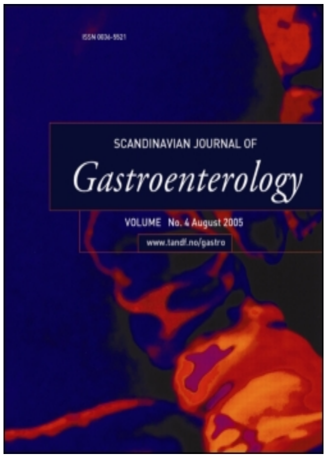

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Measuring Esophageal Motility with a New Intraluminal Impedance Device: First Clinical Results in Reflux Patients

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Measuring Esophageal Motility with a New Intraluminal Impedance Device

First Clinical Results in Reflux Patients

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Fass J, Silny J, Braun J, Heindrichs U, Dreuw B, Schumpelick V, Rau G. Measuring esophageal motility with a new intraluminal impedance device. First clinical results in reflux patients. Scand J Gastroenterol 1994;29:693–702.

Background: The study was undertaken to determine the validity of intraluminal impedance measuring for the diagnosis of esophageal motility disorders in reflux patients. *Methods:* A new impedance device was used for the detection of esophageal motility patterns in a prospective study with 10 volunteers and 10 patients with reflux esophagitis grade II–III. Perfused manometry was correlated with the impedance tracings. Test meals were saline and curd in three different preparations with liquid to semisolid viscosity. *Results:* There was a marked delay in esophageal transport with increasing viscosity of the bolus ($p < 0.01$). A significant ($p < 0.001$) delay of the bolus transport in the inflamed esophageal areas was seen in reflux patients. A reduced contractility of the lower esophagus and the lower esophageal sphincter was detected by the impedance procedure in reflux patients, indicating that the pathologic motility patterns in reflux esophagitis are most likely secondary to the tissue inflammation. *Conclusion:* We conclude that impedance procedures may give additional significant information about bolus transport and esophageal wall movements.

Key words: Bolus transport; esophagus; gastroesophageal reflux; impedance measuring; motility; reflux esophagitis

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Despite the development of sophisticated manometry systems there are still methodologic problems in the investigation of esophageal motor function: the dislocation of the measuring points during swallowing, the asymmetric distribution of the intraluminal pressure in sphincter areas, and the flow-dependent measuring kinetics. Additional disadvantages of perfused catheters are motor stimulation by the perfused fluid and the thickness of multichannel probes (1–5). The application of semiconductor miniature transducers has improved the situation in part, but their high price and mechanical fragility hinder a widespread introduction of this procedure (1, 5). Manometric continuous sphincter recording is possible with sleeve catheters (6), which sense only in one direction (5), or the sphinctometer (7), which refers to pressure and sphincter length. The first approach to three-dimensional manometric analysis of the geometry of lower esophageal sphincter (LES) motility was made by Bombeck et al. (8). But the physical limitations of the size of the pressure measurement device limited the practicability of the system.

Generally, so far manometric studies have failed to establish clear cut-off points in individuals, owing to a large overlap of manometric variables in healthy volunteers and reflux patients (9). The possible cause of this situation is that the changes in the intraluminal pressure only describe one phenomenon of esophageal motility. The real motions of the esophageal wall and their correlation with time and the characteristics of the bolus transport can be imagined but not measured.

In 1971 a first attempt was made by Harris et al. (10) to use intraluminal impedance tracings for the measurement of ureteral cross-section areas and flow characteristics of intraluminal contents. Others (11–15) have later used the method for motility studies in different luminal organs. The first impedance studies investigating esophageal bolus transport were done by Fisher et al. (15). A new impedance device for the measurement of motility patterns in the gastrointestinal tract was presented by Silny (16). The present study was undertaken to determine the validity of the intraluminal electric impedance procedure for the diagnosis of esophageal motility disorders in reflux patients. Because a pathologic esophageal clearance function is most likely a common feature of reflux esophagitis, the patterns of bolus transport were studied in particular.

PATIENTS AND METHODS

The impedance procedure used in the present study was

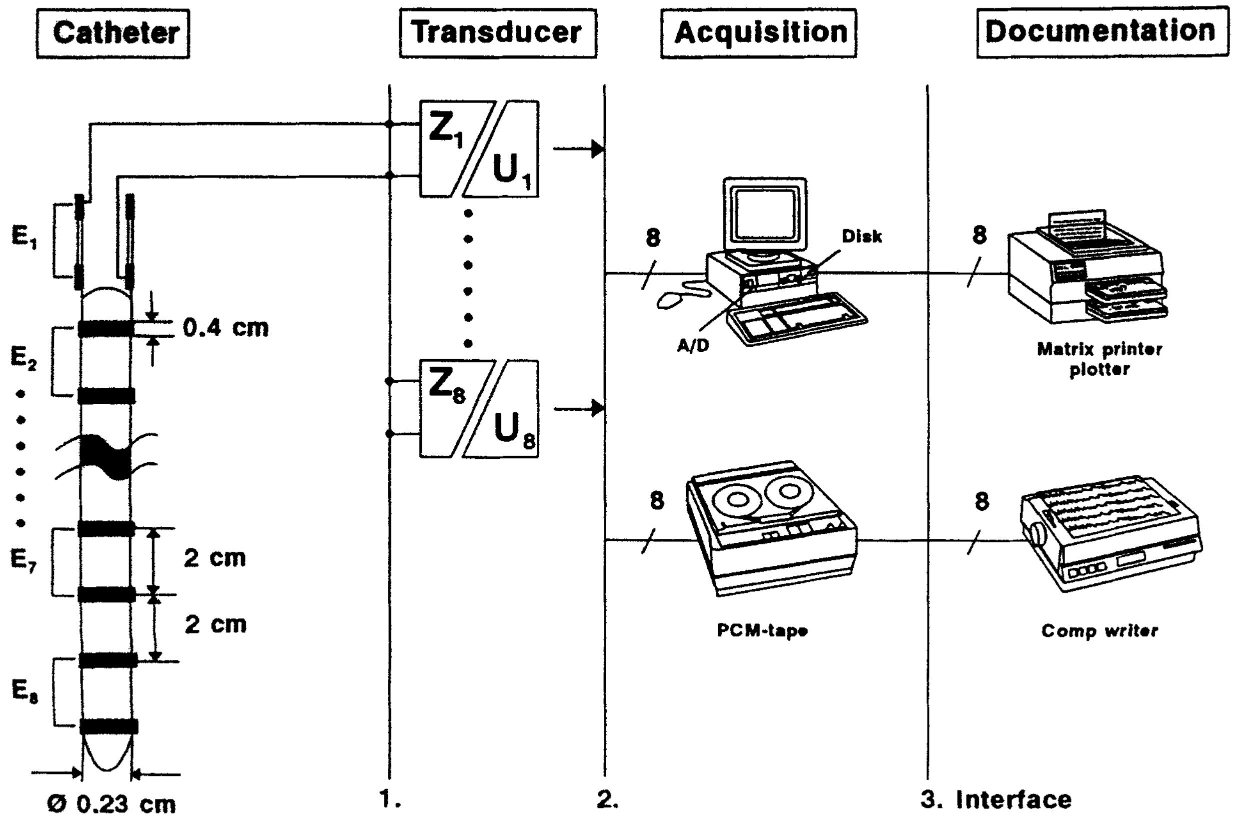


Fig. 1. Set-up for the intraluminal measurement of impedance signals. Thin wires running inside the polyamide catheter connect the electrodes to the impedance voltage transducers outside the body. Data acquisition and documentation are achieved conventionally and computer-assisted.

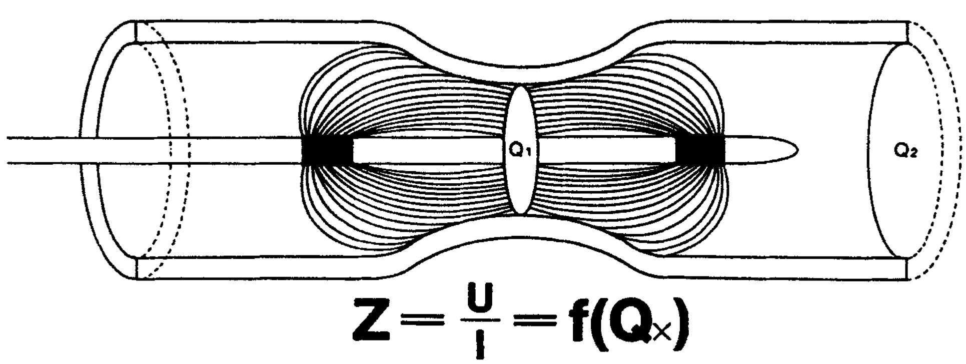


Fig. 2. Principle of impedance measurements: changing cross-section areas (Q_x) caused by peristalsis and the passing bolus generate characteristic variations of the impedance (Z) between two electrodes.

based on the multiple and simultaneous recording of intraluminal electric impedance by a probe consisting of cylinder-shaped metallic electrodes mounted on a thin plastic catheter. Each neighboring electrode pair was connected to an impedance voltage transducer outside the body via thin wires running inside the plastic tube (Fig. 1). Changing cross-section areas (Q) caused by peristalsis and the passing bolus generate characteristic variations of the impedance (Z) values, which give the possibility for a detailed analysis of the esophageal motility patterns (Fig. 2). The procedure measures an average impedance from one interval, which is denoted as a longitudinal bandwidth. The longitudinal bandwidth shows a linear correlation with the bolus thickness.

The impedance tracings were analyzed in accordance with the suggestion of Silny (16). The typical course of an imped-

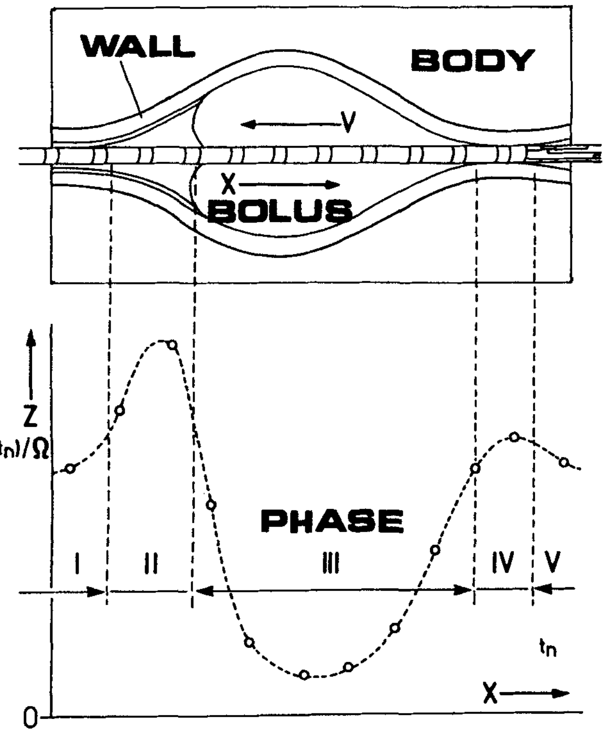


Fig. 3. Electric impedance procedure: form and interpretation of the peaks. Phase I: esophagus at rest; phase II: air in front of the bolus; phase III: region of the bolus; phase IV: contraction of the esophageal wall; phase V: relaxation of the esophageal wall. Z = impedance (Ω); v = transit velocity (cm/sec). Adapted from Ref. 16.

ance peak includes five phases (Fig. 3). Phase I characterizes the resting stage of the muscular wall. Phase II is marked by an air volume in front of the bolus. Phase III encloses the region of the bolus and starts when the descending line of the phase II peak crosses the resting level. Phase IV represents the active contraction of the peristaltic wave and correlates with the visible peak in manometry. Finally, in phase V the wall muscles relax and return slowly to the initial resting state. The propagation velocity of the contractions (v_1) was measured between the highest points of phase IV (Fig. 4a). Calculations of the bolus transport velocity (v_2) were done between the starting points of phase III. Information was thus obtained about the propagation of the bolus front. The amplitude of contraction was calculated as the difference between the deepest point of phase III and the resting line. It represents the degree of esophageal wall movement and therefore provides other information than intraluminal manometry, which refers to the strength of the muscular contraction.

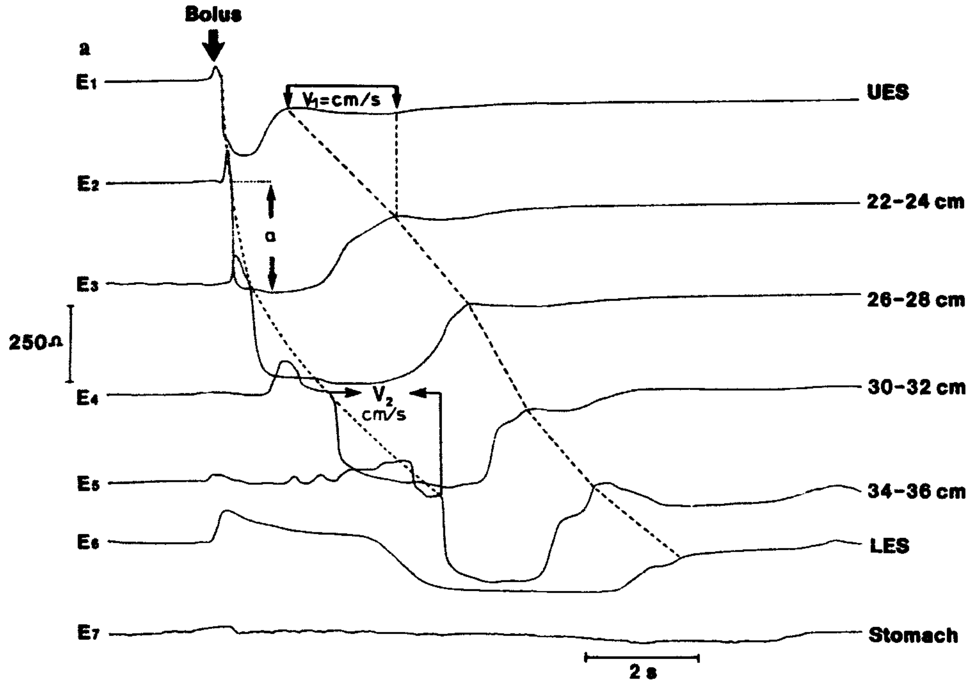
Ten healthy symptom-free volunteers aged between 24 and 33 years (mean, 28.3 years) were investigated, after giving informed consent, with the above-described impedance procedure. None of these individuals had a history of foregut symptoms, upper gastrointestinal disease, or previous esophageal, gastric, duodenal, or biliary surgery. All showed normal results in 24-h pH-monitoring. In all controls a conventional perfused manometry with eight measuring ports was performed to exclude motility disorders and for the comparison of the methods (Micro-Perfusion-Pump, MUI Scientific, Canada; flow rate, 0.5 ml/min/channel; and registration, display, and analysis, Software 'Polygram' by Synectics Corp. and IBM PC-286). The measuring ports of the manometry probe (diameter, 4.2 mm) were arranged at 4-cm distances with a radial array of 45° (MUI Scientific).

The impedance probe consisted of 20 cylinder-shaped electrodes placed on a 2.3-mm-diameter catheter at 2-cm distances guaranteeing an 8-channel study in all probe positions (Fig. 1). All catheters were made of polyamide or polyvinyl chloride and had similiar mechanical properties. Measuring value was the changing impedance between every two electrodes. Each voltage transducer was equipped with galvanic insulation between the patient and the acquisition unit. A measuring current of 6 μA at a frequency of 1 kHz flowing between the two electrodes of each impedance channel was several decades below the stimulation threshold of the nerves and muscles.

The exact position of the esophageal sphincters was measured by pull-through manometry. After the probe had been introduced into the esophagus a radiologic control of the catheter position followed. The signals after swallowing were modulated, amplified, and registered on a PCM recorder (Stellavox, 4S 17/W). Then, again, the modulated and filtered signals were analyzed as a function of time and visualized by an eight-channel polygraph (Picker Uniscript, UD 210). Test meals were 15 ml of NaCl (0.9%) solution and commercially available curd with vanilla flavor in three different preparations. A bolus volume of 15 ml was chosen because it showed the most constant bolus transport variables in preliminary investigations and, in the case of curd, represented a realistic eating situation (one tablespoonful). A semisolid to liquid viscosity was obtained by mixing the curd with different amounts of milk (100 g curd with 30 g, 60 g, and 90 g milk). All manometric and impedance investigations were done in the upright position as suggested previously (17, 18). The investigations started with water and were then followed by the curd swallows with increasing viscosity. Between each two curd swallows an application of water was introduced to clear off rests of bolus possibly remaining in the lumen or being attached to the catheter.

Additionally, 10 individuals with reflux esophagitis grades II to III were investigated in the same manner (age, 37–72 years; mean, 48.2 years). All patients had a conventional manometry, an upper gastrointestinal endoscopy, and a 24-h esophageal pH-monitoring to confirm the diagnosis. Medical treatment was interrupted 1 week before the start of the investigation series. Then the impedance and manometric measurements were performed in the above-described design.

For the analysis of manometric and impedance data of the



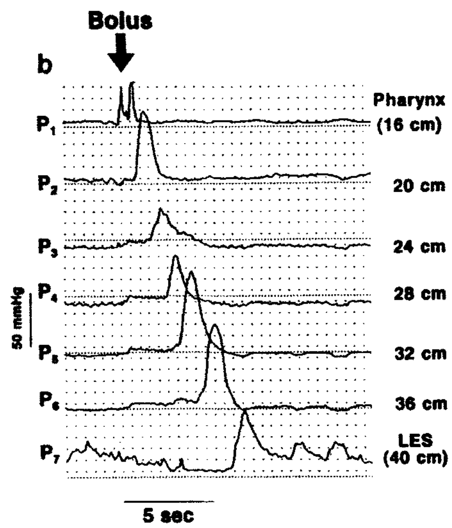


Fig 4a. Impedance tracing of a male healthy volunteer (26 years old, upright position) after deglutition of 15 ml curd with medium viscosity. UES and LES = upper and lower esophageal sphincter. E_n = electrode pairs; v_1 = velocity of contractions between E_1 and E_2; v_2 = velocity of bolus transport between E_4 and E_5; a = amplitude of contraction (E_2). E_1–E_3: the base lines do not completely return to precontraction levels because small amounts of curd stay attached to the probe. 4b. Conventional perfused manometry of the same individual. The propagation velocity of the contractions corresponds to the impedance findings (v_1). Simultaneous measurement of the UES and LES was not possible in this case.

tubular esophagus a distinction was made between the upper tubular esophagus (UTE) and the lower tubular esophagus (LTE). The position of the UTE was defined as the location of the two measuring points aborally to the UES, and the LTE was in the position of the two measuring points orally to the LES. Each segment therefore represented a length of 8 cm of proximal or distal tubular esophagus.

The Wilcoxon–Mann–Whitney U-test was used for statistical analysis of the data. A probability of less then 0.05 was taken to indicate statistical significance. Data in the tables and text are indicated as median and range. For better illustration the data in the figures are shown as mean ± SEM.

RESULTS

The transnasal introduction of the impedance probes was easy and quick, and the individuals had no complaints during the procedure. No complications occurred. The method was able to detect significant differences in the motility patterns between volunteers and patients.

Healthy volunteers

The impedance procedure showed a characteristic course of normal esophageal motility. The typical patterns of the manometrically localized sphincters could be demonstrated as well.

Table I. Motility patterns of the upper tubular esophagus in healthy volunteers and reflux patients, fed a test meal consisting of curd with medium viscosity, in the upright position. Results are indicated as median and range

	a(kΩ)	v_1 (cm/sec)		v_2 (cm/sec)
		Impedance	Manometry	
Healthy volunteers (n = 10)	0.85 (0.61–1.09)	3.3 (2.9–3.6)	3.4 (3.0–3.7)	13.4 (11.8–16.2)
Reflux patients (n = 10)	0.76 (0.53–0.98)	3.2 (2.8–3.5)	3.2 (2.9–3.6)	12.8 (11.4–16.7)
p	NS	NS	NS	NS

a = amplitude of contractions; v_1 = velocity of contractions; v_2 = velocity of bolus transport.

Table II. Motility patterns of the lower tubular esophagus in healthy volunteers and reflux patients, fed a test meal consisting of curd with medium viscosity, in the upright position. Results are indicated as median and range

	a(kΩ)	v_1 (cm/sec)		v_2(cm/sec)
		Impedance	Manometry	
Healthy volunteers (n = 10)	1.05 (0.86–1.32)	2.8 (2.6–3.1)	2.9 (2.6–3.2)	4.7 (3.6–5.9)
Reflux patients (n = 10)	0.66 (0.43–0.94)	2.7 (2.5–3.1)	2.8 (2.5–3.1)	2.2 (1.4–3.8)
p	0.01	NS	NS	0.01

a = amplitude of contractions, v_1 = velocity of contractions, v_2 = velocity of bolus transport

In Fig. 4a the area of the UES is shown in the first channel (E_1). A quick passage of the bolus is followed by a short and strong contraction. At the same time, channel 6 (E_6) shows a marked increase of the impedance, which can be interpreted as a relaxation of this segment with air contents. This is the position of the LES. After the bolus has passed in 6–8 sec, the sphincter returns to its quiescent state. In the tubular esophagus the bolus geometry changes (phase III), and the contractions (phase IV) occur at regular intervals. This correlates with the pressure peaks in perfused manometry (Fig. 4b). Channel 8 (E_8) is not shown because its position in this procedure was in the gastric fundus and showed no activity. Small amounts of remaining bolus material attached to the probe may hinder the base lines from immediately returning to precontraction levels (E_1–E_3).

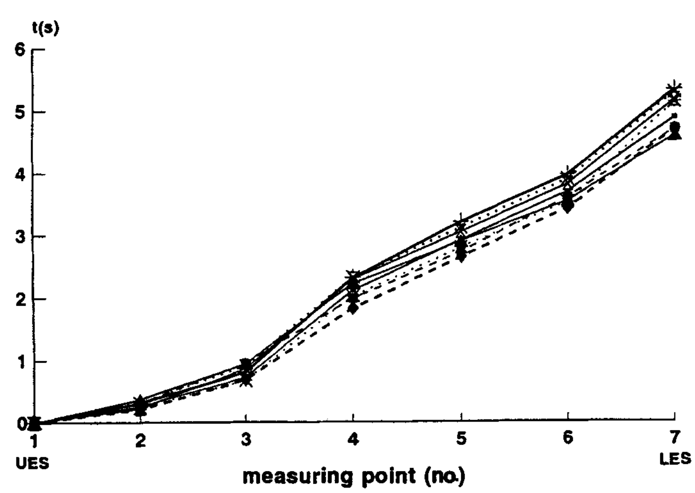


Fig. 5. Impedance procedure: intraindividual variance of eight consecutive esophageal transit functions with deglutition of 15 ml curd with medium viscosity. Healthy male volunteer (32 years old, upright position). UES and LES = upper and lower esophageal sphincter.

The median of the propagation velocity of the contractions (v_1) in the tubular esophagus with curd of medium viscosity as test meal was 3.3 (range, 2.9–3.6) cm/sec in the UTE and 2.8 (range, 2.6–3.1) cm/sec in the LTE. These data corresponded well with the manometric findings. The transit velocity of the bolus (v_2) showed a median of 13.4 (range, 11.8–16.2, UTE) cm/sec and 4.7 (range, 3.6–5.9, LTE) cm/sec, respectively (Tables I and II). Thus a significant decrease of the bolus velocity in the aboral direction was diagnosed. Intraindividual variance was small, accounting for a maximum of ±8.4% (Fig. 4). The bolus transit velocity (v_2) rose with decreasing viscosity of the curd (Fig. 5). The differences in the viscosity-dependent transit functions were significant ($p < 0.01$). The length of the bolus (phase III) increased in the aboral direction, whereas the amplitude of the contractions was nearly constant (Tables I and II).

Reflux patients

In the impedance studies a reduced motility of the LES was demonstrated in all reflux patients (Fig. 6). A diminished relaxation (median, 82 Ω; range, 43–162 Ω) was seen in an open sphincter, and a small contraction followed (E_7). In contrast, manometry showed a lack of the distal high-pressure zone in only six patients. Three patients had a high-pressure zone shorter than 2 cm, and one individual had grade-II reflux esophagitis with a manometrically normal LES. In the impedance studies the diagnosis of motility disorders of the distal parts of the esophagus was common (Fig. 7): the base line in phase V stayed far above the precontraction level and finally decreased slowly after a second swallow (E_4–E_6). This phenomenon could be demonstrated exclusively in reflux patients and was distinct from the effect of bolus rests staying attached to the esophagus, where the base line remained below the precontraction level (Fig. 4a). According to the theoretical basis of impedance measurement, this decrease of conductivity must be interpreted as a rigid contraction over a long period (spasm) or insufflation of an intraluminal content with low conductivity (for example, air). The probability that the first explanation (spasm) is correct is much higher because it would be unusual for a bolus of air to stay constantly unchanged in a long segment over at least 20 sec. Because this phenomenon was not seen in conventional manometry the motoric basis of the spasm was most likely a non-occluding contraction.

The proximal parts of the esophagus showed normal motility patterns in both types of study.

Detailed analysis of the impedance peak amplitudes showed significant differences between healthy volunteers and patients, confirming the impairment of the distal esophageal clearance function (Fig. 8). In the LTE, consequently, the median of the impedance contraction amplitudes was significantly ($p < 0.01$) higher in controls than in reflux

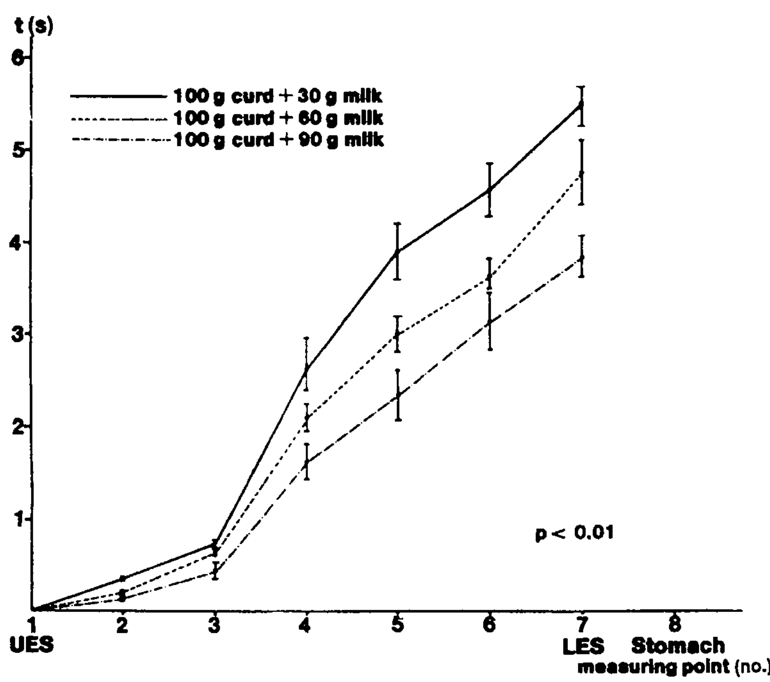


Fig. 6. Impedance procedure: correlation between esophageal bolus transit function (v_2) and viscosity in three types of curd preparation (bolus volume, 15 ml). Cumulated curves of 10 healthy volunteers (24–33 years old, upright position). The differences between the transit functions of the different viscosities were significant ($p < 0.01$). Data are mean ± SEM. UES and LES = upper and lower esophageal sphincter.

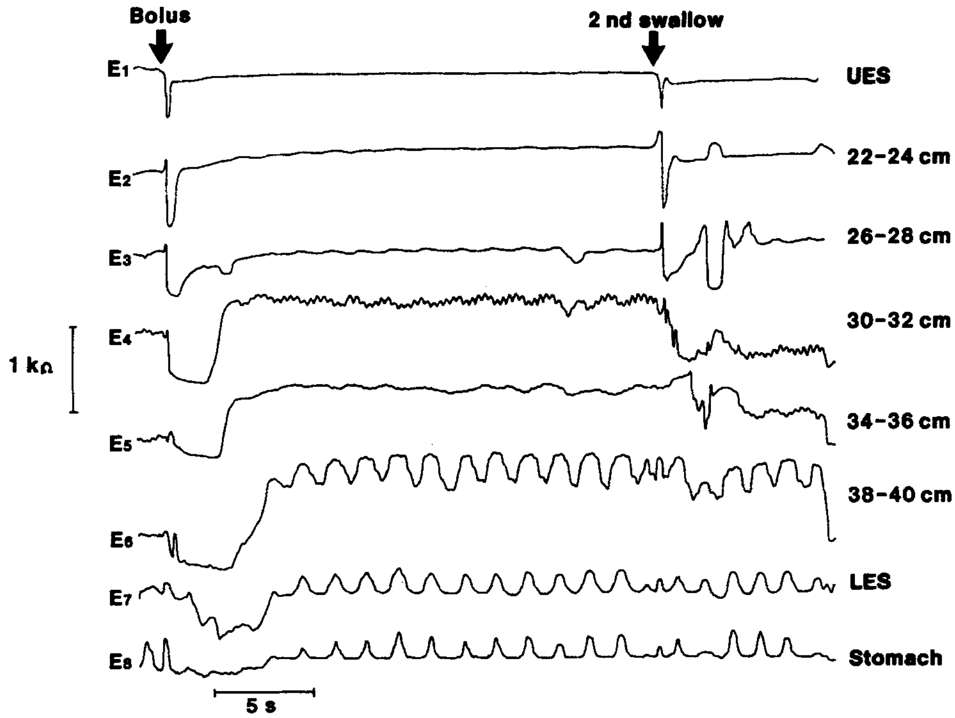


Fig. 7. Impedance tracing of a male patient with grade-II reflux esophagitis (46 years old, upright position) after deglutition of 15 ml curd with medium viscosity. In the distal parts of the esophagus (E_4–E_6) the impedance does not descend to base line again after deglutition. This can be interpreted as a non-occluding spasm of the esophageal wall that is solved by a spontaneous second swallow. E_n = electrode pairs. Artefacts: E_4 = heart action, and E_6–E_8 = breathing. UES and LES = upper and lower esophageal sphincter.

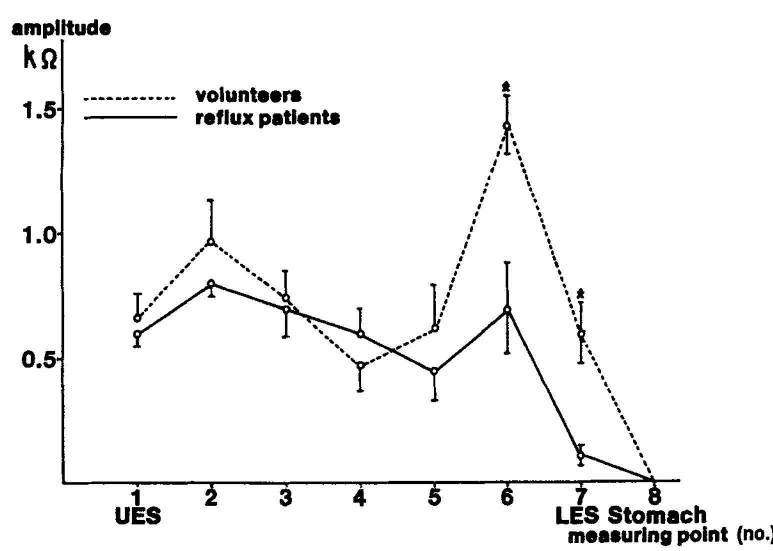


Fig. 8. Analysis of the impedance amplitudes of contraction (a) of healthy volunteers (n = 10) and reflux patients (n = 10). The lines show the means of amplitudes (a) ±SEM of all reflux patients and volunteers at each electrode pair. Asterisks indicate a significant difference of $p < 0.01$. Test meal: 15 ml curd with medium viscosity, upright position. UES and LES= upper and lower esophageal sphincter.

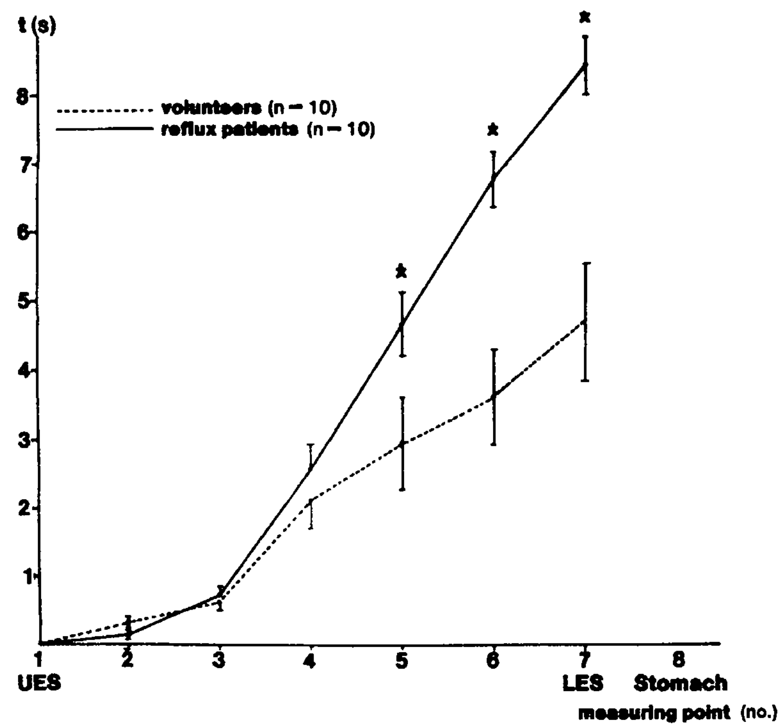


Fig. 9. Cumulated esophageal transit functions of healthy volunteers (n = 10) and reflux patients (n = 10) detected by impedance studies. There is a marked delay of the bolus passage (v_2) in the distal parts of the esophagus (E_5–E_7). Asterisks indicate a significant difference of $p < 0.001$. Test meal: 15 ml curd with medium viscosity, upright position. Data are mean ± SEM. UES and LES = upper and lower esophageal sphincter.

patients (Table II). A much better contractility of the LES was obvious in healthy volunteers too. Again there was no difference in the contractility in the proximal portions of the esophagus between the two groups. Comparison of the cumulated esophageal transit functions (v_2) of all patients with those of healthy volunteers showed a marked delay of the bolus passage in the distal parts of the esophagus (Fig. 9). The differences for the distal measuring points (E_5–E_7) again were significant ($p < 0.001$).

DISCUSSION

Very little is known about the correlation between the movements of the esophageal wall and the motions of a bolus. Recently, an attempt was made by some authors (20, 21) to combine manometry with videofluoroscopy to obtain information about the correlation between pressure recordings and the esophageal bolus transport. The results show that radiography is insensitive to contractions occurring in esophageal segments devoid of bolus fluid, whereas manometry is insensitive to contractions that do not occlude the lumen. Another important finding is that intrabolus and extrabolus pressures seem to have different properties because the transmission of pressure throughout a relatively static fluid bolus results in isobaric pressure tracings with an amplitude and waveform similar to those recorded simultaneously at all manometric sites located within this continuum (20, 22). So the proper evaluation of esophageal motor function requires both detection of occluding and non-occluding esophageal contractions and information about the bolus movements.

Impedance studies have been used for the detection of changing cross-section areas in different luminal organs (10–15). Our data again confirm that a multichannel impedance procedure seems to be able to detect the esophageal motility patterns quantitatively and in their correlation with time. Advantages are its low invasivity (thin catheters, no perfusion), the free choice of the number and distance of the measuring sections, and, above all, the possibility to detect directly the relationship between the motions of the esophageal wall and the bolus transport. A dislocation in the sphincter areas is hardly possible, because the impedance is measured over a section and not only in one point as in manometry. In contrast to other data (10, 13, 15) a bipolar two-electrode system with a spacing of 2 cm has been shown to be adequate for high-resolution measurements of bolus movements in the esophagus (16). In our study the intraindividual variance of data was small, so that reproducible results could be expected. One important variable for the interpretation of esophageal transport and velocity calculations was the consistency of the swallowed bolus. Like others (19), we found that there is a marked delay in esophageal transport with increasing viscosity of the swallowed substance. This and the slowing of the bolus in the aboral direction may have caused the big difference in the data of Fisher et al. (15), who found much higher front velocities of a liquid saline bolus. Yet it is not quite clear whether these measurements possibly refer to the air volume in front of the bolus. As a result, in all comparative studies dealing with bolus transport the viscosity of the test meals should be standardized and mentioned. In impedance studies after each procedure a swallow of clear water should be administered because small amounts of bolus material attached to the probe may cause artefacts.

The main defects that lead to esophageal reflux disease are generally attributed to a dysfunction of the gastroesophageal sphincter area. The ability of the LES to protect the esophageal mucosa from exposure to gastric juice has been identified to depend on its resting pressure, the length exposed to abdominal pressure, and overall length (18, 21, 23). Furthermore, other esophageal motor abnormalities have been found in reflux patients, such as a delayed bolus transit and a disturbance of the esophageal clearance function (21, 24–27). It is, however, not yet clearly defined whether the motor abnormalities precede or follow the appearance of the mucosal lesions.

In the impedance studies a marked delay of the bolus transport in the distal third of the esophageal body was found in reflux patients. The uninvolved parts showed normal motility patterns. The impairment of the esophageal clearance function in the presphincteric area can be explained by a non-occluding spasm of the esophageal wall disturbing its motor function. The same phenomenon was seen in the LES as well. Here the impedance procedure showed a diminished motility of the esophageal wall in reflux patients. These findings correlate with the data of Shaker et al. (27), who could show that in patients a four- to five-fold greater acid exposure occurs in the distal esophagus than in the proximal third and that the acid clearance time is also significantly longer in the distal esophagus than in the proximal esophagus. Data from experimental esophagitis (26) have shown that esophageal inflammation can lead to an increased irritability and decreased stimulus response of the smooth muscles of the esophagus. Long-term studies of patients with erosive esophagitis have shown that after healing of the inflammation the LES basal tone is significantly increased (25). All these data suggest that the disturbed motor activity of the distal esophagus and the LES in patients with reflux esophagitis are secondary to the mucosal inflammation. The impaired esophageal clearance function in the diseased parts is most likely caused by a pathologic motor response of the smooth muscles in the neighborhood of inflamed mucosa.

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