractions, and the resulting wave form recorded from three or more levels of the esophagus. In a previous publication we developed a computer software program to analyze these parameters, and relate them to propulsive efficacy (1). In this study we have used the program to study 25 normal asymptomatic volunteers in order to establish normative data for ambulatory manometric parameters at three levels of the esophagus over a complete circadian cycle.

MATERIALS AND METHODS

Twenty-five healthy volunteers (mean age 30 yr, range 22-48 yr) were studied. Study protocols were approved by the internal review board of the University of Southern California. All subjects completed a questionnaire to exclude any foregut symptoms or previous upper abdominal surgery. Stationary manometry was performed after an overnight fast using the stepwise pull-through technique to analyze the lower esophageal sphincter and monitor 10 wet swallows (5 cc room temperature water) from five levels of the esophageal body to analyze esophageal body function (2).

The ambulatory studies were performed with a 7 French catheter containing three microtransducers each separated by 5 cm (Sentron, Amsterdam, The Netherlands). The microtransducers had a response rate of 300 mm Hg/s and drifted <5 mm Hg/24 h. The catheter was connected to a 4 Mbyte solid state datalogger (Microdigitrapper version 4.0; Synectics, Stockholm, Sweden), calibrated in a water column to 50 mm Hg, introduced transnasally into the esophagus, and placed so that the lowermost pressure transducer was 5 cm above the upper border of the manometrically-determined lower esophageal sphincter (Fig. 1). In 12 subjects, a pharyngeal transducer was added and used to flag pharyngeal swallows.

Concomitant 24 h pH studies were performed to exclude the presence of increased esophageal acid exposure. A glass pH probe (Ingold, Urdorf, Switzerland) with an internal reference electrode was used and placed 5 cm above the upper border of the lower esophageal sphincter. Calibration of the pH probe and method of pH analysis were performed as previously described (3, 4). The individuals were sent home and encouraged to continue with their normal lifestyle. They were instructed to eat two meals, without interruption, consisting of foods with a pH of 5-7. A diary was kept to note accurate times of meals and sleep.
Data analysis

The subjects returned to the laboratory in 24 h and the catheters were removed and recalibrated. The drift of a transducer was calculated as the change in calibration before and after the study. If this exceeded 6 mm Hg, the records were excluded. Two studies were excluded on this basis. The data logger was downloaded onto a personal computer and the data were analyzed with the previously-mentioned software program, validated in our laboratory (1). This program has detailed algorithms for contraction recognition and for detection of artifacts such as coughing and sneezing (Fig. 2). Measurements of contraction amplitude, duration, and morphology as well as speed of propagation from one level to the next were made. The mode value for each 60 s interval was used for the esophageal baseline pressure. This enabled correction for minor drift in any particular channel. The threshold for contraction recognition was set at 15 mm Hg for a duration of 1 s (1). Contraction amplitude was measured from the baseline to the contraction peak, and duration was measured at the threshold of 15 mm Hg. Multi-peaked contractions had three or more peaks in which the secondary peaks had an amplitude of at least 10% of the highest peak, and in which each peak was separated from the dominant contraction by a duration of >0.5 s (1). The normal range for amplitudes of contractions for stationary manometry for our laboratory for the upper, middle, and lower esophagus were used for comparison with ambulatory data.

An additional feature of the software program was the ability to compare pressure events in one channel to those of the other channels within a time frame of 5 s between channels to define a wave. This allowed grouping of contractions occurring in the different levels of the esophagus as part of a single peristaltic event initiated by a swallow. This also enabled recognition of low amplitude contractions of short duration as valid contractions if they occurred within a wave (Fig. 3). Waves were defined as peristaltic if the progression speed was <20 cm/s, and simultaneous if >20 cm. The value of 20 cm/s was used because this closely approximates contractions occurring at the same time in two or more levels of the esophagus and excludes rapidly progressing contractions, which may have normal propulsion in the upright individual. Waves were characterized as complete if contractions were recognized in all three levels of the esophagus and incomplete (dropped or interrupted) if a contraction was not detected in any one level (Fig. 4). A contraction occurring in one channel without activity in the other channels was considered as an isolated contraction and not part of a wave.

Peristaltic waves were classified as "effective" if the amplitude of contractions in the upper, middle, and lower esophagus were >20, 25, and 30 mm Hg, respectively. This has previously been correlated with effective propulsion of liquid barium in supine individuals (5, 6). Waves with
Waves varied according to different physiologic states, for bolus transport. Similarly, the prevalence of peristaltic creased during meals, providing a greater propulsive force and was highest during meals. Contraction amplitude interruptions was lowest during sleep, increased when awake, different physiologic states (Fig. 5). The frequency of contraction showed a variability in frequency and amplitude with various wave forms are given in Table 2. The circadian volunteers are tabulated in Table 1 and the prevalence of peristaltic waves during meals. The increased amplitude and prevalence of peristalsis accounted for the increase in efficacy during meals.

**DISCUSSION**

Studies on normal ambulatory esophageal motor function over a circadian cycle are limited. Previous reports used water-perfused catheters, used catheters with only two solid state pressure transducers (allowing monitoring of only part of the esophageal body), or were based on intermittent monitoring (7-10). The current study continuously measured pressures from three levels of the esophagus, which improved the quality of the recording. This is important, as esophageal motor abnormalities may be segmental (11).

The contraction amplitudes measured in this study are similar to those in other reports (8, 12-15), but the durations were less because of the different reference point used to measure duration. The 15 mm Hg threshold was previously shown by us to be more accurate than measuring at the baseline, because of the artifact induced by respiratory fluctuations (1). Small changes in esophageal contraction characteristics with age have previously been noted using stationary manometry (16). Some caution consequently should be exercised when using the normative data in this study for elderly individuals until normative ambulatory data for this subpopulation is established. Multipeaked contractions were uncommon and tended to occur at night. Richter et al. also noted that such contractions were uncommon on stationary manometry and suggested that the presence of multipeaked contractions should raise the possibility of a motility disorder (16).

Ambulatory manometry has been criticized because of the interindividual variation of the contraction characteristics. Most investigators have accepted stationary manometry as a reliable tool. The normal ranges for ambulatory manometry for amplitude of contractions shown in this study is narrower than published ranges for stationary manometry (16). This is a function of measuring a large number of contractions over a long period of time and consequently suggests the reverse: i.e., ambulatory manometry gives a more complete assessment of the motor function of the esophagus than does stationary manometry, and calls into question the limitations of the latter.

The initial problem with ambulatory manometry was the acquisition of large amounts of data without a means for effective analysis. Consequently, the benefit of monitoring over a circadian cycle during different physiologic states was lost. This has been rectified with the software program used in this study. Unique to this software was the sensitivity of detecting low amplitude contractions, and the ability to relate contractions in three levels of the esophagus in terms of waves. This enabled more accurate analysis of contractions and wave forms (1).
The observation of an increased efficacy of waves during meals reflects the culmination of previous observations (15, 17, 18). It is known that there is a higher proportion of ineffective waves, i.e., dropped, interrupted, or simultaneous waves, for “dry” as opposed to “wet” swallows on stationary manometry (16, 19, 20). It has also been shown that there is a difference in contractions characteristics depending on the size, temperature, and viscosity of the swallowed bolus; the larger, warmer, and more viscous the swallowed bolus, the greater the contraction amplitude (21–30). This may be secondary to bolus feedback, either at the level of the pharynx, where peristalsis is initiated, or by local reflexes during bolus transport.

There are problems monitoring the esophagus during meals. An increased swallowing frequency affects contraction amplitude and the prevalence of peristaltic waves. This results from deglutitive inhibition and the muscle refractory period (27, 31). This is prevented during stationary manometry by limiting swallows to every 30 s. Allowing an unrestricted swallowing frequency makes interpretation of the ambulatory recordings more complex, but gives a physiologic assessment of motor function at a time when the esophagus is performing its primary function.

Esophageal contractions are disorganized at night when subjects are sleeping (8). During this time we recorded a higher prevalence of simultaneous waves and isolated contractions. Castiglione et al. showed that nocturnal esophageal motor activity is dependent of the stage of sleep (32). Using overnight esophageal manometry with simultaneous electroencephalography, these investigators noted an increased frequency of spontaneous activity during stage IV or rapid eye movement (REM) sleep. Others have recorded, during the night, bursts of simultaneous contractions asso-

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