Impedance nadir values correlate with barium bolus amount

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SUMMARY. We examined the value of impedance monitoring in measuring bolus volume compared with videoesophagram. Eighty consecutive subjects were studied with simultaneous impedance-manometry-videoesophagram. A catheter with both an impedance electrode pair and a pressure transducer at four sites (5, 10, 15, 20 cm above lower esophageal sphincter) was passed per nares. Six 10-cc boluses of 45% barium mixed with 0.9% NaCl were swallowed at 20- to 30-second intervals. When impedance fell to below 1000 ohms, other than that occurring during administered swallows, the videofluoroscopic image corresponding to the time of impedance nadir was reviewed. If barium was present at the impedance site, barium area was calculated. The video was reviewed for the cause of abnormal barium transit causing barium presence. We found 38/80 subjects had a total of 169 impedance falls to below 1000 ohms. Ninety-seven percent (164/169) of impedance falls had barium present at the impedance site, and there was good correlation ($r = 0.83, P < 0.001$) between impedance nadir value and barium area. The impedance nadir value : barium area relationship was similar for the three causes of barium presence identified by video: failed bolus clearing; gastroesophageal reflux; and esophageal escape. Impedance nadir values 700–999 ohms usually had a small barium area. In contrast, nadir values <400 ohms had a large barium area covering all or most of the catheter and filling the esophagus at the impedance site. Impedance falls from >1000 ohms to a low nadir value from all forms of abnormal esophageal bolus transit imply a large bolus amount.

KEY WORDS: bolus, bolus volume, impedance, reflux, videoesophagram.

INTRODUCTION

Bolus volume cannot be assessed by either manometry or pH monitoring. Esophageal manometry assesses peristalsis and contraction amplitude, but not bolus transport or volume. The pH probe measures only acid and not fluid volume.

Impedance monitoring can measure bolus transit. Impedance-pH monitoring detects reflux not identified by pH probe (nonacid reflux while pH is >4 and acid rerreflux while pH is already <4, and distinguishes bolus (impedance) from chemical (acid) clearance. Impedance manometry can assess the impact of normal and abnormal peristalsis on bolus transit. Therefore, if impedance monitoring could assess bolus volume and transit, there would be potential applications in both impedance-pH monitoring and impedance manometry.

Reports on the ability of impedance monitoring to assess bolus volume are conflicting. A preliminary report found that a novel catheter with closely and widely spaced impedance electrodes could measure bolus volume, when impedance decreased with bolus volume increases from 5 to 20 cc for liquids of varying ionic concentrations. However, Srinivasan et al. found bolus transit time was similar for all water volumes from 1 to 20 cc and impedance nadir was not examined.

We have compared bolus transit by impedance with barium esophagram in normal subjects, and preliminary findings in patients with a variety of esophageal motility disorders and dysphagia after fundoplication. We observed during these studies that very low impedance values usually had large amount of barium present. In addition, falls in impedance from a stable baseline above 1000 to below 1000 ohms were usually associated with barium entry at the corresponding electrodes from abnormal bolus transit such as failed clearing and GER. We also noted in normal subjects that impedance nadir was reached when barium...
amount was subjectively largest at the impedance site; i.e. when the barium bolus covered both electrodes and maximally distended the esophagus (Fig. 1).

The aim of this study was to evaluate the value of impedance monitoring in measuring bolus amount compared with videosophagram. We expanded on the observations mentioned earlier by identifying all impedance falls from above to below 1000 ohms other than the expected impedance fall as the barium/saline bolus was swallowed at investigator request.

The impedance site was examined for barium presence and amount at the moment of impedance nadir, when barium amount would be expected to be greatest and easiest to measure.

MATERIALS AND METHODS

Study population

Eighty consecutive normal subjects (n = 18) and symptomatic patients with a variety of esophageal

Fig. 1  Serial videosophagram images at very short intervals (most 0.1 second) showing barium bolus transit relative to impedance electrode pair (2.4 cm apart) and pressure site (located between electrodes) 5 cm above the LES (top), and corresponding impedance and pressure tracings matched with the time interval (bottom). The impedance nadir was reached when barium bolus covered both electrodes and distended the esophagus at impedance site (see cartoons 19–20). Note that only a portion of the entire boluses volume covers the two electrodes, and it extends into gaps above and below the impedance site.

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motility disorders \( (n = 42) \), gastroesophageal reflux disease \( \text{GERD}; \ n = 7 \) , and post-fundoplication \( (n = 13) \) who underwent simultaneous impedance-videoesophagram-manometry were the study population. All subjects were \( >21 \) years old, did not have previous gastric surgery (other than fundoplication for \( \text{GERD} \)), and did not use medications that affect esophageal motility for 72 hours before the test. Volunteers and patients gave written informed consent, and the study was approved by the Cleveland Clinic Institutional Review Board.

**Simultaneous videoesophagram-impedance-manometry**

Videoesophagram was performed at a rate of 30 frames/second (OES General Electric Medical Systems, Salt Lake City, UT, USA). A 9-channel impedance manometry catheter (Fig. 2) was passed per nasu such that circumferential solid-state pressure transducers were located at the lower esophageal sphincter (LES) and 5 cm above the LES, and three unidirectional pressure transducers were 10, 15, and 20 cm above the LES (Konigsberg Instruments, Pasadena, CA, USA). The proximal four pressure sensors also had impedance electrode pairs 2 cm apart embedded around each sensor to record impedance. The catheter was connected to a personal computer with software (Bioview, Sandhill Scientific, Highlands Ranch, CO, USA) for acquisition, analysis, and storage of data. Synchronization of videoesophagram to the impedance-manometry tracing was achieved by a custom-made device (Sandhill Scientific) that allowed their correlation at a 0.03-second interval.

All subjects were studied recumbent by simultaneous videoesophagram and impedance manometry for 2 minutes. They received five to six successive swallows of 10 mL of 45% barium sulfate (Mallinckrodt Inc, St. Louis, MO, USA) mixed with 0.9% saline given at 20–30 seconds intervals. Normal saline was used instead of water because this mixture had impedance value similar to saline that was much lower than water.

We examined impedance channels where baseline was \( >1000 \) ohms for \( \geq30 \) seconds for all impedance falls to below 1000 ohms other than the expected impedance fall with the requested barium swallow. For each impedance fall, the lowest impedance value was identified and termed impedance nadir. If more than 10 impedance falls occurred in a single patient, only the first 10 were included to prevent overrepresentation of a single subject in the study results.

Reviewing the videoesophagram identified two types of abnormal barium transit causing those impedance falls (Fig. 3). The first type of impedance fall occurred after barium-saline bolus was swallowed at investigator request and failed to return to the original baseline of \( >1000 \) ohms for at least 5 seconds. Videoesophagram showed incomplete clearing of the barium from the impedance site. The second type of impedance fall occurred between swallows after complete clearing to \( >1000 \) ohms of a requested swallow for \( >5 \) seconds, and before the next swallow. Video showed this type of impedance fall was caused by either: (i) gastroesophageal reflux after successful barium clearance from the esophagus; or (ii) esophageal escape; defined as migration of ‘trapped’ barium to an impedance site that had already cleared the barium for \( >5 \) seconds. The ‘trapped’ barium was located above or below the impedance site in an impedance ‘blind spot,’ and was a portion of the barium bolus that had incompletely cleared from the esophagus (Fig. 3A).

Fig. 2 Shows catheter configuration for simultaneous impedance and pressure monitoring. Five pressure sensors measure LES (P-5) and intraesophageal pressure (P1-P4). Four electrode pairs (Z1–Z4) to measure impedance to current flow surround the four intraesophageal pressure sensors. Note that sites have gaps between them leading to ‘blind spots.’
After impedance nadir was identified on the tracing, the corresponding 0.03-second frame from the videoesophagram was displayed on the monitor using the synchronization device. If barium was present, the authors traced the barium outline at the electrode pair site. The vertical boundary was from the top of the proximal electrode to the bottom of the distal electrode, which was 2.4 cm. Barium area was measured in mm², corrected for fluoroscopic magnification and categorized arbitrarily as: trivial 1–30 mm²; small 31–150 mm²; moderate 151–300 mm²; and large >300 mm² (Fig. 4).

Descriptive statistics were computed for all factors including medians, 25th and 75th percentiles for continuous factors and frequencies for categorical factors. Spearman’s correlation coefficient was used to study the association between impedance nadir and barium area. Wilcoxon rank sum tests for continuous factors and Pearson’s chi-square or Fisher’s exact tests for categorical factors were used to study the associations between several factors and impedance fall percentage. A significance level of 0.05 was used for all analyses. SAS version 9.1 software (SAS Institute, Cary, NC, USA) was used for analyses and R 2.0.1 software (The R Foundation for Statistical Computing, Nashville, TN, USA) was used for graphs.

RESULTS

Impedance falls to below 1000 ohms in all subjects

Forty-seven percent (38/80) of all subjects had impedance falls from above to below 1000 ohms at one or more electrode pair site other than the expected impedance fall on requested barium swallows. The median (range) number of impedance falls examined per patient was 4.1–10. Other subjects (42/80) had either low impedance baselines (21/42; e.g. achalasia), no impedance falls meeting the definition above (10/42),
or technical problems preventing comparison with esophagram (11/42; most commonly (7/11) the most proximal site was not in the radiographic field).

Impedance fall frequency and characteristics (baseline and nadir), and corresponding barium presence

The 38 subjects had 169 impedance falls from above to below 1000 ohms, and their median fall was 66% (50%, 76%) of baseline. The median (25th, 75th %) baseline before the 169 impedance falls was 1500 (1240, 1890) ohms, and impedance nadir was 561 (360, 760) ohms. There was no relationship between the median impedance baseline value and its subsequent nadir ($P = 0.28$).

Ninety-seven percent (164/169) of the impedance falls had at least a trivial amount of barium present at the impedance site. In examining the five impedance falls without barium present, their median nadir of 950 ohms (range 803–975 ohms) was much higher than the median nadir of 561 ohms for all impedance falls, while median baseline was 1300 ohms (range 1100–1580).

Correlation of impedance nadir to barium area in 164 impedance falls caused by abnormal barium transit

There was a good correlation between impedance nadir and barium area at impedance site ($r = 0.83$, $P < 0.001$).

Table 1 and Figure 5 show that impedance nadir values of >700 and <400 ohms usually have small and large barium areas at the impedance site, respectively. That is, for impedance nadir values >700 ohms, 86% (44/51) had a trivial or small barium area; however, 6/51 impedance falls had a moderate and 1/51 had a large barium area. For impedance nadir values <400 ohms, 96% (48/50) had a large barium area, only 2/50 had a moderate barium area, and none had a small or trivial barium area. However, intermediate impedance nadir values of 400–699 ohms had similar frequency of small (20/68), moderate (23/68), and large (25/68) barium areas.

The relationship of barium area at the impedance site to impedance nadir correlations was not significantly different for the 36 impedance falls in normal subjects compared with the 128 in patients ($P = 0.059$) and also for impedance falls at the sites 5, 10, and 15 cm above the LES ($P = 0.97$).

Table 1: Correlation of impedance nadir to barium area in 169 impedance falls to below 1000 ohms

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<thead>
<tr>
<th>Barium area (mm²)</th>
<th>Impedance nadir (ohms)</th>
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<tr>
<td></td>
<td>800–999</td>
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<td>≤30†</td>
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<td>31–150</td>
<td>9</td>
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<td>151–300</td>
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†Includes five impedance falls with no barium present.
The relationship of barium area at the impedance site to impedance nadir correlations was similar for the 81 impedance falls caused by failed barium bolus clearance and the 83 impedance falls between swallows from gastroesophageal reflux or esophageal escape (Fig. 3, \( P = 0.83 \)). Of the 83 impedance falls which occurred after bolus clearance from the electrode pair site, concurrent videoesophagram showed that 21/83 were from gastroesophageal reflux, and 62/83 from escape. There were two types of esophageal escape. The first was a result of incomplete distal esophageal clearing and is termed distal retrograde escape (Fig. 3). The barium bolus advanced normally to below the impedance site 5 cm above the LES resulting in impedance clearance \( >5 \) seconds at all four impedance sites. However, a portion of the bolus became ‘trapped’ in the most distal esophagus between the LES and the impedance site 5 cm above the LES in an impedance ‘blind spot.’ Then, this ‘trapped’ barium migrated orad to the site 5 cm above the LES or higher causing impedance fall below 1000 ohms. Of the 37/62 with distal retrograde escape, 13/37 occurred in patients with dysphagia after fundoplication as expected with a ‘tight’ wrap. However, 24/37 were in subjects without fundoplication. The second was termed ‘proximal escape.’ Videoesophagram found this was caused by migration of ‘trapped’ barium to any of the four electrode pair sites (5, 10, 15, or 20 cm). The ‘trapped’ barium was a portion of the ingested barium bolus that had incompletely cleared, and was trapped above or below the impedance site in an impedance ‘blind spot.’ Of the 62 episodes of escape, 25/62 were proximal escape.

**Impedance falls \( \leq 50\% \) from baseline**

Twenty-five percent (42/169) of impedance falls from above to below 1000 ohms were \( <50\% \) from baseline, i.e. median of 1235 ohms (1145, 1400) to 793 (648, 902). Though these impedance falls did not meet the traditional criteria for bolus entry of a 50% fall from baseline (37/42) were associated with barium presence at the impedance site due to abnormal barium bolus transit. The median barium area of these 37 impedance falls was 31 mm\(^2\) (14, 70), a trivial/small amount; in addition, all five impedance falls with no barium present were in this group.

**DISCUSSION**

This study analyzed all impedance falls from a stable baseline above 1000 ohms to below 1000 ohms with the exception of the entry of the barium-saline bolus into the esophagus. When barium-saline bolus enters the esophagus, impedance fall to below 1000 ohms is expected.

There are three major findings: (i) impedance fall to below 1000 ohms was nearly always associated with presence of barium at the impedance site from abnormal barium transit; (ii) nadir value of impedance fall had good correlation with the barium area at the impedance site; and (iii) impedance falls to \( <1000 \) ohms but \( <50\% \) from baseline were usually accompanied by small or trivial barium present at the impedance site.

The most important finding is the good correlation of impedance nadir value with barium area at the impedance site, whether in normal subjects or patients, whether 5, 10, or 15 cm above the LES, and whether impedance fall at a site was caused by incomplete bolus clearance versus gastroesophageal reflux or esophageal escape. However, correlation was good rather than excellent because of the wide variation in barium areas with impedance nadir values between 400 and 700 ohms as seen in Figure 5.

This good correlation would suggest that impedance nadir value has a role in assessing bolus volume. However, a study limitation is that we could examine only the portion of the bolus within the 2.4-cm impedance site rather than the entire bolus. The barium often extended above and/or below the 2.4-cm site into blind spots (see Fig. 1), which were 2.6-cm long between impedance sites in the study catheter (see Fig. 2). We speculate based on this study that impedance catheters without large blind spots between impedance sites could assess the entire bolus. Other limitations include that we measured barium area (two-dimensional) and not bolus volume (three-dimensional). We did not use biplane fluoroscopy to measure barium depth, which could measure barium volume, assess other components in the bolus,

![Fig. 5](image_url)
especially gas, and determine the exact position of the catheter relative to the esophageal wall. To our knowledge, there are no published data evaluating esophageal bolus volume in three-dimensional. Furthermore, different mucosal surfaces have a different impedance baseline. Patients with varying degrees of esophagitis, achalasia, or Barrett’s esophagus have a lower impedance baseline than normal individuals, and the degree of impedance fall may differ. Moreover, we arbitrarily chose barium areas as trivial, small, moderate, and large, as no previous data exist, and did not assess dysphagia severity to correlate with barium area. These limitations should be addressed in the future.

The recent evolution of high-resolution manometry and high-resolution impedance has allowed peristaltic integrity to be assessed simultaneous with esophageal transit clearance. The thresholds of peristaltic integrity for complete bolus clearance was determined to be transit clearance. The thresholds of peristaltic integ-

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contractions be desirable? Except for excluding achalasia, the value of esophageal manometry has not been clearly demonstrated in either deciding who should have antireflux surgery or whether surgery should be ‘tailored’ based on the severity of findings.21–23 It has been found that clearance of a food bolus at esophagram preoperatively predicts favorable outcomes after fundoplication in patients with dysmotility.24 Even though a study showed that bolus transit assessment by impedance does not predict post-fundoplication dysphagia,21 combined impedance manometry in dysphagia patients revealed that all patients with achalasia, ineffective esophageal motility, and diffuse esophageal spasm and normal manometry had abnormal bolus transit. Only nutcracker esophagus patients had normal transit.25 Perhaps prolonged falls in impedance to low values from large retained boluses may be of additional value to the manometric findings.

In summary, impedance falls to below 1000 ohms from abnormal bolus transit nearly always had barium present at impedance site. More important, there was good correlation between impedance nadir value and the amount of barium present simultaneously at the impedance site, whether for: (i) normal subjects or patients; (ii) 5-, 10-, or 15-cm impedance sites; and (iii) impedance falls from failed bolus clearing, gastroesophageal reflux, or retrograde escape. However, to allow the entire bolus amount in the esophagus to be assessed rather than just the bolus at one impedance site, higher resolution impedance catheters will be required to eliminate gaps between electrodes.

References


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