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Factors Influencing Gastric Emptying

Interest in the regulation of gastric emptying dates back to 1833, when Beaumont [*1*] observed that the amount of time food remains in the stomach after a meal depends upon the type of food eaten. The application of general rules governing gastric emptying as a technique in approximating the time of death is not generally emphasized in the forensic sciences. The postmortem changes of rigor, livor, and algor mortis as well as chemical changes in the blood and vitreous are widely used for determining the time of death, yet none of these methods is truly satisfactory because of individual variations and the host of factors influencing each of them. Yet in the individual case these can be very important. Gastric emptying is no more accurate than these other methods, and studies regarding gastric emptying during life are not customarily within the scope of the forensic scientist. However, these scientists may be called on to express an opinion estimating the postmortem interval based on knowledge of the time and character of the last meal and on observation of the presence or absence of liquids or solids in the stomach of a dead person. The condition of the stomach contents remains largely unchanged after death, as observed by the presence of liquids and solids in the stomach when deaths result from either violent or natural means during or immediately following a meal. Thus, gastric emptying time is useful when the specific question of death related to a known time and character of the last meal is raised, and the presence or absence of food in the stomach may be of great probative significance, providing important or even pivotal evidence.

The Physiology of Gastric Emptying

Fluids begin to accumulate in the stomach prior to the ingestion of food for the thought, smell, taste, or chewing of food initiates the phenomenon called the "cephalic phase" of gastric secretions [*2*]. The entrance of food into the stomach initiates the "gastric phase" with the secretion of additional gastric juices, and the entrance of chyme into the small intestine stimulates a third or "intestinal phase" of gastric secretion. Some five litres or so of fluids as saliva, gastric juice, pancreatic juice, and other body liquids are added to the usual daily intake of 3 to 4 kg of food and drink. The gastric secretions in particular are important to the forensic pathologist as the volume of gastric contents may greatly exceed the volume of the solids and liquids ingested. The greatest secretory activity occurs in the stomach within the first hour of eating. The volume of gastric juices produced during this first hour may be up to twice that of the meal, for it has been shown that approximately 800 ml of gastric juices are produced in response to a 400-ml meal [*3*].

Three anatomic areas of the stomach regulate emptying. The proximal or fundal portion serves as a reservoir, and its slow, sustained contractions exert a steady pressure on the gastric contents, gradually pressing the contents toward the distal stomach and the

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duodenum. The proximal stomach adapts to increasing volumes of food with little change in intragastric pressure. The distal or antral portion of the stomach is concerned with regulation of emptying of solids by contractions and acts as the gastric homogenizer and grinder. Its peristaltic contractions blend the contents with gastric juice and thoroughly triturate gastric solids before allowing them to pass into the duodenum. The third anatomic area of the stomach is the pylorus. This may be either open, allowing gastric contents to leave the stomach with the antral contractions, or closed, in which case there is mixing and grinding [*4*]. The pyloric sphincter relaxes with peristalsis but contracts in response to acid, fat, amino acids, and glucose, and it prevents duodenal reflux [*5*].

Normal Gastric Emptying Time

The normal rate of emptying of gastric content depends on gastric volume, the difference in the pressure between the stomach and the duodenum, and the character of the food in the stomach; it also varies with the resistance to the flow of chyme.

The measurement of gastric emptying is not an exact science for there is variation in both test subjects and the testing methods used. Gastric emptying studies employ intubation, radiologic tests with radiopaque material, or isotopes. Each method has advantages and limitations. Intubation, where gastric contents with a dye marker are sampled at intervals with a nasogastric tube, is useful only with liquid meals. In addition, the test subject is uncomfortable and there is some minor trauma with the intubation. Radiologic tests measure the amount of a radiopaque unabsorbed marker in the stomach. These studies using barium are quite simple and well tolerated and measure the total emptying time quite accurately, but they are difficult to quantitate, and barium may retard emptying [*6*]. Isotopic studies measuring the amount of radioactivity emitted over the stomach area in a volume of gastric contents have the obvious disadvantages of cost and radiation exposure of the subject; in addition, various isotopes react differently to different foods. The isotopic studies are commonly expressed as "one half gastric emptying time," a figure of limited use to the forensic pathologist.

There are two phases to gastric emptying: the lag phase and the linear phase. The term "lag phase" is somewhat misleading for the normal stomach empties in a linear fashion following the first 15 to 20 min after ingestion of the meal [*7*]. The lag phase refers to a lag in changing total volume of the stomach contents. During the first hour the volume of the secreted gastric juices approximates or exceeds the volume of the meal emptied through the pylorus.

Liquids such as tap water and saline have very short emptying times, as short as 12 to 15 min [*8*], and in one case report swallowed dentures reached the jejunum in 13 min [*9*]. By using isotopes it has been shown that the normal one half gastric emptying time for a complex meal containing ham, cheese, tea, butter, and eggs varies from 23 to 77 min [*4,10*]. Similar studies with commercial beef stew and a liquid meal of fat, protein, and hypertonic glucose demonstrate a mean emptying rate of approximately 36% per hour [*11*]. Using radiologic studies with a barium meat meal showed that the maximum total gastric emptying time for the healthy intact human stomach (good intrinsic gastric motility and patent pylorus and duodenum) is 6 h. In many healthy subjects studies by this method showed complete emptying of the stomach of a protein-barium meal after 3 h [*12*].

In adults there is no correlation of emptying rate with age [*13*], although in neonates the stomach empties more rapidly in the prone and right lateral positions than in the supine and left lateral positions [*14*]. In test subjects it was found that there was some delay in emptying a liquid meal when the person was positioned feet-up head-down at a 45-deg angle, but this did not hold true with a test meal approximating normal solids [*15*]. In no event did the gastric emptying time exceed normal limits.

Conditions Associated with Accelerated Gastric Emptying

As a general rule there is a tendency for accelerated gastric emptying of solid meals in duodenal ulcer disease [*16,17*]; however, with liquid meals there does not appear to be a difference as compared to normal subjects [*18*]. Acid secretions do not appear to be an inhibitor of gastric emptying. Gastric accommodation to distention is not altered in duodenal ulcer, but peristaltic contractions are stronger in these patients [*19*]. It is probable that the rapid entrance of acidified chyme into the duodenum contributes to the inability of the duodenum to neutralize the acid, leading to the irritation and ulceration.

The maximum total gastric evacuation time for those who have had a pyloroplasty, gastroenterostomy, or subtotal resection is 4 h [*20*]. There is more variability in the emptying of solid meals after subtotal gastrectomy than with liquid meals. There may be an initial precipitous emptying of from 15 to 65% of the food, followed by a delay of 20 to 30 min, then emptying which is complete by 3 h [*7*]. Following vagotomies there is a delay in gastric emptying for approximately six months, after which there is no significant variation from normal [*21*].

Conditions Associated with Delayed Gastric Emptying

There is a wide variety of life-threatening conditions leading to gastric retention. Peritoneal injury and irritation from any cause are associated with decreased peristalsis and retention of gastric contents. Thus visceral injury such as occurs in laparotomy, peptic ulcers, appendicitis, peritoneal abscesses, pancreatitis, ruptured liver and spleen, hemoperitoneum, or retroperitoneal hemorrhage may all be associated with gastric distention and delayed gastric emptying [*6,22,23*]. Gastric emptying is delayed following severe trauma of any type [*24*], in women in labor [*25,26*], in any condition producing nausea and vomiting [*27*], and in various other conditions such as hepatic coma, hypercalcemia, hypocalcemia, postoperative immobilization, myxedema, malnutrition, and any condition associated with elevated intracranial pressure such as brain tumor or severe head injury [*23*]. Anesthesiologists report that food may remain in the stomachs of injured children for 24 h after an injury [*28*]. According to an oral communication from Jack Moyer, M.D., president of the American Society of Anesthesiologists, in February 1977, and as noted by Professor of Anesthesiology Martin D. Sokol, M.D., in February 1977, gastric retention of solid foods for over 10 h because of preoperative fear, facial lacerations, or broken bones is frequently observed. They also state that gastric retention of solids in excess of two days does occur after more severe injuries. In reviewing our autopsy material of persons dying in a hospital after coma-producing severe head injury, up to 500 ml of liquid gastric material with chunks of undigested food have been found as late as five days. Of course the interval between injury with coma and death can be somewhat inflated because of the support measures employed and the mandatory 24-h rule between the flat electroencephalogram and pronouncing the person dead.

There are a number of chronic conditions, mostly those involving the intestinal tract, in which there is delayed gastric emptying well in excess of 6 h. In an excellent study of 300 meat-barium radiologic examinations for total gastric emptying it was found that a variety of intrinsic diseases were associated with the retention of ingested food [*12*]. These conditions include superior mesenteric artery syndrome, duodenal vascular compression, adhesions in the region of the duodenum, subsiding or subacute cholecystitis, degeneration and atrophy of the smooth muscle fibers of the stomach as might occur in pernicious anemia, and diabetic gastroparesis where there is atony with consequent gastric retention. However, it is only in the complicated diabetic with visceral neuroenteropathy, an autovagotomy as part of the disease process, that gastric emptying is delayed. Some researchers [*29*] have reported that in the diabetic the stomach may empty more rapidly than in control subjects.

Duodenal stenosis such as may follow pyloric-duodenal ulcer scarring, or more rarely acid burns of the duodenum, may lead to delayed gastric emptying [*30*]. The extent of gastric retention in some chronic conditions is quite striking, reaching 14 h in superior mesenteric artery syndrome, postoperative anastomotic stricture, mechanical obstruction with adhesions, and chronic antral gastritis or advanced gastric atrophy [*12,31*]. A delayed half-emptying time is reported in celiac disease [*32*].

Drugs Influencing Gastric Emptying

The stomach is generally not an important site of drug absorption, and when absorption does occur it is very slow, irrespective of pH and whether the drug is basic or neutral. Weakly acid drugs such as aspirin, warfarin, and barbiturates may be absorbed if they remain in the stomach for extended periods of time [*6*]. Low-molecular-weight, readily diffusible substances such as ethanol are absorbed from the stomach; in fact, the stomach is a significant site of ethanol absorption [*33*]. Drugs taken and absorbed in the intestinal tract prior to a meal may influence the rate of gastric emptying, either by affecting the smooth muscle contractions or by influencing the release of hormones that modulate gastric activity. There are few studies correlating blood drug levels with gastric retention, although many therapeutic agents are known to delay gastric emptying. These include anticholinergic compounds such as atropine [*34*], certain antihistamines such as diphenhydramine, promethazine, pheninadamine [*35*], tricyclic antidepressants [*36*], chloroquine [*37*], sodium nitrite [*38*], iproniazid [*39*], prostaglandins and pentagastrin [*40*], propantheline [*41*], ganglion blocking drugs such as hexamethonium [*42*], phenothiazines, sympathomimetics, antiparkinsonian drugs, anticholinesterases, and sedative, analgesic, and anesthetic agents [*35,43*]. Morphine and narcotic analgesics increase smooth muscle tone and interfere with normal peristalsis, thereby slowing gastric emptying [*44–48*]. There is an increased rate of gastric emptying with cholinergic drugs which stimulate gastric motility [*40*], with metoclopramide which is related to procainamide [*49*], and with reserpine [*50*].

There is a great deal of folklore as well as anecdotal material regarding alcohol and gastric emptying time in humans; however, there is really very little controlled experimental information. Animal studies indicate that the administration of ethyl alcohol interferes with gastric motility and evacuation [*51*]. It has been suggested that wine and beer delay gastric emptying, while whiskey and brandy either fail to influence gastric emptying or may promote gastric emptying and digestion [*52*]. In one well-controlled study of the influence of preprandial alcohol on gastric emptying of a subsequent meal it was found that alcohol did indeed lead to gastric retention. However, the results were somewhat variable [*52*]. Volunteer subjects ranging from 25 to 75 years of age ingested 120 ml (4 oz) of 100-proof bourbon whiskey (50% ethanol) over a 15-min period immediately prior to a test meal that included liquids and solids with protein, fats, and carbohydrates. Isotope studies testing radioactivity over the stomach area to determine the rate of emptying with a decay exponential expressed in half-time showed great variation in emptying half-time, although in all subjects the delay was substantially increased when compared to test meals not preceded by ethanol. The subjects' gastric emptying time without the ethanol varied from 52 to 211 min and after the alcohol consumption the time increased, with the range from 79 to 414 min.

General Rules Regarding Gastric Emptying Time

The extent of gastric emptying may be of evidentiary value in estimating the time of death if the time and character of the individual's last meal are known. There are a number of factors that may either accelerate or delay gastric emptying. The following

rules should be kept in mind when one attempts to estimate the time interval between the last meal and death, basing this estimate on the presence or absence of food in the stomach.

1. The emptying time of a solid meal from the normal stomach should never exceed 6 h.
2. The emptying time of a solid meal from the normal stomach may be as little as 3 h.
3. Water and saline alone may leave the normal stomach rapidly, in 12 to 15 min.
4. Gastric emptying time in post-gastrectomy and pyloroplasty patients should normally not exceed 4 h.
5. The volume of gastric contents may be double the volume of the meal because of dilution by gastric secretions.
6. The volume of stomach contents remains quite constant for the first postprandial hour because of an equilibrium of gastric secretions and food leaving the stomach.
7. Many, if not most, serious diseases and life-threatening medical conditions are associated with prolonged gastric retention.
8. Chronic diseases often lead to gastric retention exceeding 6 h.
9. Chronic gastrointestinal diseases may lead to gastric retention, at times exceeding 14 h.
10. Fear and apprehension may delay stomach contractions, leading to gastric retention.
11. A wide variety of therapeutic agents delay gastric emptying.
12. Morphine and narcotic analgesics increase smooth muscle tone and slow gastric emptying by interfering with normal peristalsis.
13. Ethanol (120 ml or 4 oz) immediately prior to a solid meal delays gastric emptying; however, the period of delay is quite variable, and there is individual variation.

Summary

Gastric emptying time may be of investigative value and evidentiary significance in estimating the time of death. However, in order to express an expert opinion with a degree of certainty, the time, volume, and character of the last meal must be known, and other factors considered. The maximum normal emptying time for the healthy intact stomach is 6 h. Factors accelerating or delaying gastric emptying include fear and apprehension, acute and chronic diseases, trauma, drugs, and the stomach that has undergone surgery. Recognition of these influences supports the conclusions that the forensic pathologist draws regarding the interval between the last meal and death.

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