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Gastric Emptying in Obesity and Weight-Loss Interventions: Physiology, Assessment, and Clinical Implications

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ABSTRACT

Gastric emptying is a key determinant of digestion, appetite regulation, and metabolic homeostasis. Its assessment relies on several techniques, among which gastric emptying scintigraphy remains the reference standard owing to its physiological relevance and reproducibility when performed using standardized protocols. In current clinical practice, scintigraphy is mainly used for the diagnosis of gastroparesis and dumping syndrome, but in the field of obesity, it appears as a promising research and phenotyping tool. Although earlier studies in obesity reported heterogeneous results, larger cohorts and meta-analyses now support an acceleration of gastric emptying in subjects with obesity, accompanied by increased gastric accommodation and alterations in gut hormone signaling. Most importantly, obesity treatments, including bariatric surgery, endoscopic bariatric procedures, and pharmacological therapies such as GLP-1 receptor agonists, induce marked and procedure-specific modifications in gastric emptying. These changes may contribute to their metabolic and weight-loss effects. This narrative review summarizes the physiological mechanisms governing gastric emptying, provides an overview of current assessment methods with a focus on scintigraphy, and examines the impact of obesity and obesity treatments on gastric emptying, highlighting its relevance as a potential biomarker and therapeutic target.

1 | Introduction

Gastric emptying is a fundamental physiological process regulating the transfer of gastric contents into the duodenum. It plays a key role in food digestion, regulation of nutrient absorption, and appetite control. This process results from the coordinated interaction between gastric accommodation, antral contractions, pyloric function, and duodenal feedback. Neuronal and

hormonal regulation, depending on the meal composition, adds to the complexity of this finely regulated process.

Alterations in gastric emptying are implicated in various gastrointestinal and metabolic disorders. Delayed gastric emptying is classically associated with gastroparesis (Camilleri and Sanders 2022; Li et al. 2025) and can be present in functional dyspepsia. On the other hand, accelerated gastric emptying

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occurs after certain gastric surgeries leading to dumping syndrome. Beyond these conditions, gastric emptying has been shown to influence postprandial glycemic control, satiation signaling, and food intake (Camilleri 2019). Accurate assessment of gastric emptying is of major clinical and research interest: among available methods, gastric emptying scintigraphy remains the reference technique. Gastric emptying alterations play a central role in obesity and after bariatric procedures.

In obesity, gastric emptying is increasingly recognized as accelerated when assessed in adequately powered cohorts and through meta-analytic data (Lu et al. 2021), in association with increased gastric volume and accommodation, and altered postprandial gut hormone signaling.

Moreover, gastric emptying is significantly altered by obesity treatments, including bariatric surgery, endoscopic bariatric procedures, and anti-obesity pharmacotherapies such as GLP-1 receptor agonists and newer multi-agonist compounds. Given the expanding use of bariatric and pharmacological therapies, understanding how gastric emptying is modified in obesity has become increasingly relevant for optimizing treatment strategies.

This narrative review aims to summarize the physiological mechanisms of gastric emptying, outline current assessment methods with a focus on scintigraphy, and review available data on alterations in gastric emptying in obesity and following surgical, endoscopic, and pharmacological obesity treatments.

2 | Methods

A literature search was performed in PubMed, Google Scholar, and Embase for articles published between 1900 and 2026 using the keywords “gastric emptying,” “gastric emptying scintigraphy,” “GLP-1 receptor agonist,” “obesity,” “bariatric surgery,” “endoscopic sleeve gastropasty,” and “intra-gastric balloon.” Additional relevant studies were identified through manual screening of reference lists. Only studies in the English language were screened. Studies were eligible if they were peer-reviewed human or translational studies reporting objective measurement of gastric emptying, gastric accommodation, antro-pyloric motility, or related gut hormone responses, in healthy subjects, in subjects with obesity, or after surgical, endoscopic, or pharmacological weight-loss interventions. Clinical research, narrative or systematic reviews were included; while case reports, conference abstracts without full-text publication, and studies without objective assessment of gastric motor function were not considered.

The aim of this manuscript was to provide an integrative physiological synthesis rather than a systematic quantitative appraisal; thus no formal risk-of-bias assessment or meta-analytic pooling was performed. This work was conducted as a narrative review, not as a systematic review; therefore no PRISMA diagram was performed. Where published findings were discordant, particularly regarding gastric emptying in obesity, studies were weighted according to sample size, methodological standardization, and study design. Priority

was therefore given to adequately powered cohorts using standardized scintigraphic protocols and to meta-analytic data, whereas earlier studies including fewer than 30 subjects, using heterogeneous meals or non-standardized acquisition protocols, were considered exploratory and interpreted with caution.

3 | Physiology and Mechanisms of Gastric Emptying

3.1 | Functional Anatomy of the Stomach

The stomach can be divided into three functional regions: the proximal stomach, the distal stomach, and the pylorus (Di Natale et al. 2023). The proximal stomach, which includes the fundus and the upper body, primarily acts as a reservoir. Following food ingestion, receptive relaxation and fundic accommodation allow the stomach to store large volumes without a significant increase in intragastric pressure. This process is essential to prevent rapid delivery of nutrients into the duodenum and accounts for the initial lag phase observed for solids. The distal stomach, which consists of the lower body and the antrum, is responsible for trituration and propulsion of gastric contents. Coordinated antral contractions mechanically break down solid food particles into smaller fragments, which are suitable for passage through the pylorus. The pylorus itself acts as a dynamic filter, regulating the outflow of chyme and preferentially allowing the passage of small particles, conventionally considered to be around 1–2 mm, while larger fragments are retropulsed into the antrum for further trituration. This size threshold should be regarded as an approximate physiological concept rather than an absolute cutoff, as transpyloric passage also depends on meal consistency, antral contractile activity, and pyloric tone. The pylorus also prevents retrograde flow (Soliman and Gourcerol 2023). Gastric emptying, therefore, depends on a balanced interaction between proximal gastric tone, distal gastric motility, and pyloric resistance, all of which are tightly coordinated with duodenal feedback mechanisms (Camilleri 2019).

In the proximal stomach, tonic contractions determine fundic tone and regulate intragastric pressure. An increase in fundic tone promotes gastric emptying by facilitating the transfer of contents toward the distal stomach, whereas fundic relaxation delays emptying by enhancing gastric accommodation.

In the distal stomach, phasic peristaltic waves originate in the mid-body and propagate toward the pylorus at a maximal frequency of approximately three contractions per minute. These antral contractions generate both mixing and propulsive forces. When the pylorus is partially closed, retropulsion occurs, enhancing the mechanical breakdown of solids. When pyloric resistance decreases, coordinated antral contractions facilitate gastric emptying into the duodenum. Importantly, gastric emptying requires synchronized antro-pyloro-duodenal coordination. The timing and amplitude of antral contractions must be appropriately matched with pyloric relaxation and duodenal receptive responses to ensure efficient and regulated nutrient delivery (Hellström et al. 2006; Vella and Camilleri 2017; Camilleri 2006).

3.2 | Neurohormonal Regulation

The regulation of gastric emptying relies on an integrated network involving the enteric nervous system, extrinsic autonomic pathways, and gastrointestinal hormones. Gastric contractions are performed by smooth muscle cells (SMC) under the influence of interstitial cells of Cajal (ICC). ICC generate and propagate the intrinsic slow-wave electrical activity and are thus considered the gastric pacemaker. Beyond rhythm generation, ICC play a crucial role in coordinating antral peristalsis and pyloric function, thereby ensuring an effective antro-pyloro-duodenal coupling required for appropriate gastric emptying. Disruption or loss of ICC networks has been associated with impaired gastric motility and delayed gastric emptying in several pathological conditions (O'Grady et al. 2021).

The enteric nervous system plays a central role by coordinating local reflexes within the gastric wall. Excitatory and inhibitory motor neurons modulate ICC and smooth muscle activity in response to luminal stimuli, including distension and nutrient composition. Extrinsic autonomic regulation is mainly provided by vagal pathways, especially during the postprandial phase. Vagal efferent fibers mediate receptive relaxation of the proximal stomach and modulate antral contractility, while vagal afferents convey sensory information to central regulatory centers. Moreover, the vagus nerve can exert both inhibitory and excitatory effects on gastric motility.

Several gastrointestinal hormones exert a major influence on gastric emptying. Gastrin promotes gastric motility and may accelerate emptying under certain conditions. In contrast, cholecystokinin, glucagon-like peptide-1, and peptide YY (PYY) delay gastric emptying by increasing pyloric tone and reducing antral contractions. These hormones are released in response to nutrient exposure in the small intestine and constitute key mediators of the so-called “intestinal brake,” preventing excessive nutrient delivery to the duodenum. Motilin, primarily active during the fasting state, is involved in the generation of migrating motor complexes but has a limited role in postprandial gastric emptying (Hellström et al. 2006; Goyal et al. 2019; Browning and Travagli 2019; Mori et al. 2022; Ramkumar and Schulze 2003).

3.3 | Determinants Influencing Gastric Emptying

Multiple factors influence the rate of gastric emptying, contributing to significant interindividual variability. Gastric emptying is governed by specific motor patterns that differ according to the physical properties of the ingested meal. Liquids empty more rapidly than solids, following an exponential curve, whereas solids exhibit an initial lag phase related to gastric accommodation and trituration before linear emptying occurs (Collins et al. 1983).

Meal characteristics represent a major determinant of emptying kinetics. In particular, gastric emptying adjusts to the caloric content of the meal, as nutrient delivery to the duodenum activates neural and hormonal feedback mechanisms that regulate transpyloric flow. Both meal volume and caloric density

modulate emptying through mechanical distension and duodenal feedback. Therefore, hyperosmolar or highly energy-dense meals tend to delay gastric emptying by stimulating duodenal chemoreceptors (Hunt et al. 1985; Brenner et al. 1983; Meeroff et al. 1975; Moore et al. 1984; Wisén et al. 1993).

Physiological factors such as posture, circadian rhythm, age, and sex have been shown to have a limited influence on gastric emptying (Hellström et al. 2006; Vella and Camilleri 2017; Camilleri 2006; Goyal et al. 2019). On the other hand, pathological conditions, including diabetes mellitus, functional gastrointestinal disorders, and obesity, may significantly alter gastric motor function and emptying dynamics (Camilleri and Sanders 2022; Li et al. 2025).

4 | Methods for Assessing Gastric Emptying

Accurate assessment of gastric emptying is essential for both clinical evaluation and research purposes. Over the years, multiple techniques have been developed to measure gastric emptying, differing in their physiological relevance, accuracy, availability, and invasiveness. These methods can be broadly categorized into indirect tests, imaging-based techniques, and motility assessments and are summarized in Table 1.

4.1 | Indirect and Non-Imaging Techniques

Indirect methods estimate gastric emptying based on downstream physiological effects rather than direct visualization of gastric contents. Breath tests using ^{13}C -labeled substrates, such as ^{13}C -octanoic acid or ^{13}C -spirulina, have been widely used to assess gastric emptying of solids. After gastric emptying and intestinal absorption, the labeled compound is metabolized and exhaled as $^{13}\text{CO}_2$. Although non-invasive and radiation-free, breath tests rely on multiple physiological steps beyond gastric emptying, including intestinal absorption, hepatic metabolism, and pulmonary excretion, which may confound results. This test remains the most validated alternative technique for gastric emptying scintigraphy, with a good correlation with the results of scintigraphy for the measurement of gastric emptying rate (Ghoos et al. 1993).

The paracetamol absorption test is based on the assumption that paracetamol is minimally absorbed in the stomach and rapidly absorbed in the proximal small intestine. Plasma paracetamol concentrations therefore reflect the rate of gastric emptying of liquids, but not solids as reported in a systematic review by Willems et al. (2001). While simple and inexpensive, this method provides only indirect information and is limited by variability in intestinal absorption and hepatic metabolism. Moreover, outcome parameters and protocols still lack standardization (Willems et al. 2001; Koyama et al. 1995; Petring et al. 1986; Petring and Flachs 1990; Heading et al. 1973).

Symptom-based assessments and questionnaires are sometimes used in clinical practice but poorly correlate with objective measurements of gastric emptying and should not be considered reliable diagnostic tools (Banks et al. 2024).

TABLE 1 | Comparison of methods for the assessment of gastric emptying.

Method	Principle	Advantages	Limitations	Radiation	Validation vs. scintigraphy	Applicability after bariatric surgery
Scintigraphy	Serial gamma-camera imaging of a technetium-99m-labeled standardized meal	Reference method; direct, quantitative; separate solid and liquid phases; standardized normative values	Methodological variability across centers; logistical constraints; radiation exposure	Yes (low)	Reference standard	Feasible after sleeve and ESG; difficult to interpret after RYGB (small pouch, rapid transit, normative values not applicable)
¹³ C breath test	Exhaled ¹³ CO ₂ after ingestion of a ¹³ C-labeled substrate (octanoic acid, spirulina)	Non-invasive; radiation-free; validated for solids	Depends on intestinal absorption, hepatic metabolism and pulmonary excretion; indirect	No	Most validated alternative; good correlation with scintigraphy for emptying rate	Usable after sleeve, ESG and balloon; interpretation after RYGB not validated
MRI	Non-invasive imaging of gastric volume, accommodation and emptying	No radiation; high spatial resolution; additional data on gastric contents and accommodation	Cost; limited availability; lack of standardization	No	Correlates with scintigraphy for volume and emptying; not yet standardized	Applicable, particularly to study accommodation after ESG and sleeve; scarce post-RYGB data
Wireless motility capsule	Ambulatory recording of pH, pressure and temperature to derive transit times	Ambulatory; radiation-free; global gut motility assessment	Indirect for gastric emptying; single-point measurement; influenced by pyloric retention	No	Validated cutoff vs. scintigraphy for gastric residence time	Contraindicated with altered anatomy or recent GI surgery; unsuitable in most post-bariatric settings
Ultrasonography	Measurement of antral cross-sectional area and gastric volume over time	Non-invasive; bedside; radiation-free; useful for liquids	Highly operator-dependent; less accurate for solids; no standardized protocol	No	Correlates with scintigraphy for liquid emptying in validation studies	Feasible but limited by altered post-surgical anatomy and operator dependence
Body surface gastric mapping	High-resolution recording of gastric myoelectrical activity using a 64-electrode epigastric array, with concurrent symptom profiling	Non-invasive; radiation-free; assesses gastric rhythm, frequency and amplitude; high reproducibility; simultaneous symptom correlation	Does not measure gastric emptying itself; limited availability; complementary rather than substitutive	No	Not a measure of emptying; normative reference intervals established; complementary to scintigraphy	Feasible with a protocol adapted to reduced gastric volumes; abnormalities documented after sleeve gastrectomy

(Continues)

TABLE 1 | (Continued)

Method	Principle	Advantages	Limitations	Radiation	Validation vs. scintigraphy	Applicability after bariatric surgery
Antro-duodenal manometry	Direct recording of intraluminal pressure patterns	Detailed information on antral and small-bowel contractions	Invasive; cannot quantify emptying rate; does not track meal transit	No	Not a measure of emptying; complementary only	Rarely used; limited relevance in the post-bariatric context

Abbreviations: ESG, endoscopic sleeve gastropasty; GI, gastrointestinal; MRI, magnetic resonance imaging; RYGB, Roux-en-Y gastric bypass.

4.2 | Gastric Emptying Scintigraphy

4.2.1 | Principles and Technical Basis

Gastric emptying scintigraphy is based on the ingestion of a standardized meal labeled with a gamma-emitting radionuclide, most commonly technetium-99m. Serial images are acquired using a gamma camera to track the distribution of the radiolabeled meal within the stomach over time. This technique allows direct visualization and quantitative assessment of gastric emptying under near-physiological conditions. Separate evaluation of solid and liquid phases is possible, providing comprehensive information on gastric motor function (Banks et al. 2024; Abell et al. 2008).

4.2.2 | Standardized Protocols

To ensure reproducibility and comparability across studies, standardized protocols for gastric emptying scintigraphy have been developed. For solid meals, a calibrated low-fat egg-white meal labeled with technetium-99m sulfur colloid is most commonly used. Imaging is typically performed immediately after meal ingestion and at fixed time points, usually at 1, 2, and 4 h. International guidelines by the American Neurogastroenterology and Motility Society and the Society of Nuclear Medicine recommend assessment for at least 4 h, as delayed gastric emptying may be missed with shorter protocols. Patients are examined in the upright position whenever possible, and medications affecting gastric motility should be discontinued 48 h prior to the study (Abell et al. 2008). Glycemic control is also required in patients with diabetes (ideally <220 mg/dL) (Samsom et al. 1997).

4.2.3 | Measured Parameters

Scintigraphy provides several quantitative parameters to characterize gastric emptying. The most widely used measure is the percentage of gastric retention at predefined time points, particularly at 2 and 4 h for solid meals. The half-emptying time ($T_{1/2}$), defined as the time required for 50% of the meal to leave the stomach, can also be calculated. In addition, time–activity curves allow visualization of the overall emptying pattern, including the presence of an initial lag phase for solids or rapid emptying for liquids, using earlier images at 30 min. The distribution of the meal in the proximal or distal stomach can also be evaluated on the scintigraphic images.

4.2.4 | Normal Values and Diagnostic Thresholds

Normal reference values for gastric emptying scintigraphy are well established when using the standardized 250-kcal low-fat egg-white meal recommended by the American Neurogastroenterology and Motility Society and the Society of Nuclear Medicine guidelines. With this protocol, delayed gastric emptying is defined by > 60% gastric retention at 2 h or > 10% retention at 4 h. Conversely, accelerated gastric emptying is diagnosed when gastric retention is < 70% at 30 min or < 30% at 1 h. These thresholds are derived from large normative studies in

healthy volunteers and provide a robust framework for identifying both delayed and rapid gastric emptying. Their use is essential for ensuring comparability across centers, as methodological variations, including meal composition, imaging duration, and patient preparation, can significantly alter quantitative values (Abell et al. 2008).

4.2.5 | Validity and Clinical Relevance of Gastric Emptying Scintigraphy

Gastric emptying scintigraphy is widely regarded as the reference method for assessing gastric emptying, as it provides a direct, quantitative evaluation of gastric emptying kinetics using a standardized meal. Its major strengths include good reproducibility when standardized protocols are applied, the ability to assess solid and liquid emptying separately, and strong construct validity reflecting integrated gastric motor function (Desai et al. 2018). From a clinical perspective, the validated clinical indications of scintigraphy remain the diagnosis of gastroparesis and dumping syndrome. In the field of bariatric surgery and endoscopic bariatric procedures, it is primarily used as an objective research outcome and a potential marker of procedural efficacy rather than as a routine clinical tool. However, correlations between scintigraphic findings and symptom severity remain modest, highlighting the multifactorial nature of gastrointestinal symptoms.

A systematic review and meta-analysis by Vijayvargiya et al. nevertheless showed that, when scintigraphy is performed according to optimal methodology (notably with a 4-h acquisition and a standardized meal), delayed gastric emptying is significantly associated with nausea, vomiting, abdominal pain, and early satiety/fullness. This underlines the importance of strict methodological standardization for the clinical interpretation of scintigraphic results (Vijayvargiya et al. 2019). Limitations include residual methodological variability, logistical constraints, and low-level radiation exposure, which should be considered when interpreting results.

4.3 | Alternative Imaging and Motility Techniques

Magnetic resonance imaging allows non-invasive visualization of gastric volume, accommodation, and emptying without radiation exposure. It provides high spatial resolution and additional information on gastric contents but remains limited by cost, availability, and lack of standardization (Banks et al. 2024).

Antro-duodenal manometry directly measures intraluminal pressure patterns and provides detailed information on gastric and small intestinal contractions. However, it cannot measure gastric emptying rate, since it does not follow the evolution of gastric content. A reduced frequency of antral contractions has been associated with delayed gastric emptying, but this exam remains invasive and poorly suited for assessment of gastric emptying (Soliman et al. 2024).

Wireless motility capsule enables ambulatory assessment of gastrointestinal transit times by measuring pH, pressure, and temperature changes. While useful for global motility evaluation, it

provides indirect information on gastric emptying and may be influenced by pyloric retention of the capsule (Kuo et al. 2008).

Ultrasonography can estimate gastric volume and emptying, particularly for liquids, but is highly operator-dependent and lacks standardized protocols (Darwiche et al. 2003; Hveem et al. 1996).

4.4 | Emerging Techniques and Future Directions in the Assessment of Gastric Motor Function

Beyond the standardization of existing techniques, several methodological developments are likely to reshape the assessment of gastric motor function in obesity and after bariatric interventions. Body surface gastric mapping (BSGM), a non-invasive technique combining high-resolution gastric myoelectrical recording with validated symptom profiling, has recently achieved clinical translation and provides reproducible metrics of gastric rhythm stability, frequency, and amplitude (Schamberg et al. 2023; Law et al. 2024). Its relevance after bariatric procedure was recently explored given that the gastric pacemaker region located on the greater curvature of the corpus is entirely resected during sleeve gastrectomy. The electrophysiological consequences of the procedure remained poorly characterized. In a controlled study of 38 patients assessed 36 months after sleeve gastrectomy, 35 exhibited at least one abnormal parameter compared with controls, typically reduced gastric frequency (2.30 vs. 3.08 cycles per min) and reduced amplitude (14.8 vs. 31.5 μ V), together with higher symptom scores and lower quality of life (Wang et al. 2025). Such approaches may help to unravel the respective contributions of altered gastric emptying, disrupted myoelectrical activity and visceral hypersensitivity to post-bariatric symptoms, factors which cannot be distinguished from one another using conventional scintigraphy.

In parallel, magnetic resonance imaging is emerging as a comprehensive alternative capable of assessing gastric volume, emptying, and wall motion simultaneously without ionizing radiation, although quantitative analysis of gastric peristalsis remains methodologically challenging (Neubauer et al. 2026). Its applicability to post-bariatric anatomies has recently been illustrated by dynamic MRI with three-dimensional gastric segmentation performed before and after endoscopic sleeve gastropasty (ESG), allowing precise quantification of geometric changes at the esophagogastric junction (Vannucci et al. 2026). Extending such approaches to the systematic assessment of gastric emptying in post-bariatric anatomies, where conventional scintigraphic normative values do not apply, represents a priority for future research.

5 | Gastric Emptying in Obesity

Studies investigating gastric emptying in obesity have reported heterogeneous results, partly explained by small sample sizes, methodological variability, and differences in meal composition. A first scintigraphic study reported accelerated emptying of solids in obese subjects compared to controls, without a clear mechanistic explanation (Wright et al. 1983). In contrast, other dual-isotope scintigraphic studies reported delayed emptying

of solids due to prolongation of the solid lag phase with little change in liquid emptying, and demonstrated that the lag phase correlated with excess body weight (Horowitz et al. 1983; Maddox et al. 1989). Further studies showed that modifying the caloric/osmotic content of a mixed meal affected emptying kinetics similarly in obese and lean subjects, suggesting that the obesity-related differences in gastric emptying are not driven by meal composition but reflect an intrinsic motor phenotype (Horowitz et al. 1986).

Studies using a breath test approach reinforced this heterogeneity. Jackson et al. (2004) reported a prolonged lag phase and delayed gastric emptying in obese women. By contrast, Verdich et al. (2000) found that overall 3-h solid emptying was similar between obese and lean men, but that early emptying (first 30 min) appeared increased in obese subjects and normalized after major weight loss.

However, most of these earlier studies included small samples (typically fewer than 30 obese subjects), used heterogeneous protocols, and were not powered to detect modest but clinically relevant differences. More recent and larger sample size studies provide a clearer picture. Vazquez Roque et al. (2006), in a scintigraphic and single-photon emission computed tomography (SPECT) study of 73 normal-weight, overweight, and obese subjects, reported that overweight and obesity were associated with a tendency for acceleration of gastric emptying of solids and lower postprandial gastric volumes. Subsequently, Acosta et al. (2015), in a large cohort of more than 500 subjects (85 normal weight, and 424 overweight and obese subjects) studied with standardized solid-phase scintigraphy, identified accelerated gastric emptying for solids and liquids as one of the quantitative gastrointestinal traits associated with obesity, with potential predictive value for response to weight-loss therapy. Finally, a meta-analysis by Lu et al. (2021) including 17 studies with a total of 906 participants confirmed that gastric $T_{1/2}$ was significantly shorter for both solids (weighted mean difference -10.4 min) and liquids (-6.1 min) in obese compared to lean individuals.

Taken together, although protocol heterogeneity and small sample size studies explain part of the discrepancies with older studies, the most consistent findings emerging from adequately powered cohorts and meta-analytic data support that obesity is associated with an acceleration of gastric emptying, a feature that may contribute to reduced postprandial satiation and increased food intake, and which has been proposed as a predictor of response to weight-loss interventions. Beyond emptying kinetics, several other gastric functions are altered in obesity. Gastric accommodation is increased, with larger fasting and postprandial gastric volumes, contributing to greater meal intake before satiation. Data on antral and pyloric motility in obesity remain limited; available studies suggest rapid antral filling without consistent alteration of antral contractility (Wisén and Hellström 1995; Xing and Chen 2004; Gallagher et al. 2007).

Regarding gut hormone secretion, obesity is associated with attenuated postprandial GLP-1 responses, decreased fasting ghrelin and GIP, and increased leptin, whereas PYY responses appear largely preserved (Tzeravini et al. 2026). These

neurohormonal modifications interact with gastric motor function and contribute to the dysregulation of appetite and energy intake observed in obesity. However, although these alterations correlate with body weight and metabolic outcomes, scintigraphic assessment of gastric emptying in obesity remains, at present, a research and phenotyping tool rather than a clinically actionable parameter.

6 | Evolution of Gastric Emptying After Obesity Treatments

Obesity treatments induce profound anatomical, functional, and neurohormonal changes that significantly affect gastric emptying. These modifications are increasingly recognized as key mediators of weight loss, metabolic improvement, and gastrointestinal symptoms. The magnitude and pattern of gastric emptying changes vary according to the type of intervention, ranging from surgical reconstruction to minimally invasive endoscopic procedures and pharmacological modulation. The main physiological changes associated with obesity and obesity treatments are summarized in Table 2.

6.1 | Changes After Bariatric Surgery

Bariatric surgery induces the most pronounced and consistent alterations in gastric emptying due to major anatomical modifications of the stomach and gastrointestinal tract. Sleeve gastrectomy involves longitudinal resection of approximately 70%–80% of the stomach, including the entire fundus, resulting in a narrow tubular gastric remnant. It is associated with substantial and durable weight loss as well as significant improvement in metabolic comorbidities. Its physiological effects involve not only a mechanical restriction, but they mainly arise from the combination of a marked reduction in gastric reservoir capacity and accommodation, accelerated transit of nutrients toward the antrum and duodenum, removal of the main site of ghrelin production, and enhanced distal nutrient delivery driving an amplified enteroendocrine response. Sleeve gastrectomy accelerates gastric emptying for both liquids and solids (Sista et al. 2017). In a scintigraphic study comparing preoperative and early postoperative measurements, $T_{1/2}$ was markedly shortened for liquids (from 25.3 to 11.8 min) and for solids (from 74.9 to 28.4 min), with significantly reduced gastric retention at all-time points for both phases. Subsequent scintigraphic studies performed before and 3–12 months after surgery assessed solid-phase emptying only, and consistently confirmed this acceleration (Kandeel et al. 2015; Melissas et al. 2013; Vives et al. 2017). Resection of the gastric fundus reduces gastric reservoir capacity and should reduce gastric accommodation, leading to rapid transit of ingested contents toward the antrum and duodenum. Accelerated gastric emptying after sleeve gastrectomy could then lead to enhanced postprandial secretion of incretin hormones, including GLP-1 and PYY, which may contribute to appetite suppression and metabolic benefits of the procedure. However, rapid emptying may also be associated with postoperative symptoms such as dumping syndrome. Paradoxically, sleeve gastrectomy is associated with a high incidence of postoperative gastroesophageal reflux, explained by anatomical changes that are independent of the effects on emptying (Braghetto et al. 2009; Burgerhart

TABLE 2 | Impact of obesity and obesity treatments on gastric physiology and gastric emptying.

Condition	Gastric accommodation	Antral motility	Pyloric function	Hormonal changes	Gastric emptying—liquids	Gastric emptying—solids
Obesity	Increased gastric volume and compliance	No consistent abnormality	No consistent abnormality	Attenuated postprandial GLP-1; preserved PYY; ↓ fasting ghrelin and GIP; ↑ leptin	Accelerated (meta-analytic evidence)	Accelerated (meta-analytic evidence)
Sleeve gastrectomy	Markedly reduced (fundus resection)	Rapid antral filling without significant alteration of antral contractility	Preserved but exposed to rapid transit	Increased postprandial GLP-1 and PYY	Accelerated	Accelerated
Roux-en-Y gastric bypass	Markedly reduced (small pouch)	Antrum bypassed	Pylorus bypassed	Exaggerated incretin response (GLP-1, PYY)	Markedly accelerated	Markedly accelerated
Endoscopic sleeve gastropasty	Preserved/ increased gastric accommodation (fundus and angle of His preserved)	Reduced antral contraction amplitude and extension (MRI data)	Preserved	No clear modification in fasting GLP-1 or PYY (conflicting data)	Variable or slight delay	Delayed in several studies
Intragastric balloon	Mechanical distension, increased accommodation	No data	Preserved	Conflicting data on ghrelin (↑ or ↓); no significant change in PYY; limited data on GLP-1	Delayed	Delayed
GLP-1 receptor agonists	Functional relaxation, increased accommodation	Reduced antral contractility	Increased pyloric tone	Pharmacological GLP-1 effect	Delayed (especially acute phase)	Delayed (acute phase); partial tachyphylaxis reported

et al. 2015; Pilone et al. 2013; Shah et al. 2010; Wickremasinghe et al. 2022).

Roux-en-Y gastric bypass (RYGB) creates a small gastric pouch anastomosed directly to the jejunum, bypassing the distal stomach, the pylorus, and the proximal small intestine. Its physiological effects are only marginally attributable to malabsorption in standard-limb configurations; they result primarily from the loss of gastric accommodation and of pyloric regulation, leading to unregulated delivery of undiluted nutrients to the distal gut, resulting in an amplification of enteroendocrine and bile acid signaling, together with modification of vagal innervation. This procedure achieves profound and sustained weight loss and remains one of the most effective metabolic surgeries (Grönroos et al. 2021). RYGB results in even more profound changes in gastric emptying kinetics. No study has assessed gastric emptying both before and after RYGB using scintigraphy or breath testing. Available data are therefore derived from postoperative assessments only, and consistently show rapid emptying of the gastric pouch, documented for both liquids and solids in one study and for solids in the others, with accelerated pouch emptying persisting at a median follow-up of 47 months (Nguyen et al. 2016; Riccioppo et al. 2018; Dirksen et al. 2013). Alteration of the vagus nerve during surgery might also accelerate gastric emptying, but no data have confirmed this alteration in the context of RYGB. This accelerated delivery is considered a major driver of the exaggerated incretin response and early satiety observed after gastric bypass. Scintigraphic assessment in this context is difficult to interpret because the small gastric pouch retains very little radiolabeled meal, the rapid transit through the pouch into the jejunal alimentary limb makes conventional quantification inadequate, and standardized normal values established for an intact stomach do not apply. Despite these limitations, available scintigraphic data have consistently demonstrated markedly altered emptying patterns (Steenackers et al. 2021; Steinert et al. 2017).

Overall, changes in gastric emptying after bariatric surgery are closely linked to both therapeutic efficacy and adverse gastrointestinal symptoms, highlighting the importance of understanding individual emptying patterns.

6.2 | Gastric Emptying After Endoscopic Bariatric Procedures

Endoscopic bariatric procedures aim to induce weight loss by reducing gastric volume and modifying gastric geometry without surgical resection. These minimally invasive techniques are associated with lower procedural risk and shorter recovery compared to surgery, but generally result in more moderate weight loss. Their effects on gastric emptying appear more heterogeneous and generally less pronounced than those observed after surgery.

ESG is a restrictive endoscopic procedure that uses full-thickness suturing to reduce gastric volume and create a tubular gastric configuration without gastric resection. ESG has been shown to induce clinically meaningful weight loss and improvement of metabolic comorbidities, with a favorable safety

profile. ESG reduces gastric volume along the greater curvature while preserving gastric anatomy. In contrast to surgical sleeve gastrectomy, the gastric fundus and the angle of His are preserved, no tissue is resected, and the gastric tube is shaped by full-thickness sutures rather than by stapling. This anatomical preservation has recently been quantified: using dynamic MRI with 3D gastric segmentation before and 6 months after ESG, Vannucci et al. (2026) showed a significant reduction of the His angle (62.2° – 59.6°), with resolution of pre-existing reflux symptoms in half of the affected patients and no de novo GERD over 12 months, in contrast with the high incidence of reflux reported after sleeve gastrectomy.

Several studies have reported delayed gastric emptying using scintigraphy or breath test measurement of gastric emptying, particularly for solids, up to 12 months after ESG (Vargas et al. 2023; Abu Dayyeh et al. 2017). In the study by Vargas et al., ESG led to an increase in gastric accommodation, since the technique is associated with less reduction of the gastric fundus as compared to surgical sleeve gastrectomy. A lower amplitude and shorter extension of antral contractions assessed by MRI were reported after ESG (Vargas et al. 2023). Finally, conflicting results on hormonal modifications have been published, but there does not seem to be a change in GLP-1 or PYY fasting levels (Vargas et al. 2023; Lopez-Nava et al. 2020). Delayed gastric emptying may enhance satiety and extend postprandial fullness, thereby contributing to reduced caloric intake and correlating with the total weight loss after ESG (Vargas et al. 2023).

Intragastric balloons are space-occupying devices temporarily placed within the stomach to promote early satiety and reduce food intake. They induce short-term weight loss but are typically intended as temporary or bridging therapies. A recent meta-analysis of solid-phase gastric emptying reported a significant delay when comparing pre- versus post-procedure measurements with fluid-filled balloons, whereas the difference was not significant with air-filled balloons (Vargas et al. 2020). Intragastric balloons lead to an increase in gastric volume and accommodation, which might explain the delay in gastric emptying (Layec et al. 2010). Data on antral motility specifically after IGB placement are scarce, with most studies focusing on global emptying parameters rather than on regional gastric motor function. The magnitude of this effect varies depending on balloon volume and filling characteristics. Delayed emptying may contribute to early satiety but is also associated with nausea and vomiting, particularly in the early post-placement period. From a neurohormonal perspective, available data on the impact of IGB on appetite-regulating hormones remain conflicting. Mion et al. (2005) reported a decrease in plasma ghrelin levels following IGB placement in non-morbidly obese subjects, with weight loss correlated to ghrelin variations rather than to changes in gastric emptying. Conversely, Konopko-Zubrzycka et al. (2009) observed a transient increase in plasma ghrelin in morbidly obese subjects, while Fuller et al. (2013) similarly reported an increase in ghrelin during balloon insertion, with no significant change in PYY. Specific data on postprandial GLP-1 after isolated IGB therapy remain limited. Overall, the satiating effect of the IGB appears to be primarily mediated by mechanical gastric distension and modulation of accommodation, while neurohormonal mechanisms remain incompletely characterized.

Compared to bariatric surgery, endoscopic procedures induce more moderate and potentially reversible changes in gastric emptying, which may partly explain differences in weight loss efficacy and symptom profiles. Nonetheless, changes in weight loss were correlated with changes in gastric emptying, whether the procedure results in an acceleration or a delay in gastric emptying.

6.3 | Effect of Anti-Obesity Pharmacotherapy on Gastric Emptying

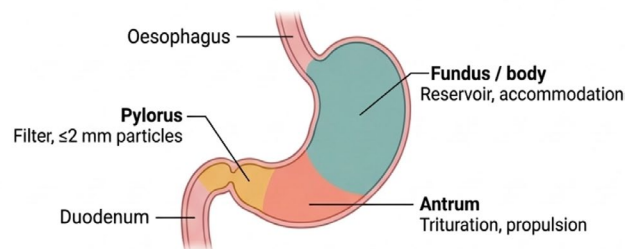
Anti-obesity pharmacotherapies, particularly incretin-based agents, exert a significant part of their therapeutic effect through modulation of gastric emptying. These medications have demonstrated clinically significant weight loss and metabolic benefits and now represent a major pillar of obesity management.

GLP-1 receptor agonists are pharmacological analogues of endogenous incretin hormones and have shown robust efficacy in inducing weight loss and improving glycemic control (Davies et al. 2021). Scintigraphic studies, predominantly assessing solid-phase emptying, have consistently demonstrated delayed gastric emptying after acute administration of GLP-1 receptor agonists (Jalleh, Marathe, et al. 2024; Hiramoto et al. 2024; Jalleh, Plummer, et al. 2024; Jalleh, Rayner, et al. 2024). GLP-1 receptor agonists delay gastric emptying by reducing antral contractility and increasing pyloric tone. They also lead to an increase in gastric volumes and gastric accommodation which might contribute to delayed gastric emptying (Delgado-Aros et al. 2002). These effects are more pronounced during the early phase of treatment and contribute to reduced postprandial glucose excursions, enhanced satiety, and decreased food intake (Figure 1).

However, with chronic treatment, partial tachyphylaxis of the gastric emptying effect has been described, whereas appetite suppression and weight loss persist. This dissociation is consistent with experimental data showing that long-acting GLP-1 receptor agonists induce weight loss independently of changes in gastric emptying, and that central rather than vagal GLP-1 receptors are required for the full anorectic response to liraglutide. Central nervous system mechanisms therefore appear to become increasingly important contributors to long-term efficacy, while the delay in gastric emptying contributes predominantly to early postprandial glycemic control and satiety (Baggio and Drucker 2014).

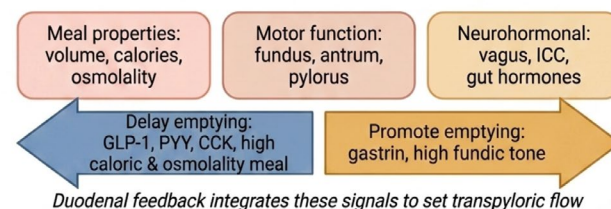
Dual and triple incretin agonists, targeting combinations of GLP-1, GIP, and glucagon receptors, represent a new generation of anti-obesity drugs with greater weight loss efficacy than GLP-1 receptor agonists alone (Aronne et al. 2024; Saha et al. 2025). Their effects on gastric emptying appear complex and agent-specific. While GLP-1-mediated slowing of gastric emptying is preserved, concurrent activation of other receptors may modulate this effect and influence tolerability, energy expenditure, and overall efficacy. Data on gastric emptying assessed by scintigraphy in this context remain limited but are of growing interest.

A. Functional regions of the stomach



Gastric emptying requires synchronized antro-pyloro-duodenal coordination

B. Determinants of gastric emptying



C. Impact of obesity treatments on gastric emptying

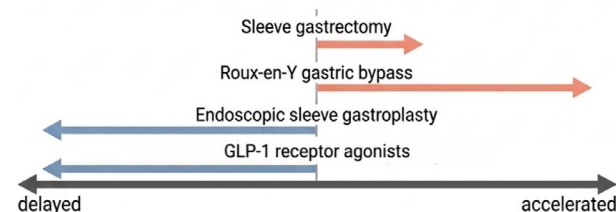


FIGURE 1 | Gastric emptying: functional anatomy, physiological determinants, and modulation by obesity treatments. (A) Functional regions of the stomach. The proximal stomach (fundus and body) acts as a reservoir, accommodating ingested food through receptive relaxation. The antrum ensures trituration and propulsion of solids, while the pylorus acts as a dynamic filter allowing only particles ≤ 2 mm to pass into the duodenum. Efficient gastric emptying depends on synchronized antro-pyloro-duodenal coordination. (B) Physiological determinants of gastric emptying. Emptying rate is set by the interaction of meal properties (volume, caloric content, osmolality), gastric motor function (fundic tone, antral contractility, pyloric resistance), and neurohormonal regulation (vagal pathways, interstitial cells of Cajal, and gut hormones). Cholecystokinin (CCK), glucagon-like peptide-1 (GLP-1), peptide YY (PYY), and high-caloric or hyperosmolar meals delay emptying, whereas gastrin and high fundic tone promote it. Duodenal feedback integrates these signals to regulate transpyloric flow. (C) Direction of change in gastric emptying induced by obesity treatments, relative to the untreated state. Bariatric surgery accelerates gastric emptying, markedly so after Roux-en-Y gastric bypass and to a lesser degree after sleeve gastrectomy. In contrast, endoscopic sleeve gastroplasty, intragastric balloons, and GLP-1 receptor agonists delay gastric emptying. Arrow direction indicates acceleration (right) or delay (left); arrow length reflects the relative magnitude of the effect. CCK, cholecystokinin; GLP-1, glucagon-like peptide-1; ICC, interstitial cells of Cajal; PYY, peptide YY.

7 | Conclusion

Gastric emptying is a complex and tightly regulated physiological process that plays a central role in digestion, appetite control,

and metabolic homeostasis. It reflects the integrated function of gastric accommodation, antral motility, pyloric regulation, and neurohormonal signaling and is influenced by both physiological and pathological conditions.

Gastric emptying scintigraphy remains the reference method for assessing gastric emptying, providing a direct, quantitative, and physiologically relevant evaluation when performed using standardized protocols. In current clinical practice, its main validated indications are the diagnosis of gastroparesis and dumping syndrome; in the field of obesity and bariatric procedures, it remains primarily a research and phenotyping tool, although its potential clinical applications, including phenotype-based patient selection and post-procedural monitoring, deserve further investigation. Emerging techniques such as BSGM and quantitative MRI may help to characterize the distinct contributions of altered emptying, myoelectrical dysfunction and accommodation, particularly in post-bariatric anatomies where conventional scintigraphic normative values do not apply.

In obesity, gastric emptying tends to be accelerated, as demonstrated by larger cohorts and meta-analytic data, in association with increased gastric accommodation, larger fasting and postprandial gastric volumes, and altered postprandial gut hormone signaling. These features may contribute to reduced satiation and dysregulated eating behavior.

Importantly, gastric emptying is profoundly modified by obesity treatments, including bariatric surgery, endoscopic bariatric procedures, and anti-obesity pharmacotherapies. Each intervention induces a specific gastric emptying signature—acceleration after sleeve gastrectomy and RYGB, delay after ESG, intragastric balloon, and GLP-1 receptor agonists—which contributes to weight loss and metabolic benefits through distinct but complementary mechanisms involving accommodation, motility, and neurohormonal signaling.

Future research should focus on improving the standardization of gastric emptying assessment, particularly in obese populations and post-intervention settings. Longitudinal studies integrating gastric emptying measurements with clinical outcomes, hormonal responses, and behavioral parameters are needed to clarify causal relationships and interindividual variability. In this context, gastric emptying may emerge as a key physiological biomarker to guide treatment selection and support personalized therapeutic strategies, including combined or sequential approaches such as endoscopic interventions associated with pharmacotherapy.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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