Human Gastric Blood Circulation Evaluated by Endoscopic Laser Doppler Flowmetry

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Endoscopic laser Doppler flowmetry was used to study gastric blood circulation in 34 healthy subjects. This paper presents the results of methodological studies and blood flux measurements in different parts of the stomach. In the recorded curve the flux level was easy to define, even though fluctuations synchronous with heart beat, respiration, and peristalsis were visible. The temporal and spatial variations of recorded values were within acceptable limits. Angulation between the measuring probe and mucosa and moderate pressure of the probe against the gastric wall did not seem to influence the recorded values significantly. When the blood circulation was examined in different parts of the stomach, the values along the lesser curvature were significantly lower than the values along the greater curvature ($p < 0.01$).

Key words: Gastroscopy; laser Doppler flowmetry; lasers; methods; splanchnic circulation; stomach

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Several techniques, including clearance methods and microsphere distribution techniques, have been applied to investigate changes in the mucosal circulation (1–3). The clinical usefulness of these techniques has for technical reasons been limited.

The use of the laser Doppler technique for blood flow measurements was first described by Riva et al. (4). Preliminary results have been presented, using this technique to examine gastric wall circulation (5, 6).

The aims of the present paper were to discuss the technical aspects of the method and to present the results of measurements of human gastric circulation by means of endoscopic laser Doppler flowmetry (LDF).

METHODS AND MATERIALS

Principle of determination of relative blood flow with laser Doppler flowmetry

When light is scattered from a moving object, such as an erythrocyte, the frequency of the light is changed (Doppler-shifted). The magnitude of the Doppler shift in illuminated tissue is dependent on the product of the number of moving erythrocytes and their velocity (cell flux). By means of monochromatic laser light and a photodetector the Doppler shift of the scattered laser light reflecting back to the probe can be measured, and hence blood flow may be estimated (Fig. 1).

Laser Doppler equipment

Cell flux was measured with a 2-mW helium neon laser Doppler flowmeter (Periflux, Perimed, Sweden), operating at a wavelength of 632.8 nm. The results were recorded with a linear pen recorder (Graphtec Mark VII). The flux value was expressed in units of relative flux. The zero value was defined by placing the laser probe against a white surface, and 40% of full scale level was calibrated against a standard latex solution, as recommended by Perimed. At Periflux gain 1 and full flowmeter deflection the relative flux was defined as 100; at gain 10 the related flux value was 10. All measurements were performed with a 4-kHz Periflux filter.

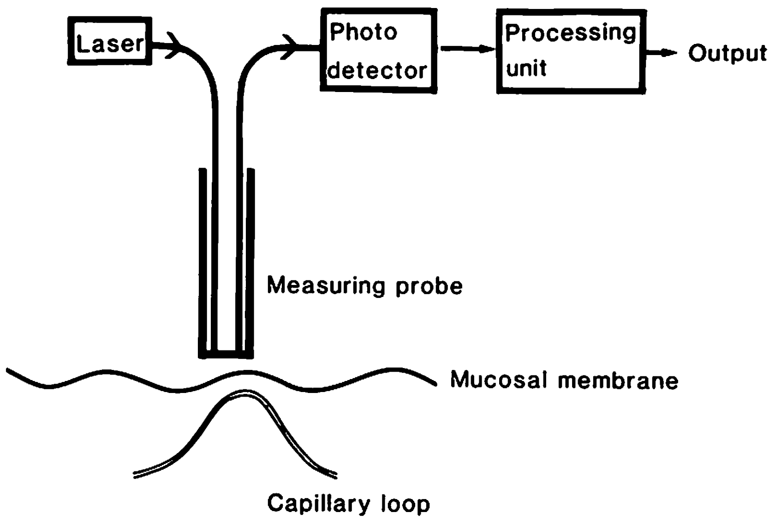

Fig. 1. Schematic illustration of the laser Doppler equipment.

Endoscopic equipment

Gastroscopies were performed with Olympus GIF K II flexible gastroscope with one biopsy channel or with Olympus T.G.F. 2 D with two biopsy channels. During the endoscopy air insufflation was minimal, to prevent distention of the stomach.

The laster light was transmitted through the biopsy channel of the endoscope by a fiberoptic cable with an outer diameter of 2.35 mm, and all parts of the stomach could be investigated.

Measurements of peristalsis

A displacement transducer ('peristaltometer') was constructed to record linear movement in the gastric wall during peristalsis. The transducer had an outer diameter of 2.5 mm, and it could be passed through one of the biopsy channels in the two-channel gastroscope for simultaneous measurements with the LDF. The tip of the transducer was placed against the gastric wall, and movement caused by peristalsis was recorded by the linear pen recorder.

Subject selection

The material consisted of 34 healthy volunteers, 18 female and 16 male. Mean age was 28 years (range, 19–36 years). No one was taking medication regularly or had a history of previous gastrointestinal disease. They were examined after an overnight fast. Premedication was not given.

Studies performed

1. On eight occasions the effect of distance and contact pressure between the probe and the mucosa was recorded a) with the probe 2–3 mm from the mucosa; b) with the probe in slight contact with the mucosa (the red laser light diffused was easily visible in the gastroscope); c) with more firm pressure applied (no red light visible); and d) with heavy pressure applied (bending of the probe and no red laser light visible).

2. The influence of the angle between the measuring probe and the gastric wall was examined in six subjects.

3. The influence of peristalsis on the laser Doppler curve was examined by simultaneous recordings with the laser Doppler and the 'peristaltometer'. In seven patients with heavy peristalsis an anticholinergic drug, butylscopolammonium bromide (Buscopan®), 20 mg, was given intravenously to inhibit peristalsis, while the laser Doppler curve was recorded continuously.

4. The circulatory effects of deep inspiratory gasps were recorded in six subjects.

5. On 68 occasions in 22 subjects 2 measurements were performed with a distance of 0.5–1 cm to test the spatial variation.

6. On 14 occasions in 7 subjects the measurements were performed twice with a 10-min interval in the same area to test the reproducibility of the method (temporal variation).

7. In 23 subjects measurements were performed at 8 defined positions in the esophagus and the stomach. In addition, the circulation in the duodenum was recorded in six subjects.

Statistical methods

All results are expressed as medians with 95% confidence intervals and total ranges. The Bernoulli–Wilcoxon method (7) was used to determine the confidence intervals. Both the coefficient of variation (SD/mean) and the 50% interquartile range were used as dispersion indexes.

All tests performed during these studies were one-tailed. Differences were considered to be significant when the p values were less than or equal to a 5% level (8).

Non-parametric methods with correction for ties were used to test differences in the location parameter (7). For testing differences in dispersion Sandvik's test (9) was used.

RESULTS

Technical aspects

It was technically difficult to record stable curves when the probe had no direct contact with the mucosa.

Fig. 2 shows that with slight and firm contact pressures, the recorded values were similar to those obtained without contact between the probe and the mucosa. A heavy pressure may cause a small reduction in flux value, as shown by the 95% confidence intervals.

The flux values recorded at one spot with varying angulation between the probe and the mucosa did not change significantly for angles between 30° and 90°. The angles associated with all reported results were kept within these limits.

Fluctuations in flux level

A total of 424 recordings were made. The flux curve was often fluctuating. We have isolated four factors that influence the flux curve (Fig. 3):

1. Pulse-synchronous fluctuations with frequencies of 60–90/min. By filtration through a time constant of 1.5 sec these fluctuations were negligible.

2. Fluctuations synchronous with respiration.

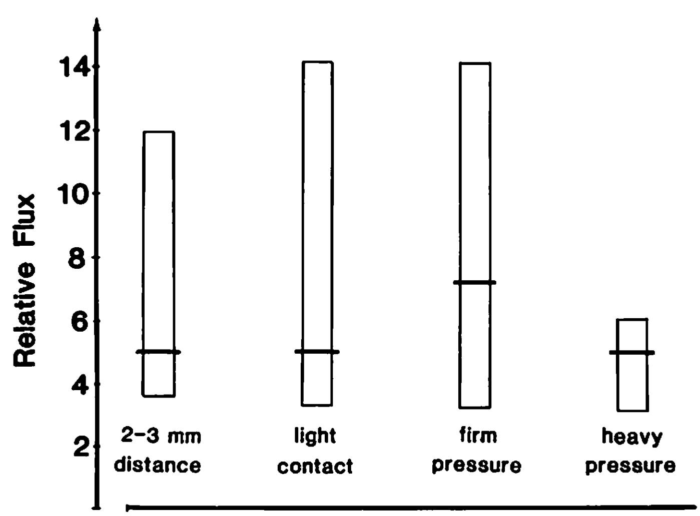

Fig. 2. Effect of pressure of the probe against the mucosa. Values are expressed as median with 95% confidence interval.

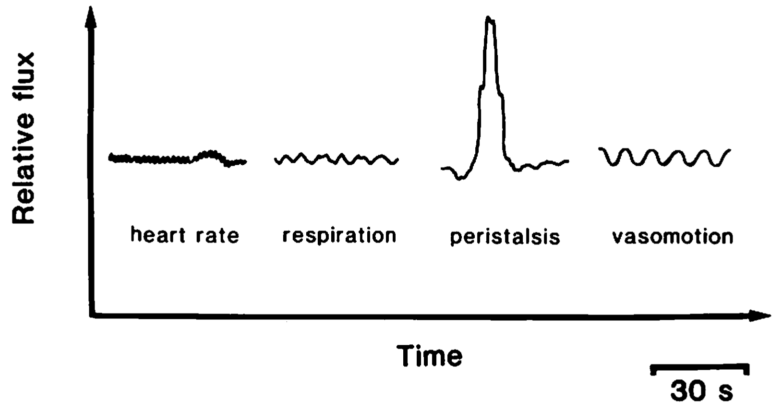

Fig. 3. Recorded flux patterns with fluctuations synchronous with the heart rate, with respiration, and with peristalsis and fluctuations possibly caused by internal vasomotion.

With a time constant of 1.5 sec, these fluctuations were also reduced.

3. Fluctuations of greater amplitude occurring simultaneously with peristalsis were recorded in some subjects. Fig. 4 shows results of simultaneous recording of visual peristalsis, laser Doppler flowmetry, and recordings with the 'peristaltometer' in a patient with marked peristalsis. These fluctuations were eliminated by giving the patient an anticholinergic drug intravenously (Fig. 5).

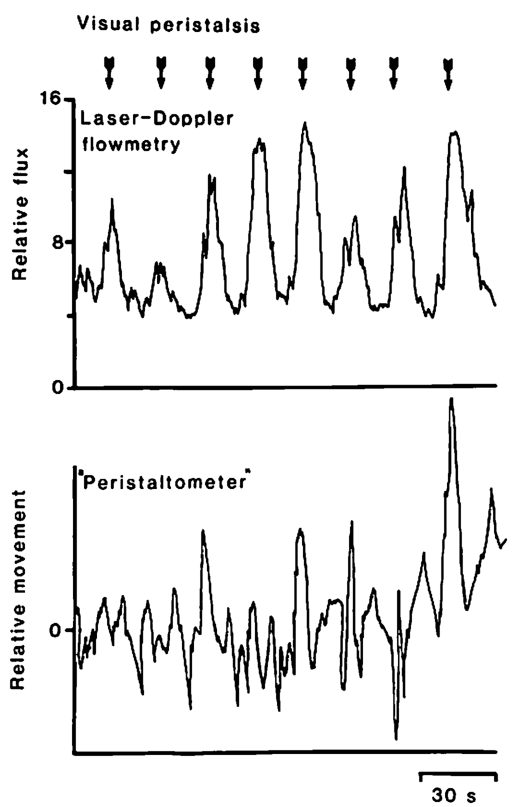

Fig. 4. Simultaneous recording of visual peristalsis by laser Doppler signal and the 'peristaltometer' curve.

4. In some subjects there was no peristalsis, but the curve still fluctuated with a frequency of 5–10/min. Possibly, these fluctuations were caused by internal vasomotion (10).

Most recordings showed stable curves, and the flux level was easy to define. For fluctuating curves the visual mean of the curve was used to define the flux level, omitting the largest waves caused by peristalsis.

Autonomic vascular reflexes were examined through continuous measurement while the subjects sustained a deep inspiratory gasp. In most cases a reduction of approximately 50% of the initial flux value was observed (Fig. 6). In one subject it was not possible to demonstrate this response.

The results of the tests for spatial and temporal variations are shown in Tables I and II.

Regional flux differences

Fig. 7 shows the flux values in the esophagus and different parts of the stomach. The circulation level at the lesser curvature was significantly

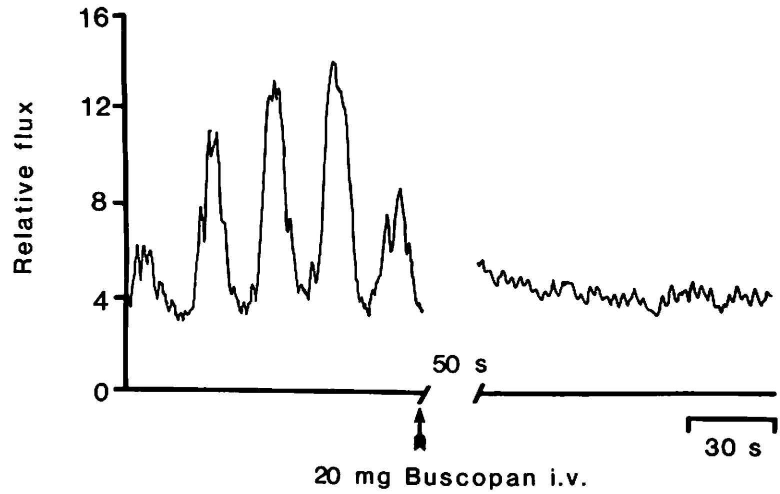

Fig. 5. Laser Doppler flow signal before and after giving an anticholinergic drug intravenously to a patient with heavy peristalsis.

lower than at the greater curvature ($p < 0.01$). The lowest values were observed at the angle of the lesser curvature. Additionally, the median value of the six observations of duodenal circulation was 5.4, with a 95% confidence interval of 4.0–7.4.

DISCUSSION

The use of the laser Doppler technique for blood flow measurements was first demonstrated by Riva et al. (4). Stern (11) demonstrated that the method was applicable to human skin blood flow

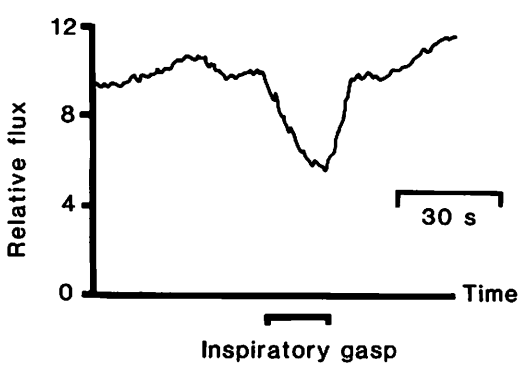

Fig. 6. Reduction in flux caused by a deep inspiratory gasp.

assessment. Nilsson et al. (12) have demonstrated in vitro that the equipment used in this study gives a linear response to flow for low and moderate erythrocyte velocities and volume fractions.

The laser Doppler technique has been used during operations to predict intestinal viability in animals with vascular lesions in the small intestine (13). In isolated segments of the small intestine in cats, an almost linear correlation between the laser Doppler signal and blood perfusion has been shown (14). Øveraasen (15) has measured the depth of penetration of Ne-He laser light in the fresh, non-circulated urinary bladder of a calf. At 37°C, 37% of the effect of the illuminating laser light was found at a depth of 2.3 mm. The human stomach wall is about 3 mm, of which the mucosal membrane is about 1 mm (16). The optical properties of the urinary bladder of a calf and a human gastric wall are probably comparable, and hence one would assume that our measurements represent blood circulation throughout most of the gastric wall. However, different LDF equipment with potentially different sampling volumes is currently available, and Kiel et al. (17) have provided evidence against transmural LDF measurements with their equipment.

When the laser Doppler equipment is applied to the gastric mucosa, the recorded curve is in

Table I. Results of tests for spatial variation ($n = 68$)

	First measurement	Second measurement	Difference
Median value with	3.0	3.0	0
95% confidence interval	2.5–3.3	2.7–3.3	−0.16 to 0
Coefficient of variation	0.39	0.33	10.3
50% interquartile range	2.3–3.8	2.3–3.8	−0.3 to 0.5
Total range	1.0–7.3	0.5–5.8	−1.5 to 2.9

most cases smooth, with few disturbing spikes, and the flux level is easy to define. Peristaltic movements caused by too heavy pressure between the gastric wall and the endoscope make the curve more complex. Some endoscopic experience is therefore necessary. If strong, disturbing peristalsis occurs, an anticholinergic drug may be used.

Peristalsis is due to contractions of the muscular layers causing a propulsing movement of the entire stomach wall. The spikes in the recorded curve may be caused by the squeezing of blood in the venous plexa in the gastric wall, like the action of the muscle pump in the lower extremity. Sometimes the peristaltic waves do not reach the laser Doppler probe, even though typical spikes are still observed in the curve. These findings suggest that these waves are caused at least partly by changes in blood flow and not only by muscular layer movement.

When the same area is examined several times, changes in recorded values are dependent on the stability of the apparatus, spatial variation, and biological variations in the subject. The measurement reproducibility of the equipment is reported to be reliable (18). Since the flux value is recorded from a tissue volume of only a few square millimeters, a considerable spatial variation could be expected, like that which has been shown in the skin (18). When two measurements are performed in the same region of the stomach, the reproducibility observed in this study is consistent (Table I).

Changes in circulation level may occur during the examination, and endoscopy may possibly initiate circulatory changes. This biological variation may explain the difference in recorded values shown in this study when an area was examined twice with a time interval of 10 min.

Reflex-induced reduction in the skin blood flow caused by a deep inspiratory gasp has been described (12, 19). This study shows a reduction in gastric wall perfusion by about 45–50% after a deep inspiration. Inspiration creates an increase in intra-abdominal pressure and a reduction in intrathoracic pressure. Pressure differences may possibly explain the response, but increased sympathetic activity during inspiration is probably a more reliable explanation of this phenomenon. Similar mechanisms may also explain the recorded flux level variations, synchronous with respiration.

During the recordings there are often slight movements of the gastric wall, caused by respiration or by movements of the subject. This may cause unstable recordings if there is no contact between the probe and the mucosa. The results in this study show that slight contact pressure does

Table II. Results of tests for temporal variation (10 min) ($n = 14$)

	First measurement	Second measurement	Difference
Median with	3.8	3.5	0.1
95% confidence interval	2.9–4.3	2.7–4.3	−0.7 to 1.2
Coefficient of variation	0.29	0.28	12.3
50% interquartile range	2.7–4.4	2.6–4.4	−0.7 to 1.2
Total range	2.0–5.5	2.3–5.3	−3.3 to 1.9

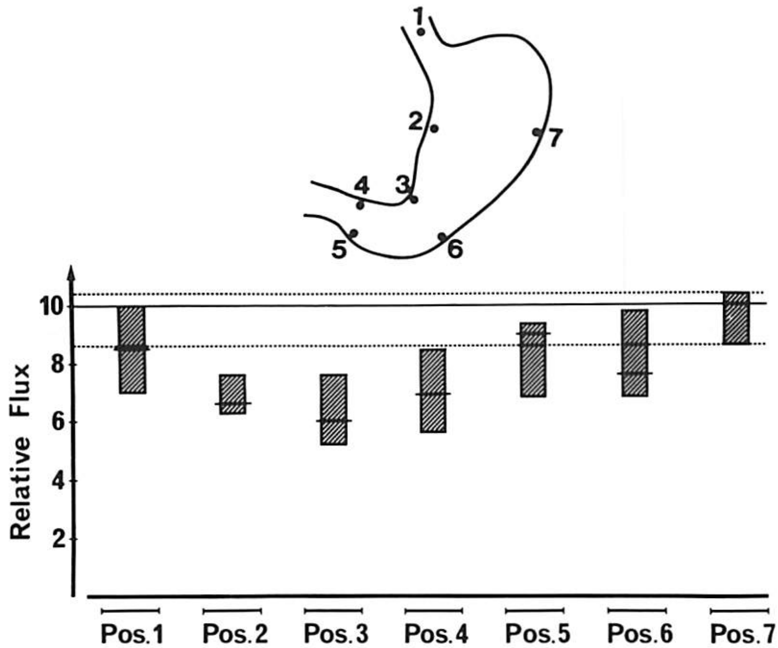

Fig. 7. Regional circulatory differences. The mean value is shown with 95% confidence interval. The dotted lines represents position 7, the major curvature. The observations along the lesser curvature are all highly significantly lower than those at the major curvature ($p < 0.01$).

not affect the recorded values significantly. A fall in recorded value may be observed when heavy pressure is applied.

It is often difficult to keep the probe perpendicular to the mucosal surface. Since the microvascular bed consists of an intricate network of interlinked small blood vessels, the angle between the erythrocyte velocity vectors and the beam propagation vectors of the diffuse scattered light can be regarded as randomized (20). Hence one would not expect angulation of the probe to be a critical factor. Our experiments showed that the recorded values did not change significantly with angulation of 0° to 60° from the perpendicular axis.

The blood circulation was examined in six areas of the stomach, in the distal oesophagus, and in the duodenum. In the stomach the recorded circulation at the lesser curvature was lower than at the greater curvature, the differences being highly significant ($p < 0.01$). As far as we know, a significant difference between the greater and lesser curvature has not earlier been demonstrated. Differences in the architecture of the microcirculatory network or other differences in the topographic anatomy may explain these results.

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