Measurement of gastric emptying by real-time ultrasound

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SUMMARY A safe non-invasive technique for the measurement of gastric volume by real-time ultrasound is described. The application of this technique to the measurement of the emptying of liquid from the stomach is outlined. Gastric emptying of liquid was found to be log-linear, the mean half-life of emptying in 10 volunteers being 22.0 ± 2.5 min. Ultrasound measurement of gastric emptying provides an opportunity to study the effects of drugs and disease on gastric motor function in man.

The rate of gastric emptying of orally administered drugs is recognised to be of great importance in controlling both the rate of drug absorption, and the peak plasma concentrations that result. The factors that alter gastric emptying rate will in turn influence these parameters.¹ Current techniques for the direct assessment of gastric emptying involve the swallowing of orogastric tubes or exposure of the subject to ionising radiation.² There is thus a need for a non-invasive method for the measurement of gastric emptying which is safely repeatable in normal subjects. We have previously described the application of single beam ultrasound for the measurement of gastric contraction frequency.^{3,4} We have also outlined a simple but approximate method for the determination of stomach volumes by a hand-held real-time probe.⁵ Subsequently other workers have also reported the usefulness of real-time ultrasound in recording and measuring gastric contractions.⁶

We now report the application of real-time ultrasound to enable the accurate and rapid direct measurement of the volume of liquid in the stomach, and the use of this technique to measure the gastric emptying rate of a liquid meal.

Method

PRINCIPLE

Short pulses of ultrasound will pass through a liquid but are partially reflected by solid interfaces, producing echoes. The time taken for an echo to return to a sensor (transducer) on the skin is determined by

the depth of the reflecting interface. In a real-time linear-array scanner 60 or more transducers are regularly spaced in a straight line within a single probe. These are rapidly activated in turn to produce a continuous, moving, two-dimensional image of a slice of tissue, such as a cross-section of a liquid filled stomach. If a series of cross-sectional images (B) at regular (1 cm) intervals are obtained at right angles to the long axis (A) of the stomach, a three-dimensional representation of the stomach is produced (Fig. 1). The volume of the stomach can thus be computed from the measurements of the areas of the cross-sectional images.

TECHNICAL DETAILS

A Toshiba SAL 20A real-time ultrasound scanner is interfaced with an Apple II + microcomputer and a video cassette recorder. The microcomputer allows data about the subject, the probe position, and the time to be superimposed on the ultrasonic images during video tape recordings. It also performs calculations of cross-sectional areas and volumes during subsequent playback.

The long axis of the stomach is first determined by the operator using the scanning probe 'free hand'. The probe is then placed in a gantry (Fig. 2) which is adjusted to constrain the plane of the scan to remain perpendicular to the stomach's long axis. A potentiometer in the gantry mechanism permits the direct measurement of the position of the probe along this axis. A series of scans for a volume measurement are obtained by traversing the scanning probe along the axis of the stomach and recording the consecutive series of images directly onto video tape. This

Fig. 1 Diagram to illustrate the calculation of stomach volume by representing the stomach as a series of parallel cross-sectional slices (B) at regular intervals along its long axis (A).

equipment enables such scanning sweeps to be made along the full length of the stomach in 10 seconds or less.

The series of scans for each volume measurement are subsequently replayed from the tape. Since the probe position for each scan image is recorded on every frame of the video tape the cross-sectional areas of scans precisely 1 cm apart can be obtained by stepping through the tape sequence and freezing the required frame for computer graphic analysis. The position of the stomach wall is delineated by a graphics pen used by the operator, and the area of the stomach cross-section calculated by the micro-computer. The volume of the stomach is thus derived by summing the cross-sectional areas as described above (Fig. 1).

ACCURACY

The accuracy of the volume measurement technique in the hands of the usual operator was assessed by scanning nine balloons containing known volumes of water. The potential source of error created by the

air-water interface within the stomach was investigated by including an air pocket of between approximately 20 and 100 ml in five of the balloons. The volumes of water used ranged from 50 to 600 ml and the measurements were done in a double-blind manner. After correction for the temperature dependence of the speed of sound in water, the root mean square percentage error of the computed volumes was 4%. The presence of an air pocket did not significantly affect the accuracy of the liquid volume measurements.

MEASUREMENT OF GASTRIC EMPTYING

Subjects were asked to attend the laboratory in the morning having fasted overnight. They consumed 500 ml of orange cordial at 37°. Stomach volumes were measured directly by the above techniques five minutes after the drink and subsequently at regular intervals (five, 10, 15, 20, 30, 40 minutes). The first readings were taken at five minutes to allow air bubbles to separate from the liquid in the meal. Two scanning sweeps were recorded at each time point, the subject holding his breath in inspiration during each sweep of the scanning probe to avoid artefacts due to respiration and help to keep the gastric contents clear of overlying ribs and lungs.

Results

The emptying of liquid from the stomach was log-linear. In 10 normal volunteers the half-life of emptying ranged between 9.0 and 40.1 min with a mean of 22.0 ± 2.6 min. A single blind study to compare the effects of metoclopramide (10 mg) and saline on gastric emptying was performed in five volunteers. The drug or saline was given intravenously 10 minutes before the drink. The half-life of gastric emptying was diminished by metoclopramide in four of the five subjects (Table), and the volume in the stomach at 40 minutes after the drink was significantly reduced ($p < 0.05$) by metoclopramide (Fig. 3).

Discussion

Ultrasound is considered to be safe, and the technique we describe is non-invasive and readily repeatable. It is therefore ideally suited for studying the effects of drugs and disease on the emptying of liquid from the stomach. Modern real-time scanners are not difficult to use and we have found that operators with no previous experience of their use can achieve high accuracy. Direct volume measurements can be made at frequent intervals after a single drink and precise estimates of gastric emptying may be thus obtained. Other aspects of gastric

Fig. 2 Ultrasound and recording equipment in use.

function may be investigated, in particular adaptive relaxation mechanisms⁷ and the frequency and amplitude of gastric contractions.

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Table Gastric emptying half-life ($t_{1/2}$) and correlation coefficients (r) for five subjects receiving intravenous saline or metoclopramide 10 minutes before drink

Subject	Saline		Metoclopramide	
	$t_{1/2}$ (min)	r	$t_{1/2}$ (min)	r
1	25.0	-0.93	16.8	-0.99
2	18.8	-0.99	15.0	-0.98
3	40.1	-0.98	40.1	-0.97
4	21.5	-0.91	20.1	-0.94
5	15.8	-0.98	12.5	-0.99
Mean	24.2		20.9	
($\pm$ SEM)	4.3		5.0	

The correlation coefficients (r) are the coefficients of the least squares linear regression of log volume against time for volumes between five and 40 minutes after the drink.

Fig. 3 Gastric emptying of a liquid meal in five normal volunteers after saline (●—●) and metoclopramide 10 mg intravenously (+----+). One half of each standard deviation bar has been omitted for clarity.

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