Case Report

Consuming the Main Meal at Lunch and an Earlier, Smaller-Sized Dinner Reduced Pre-Bedtime and Nocturnal Refractory Gastro-Oesophageal Reflux but Was Less Effective for Early-Morning Laryngopharyngeal Reflux: A Case Report with Discussion

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A case is reported where consuming the main meal at lunch and an earlier, smaller-sized dinner reduced averaged, refractory pre-bedtime reflux scores (over 5 days and, three months later, over 8 days) from a maximum of 3 (significant symptoms) to 0.23 ± 0.44, nocturnal reflux scores from 1 or 2 (mild to moderate symptoms) to 0.69 ± 0.85, and sore throat and cough scores from 1 or 2 to 0.85 ± 0.90. Anecdotal evidence suggested that mealtime and meal volume changes brought significant benefits for pre-bedtime and nocturnal gastro-oesophageal reflux (GER) but were less effective for laryngopharyngeal reflux (LPR) symptoms of early morning sore throat and cough.

A review of the literature found that early meals before bedtime and reduced meal volumes were likely to reduce the risk of GER and developing GERD. When recumbent, it was reported that meals were digested more slowly and gastric emptying rates decreased. Meals were also digested faster in the morning than in the evening, even when awake, with circadian rhythm and air swallowing also influencing the metabolism and the absorption of food. These reports indicate a biochemical basis for the benefit of early meals before bedtime and reduced meal volumes to reduce the risk of GER.

It was also reported that when recumbent, for meals close to bedtime or large meals, gravity could assist the backflow of stomach contents into the oesophagus, indicating a biophysical basis for GER.

To understand the role of gravity in GER, values for hydrostatic pressure were calculated for pre-meal to meal volumes of 1000 ml and found to be from 2–23 mmHg, in the same order of magnitude as the reported tonically contracted lower oesophageal sphincter pressure of 15–30 mmHg. Hypothetical models are developed to show how gastric content (GC) and body orientation change the hydrostatic pressure on the lower oesophageal sphincter and influence the risk of GER in the fed state.

In summary, it is likely there is both a biochemical and a biophysical basis for GER and LPR, with meals 5 hours before bedtime, or smaller meals before bedtime, over 5 consecutive days, together with a raised bed head and sleeping dominantly on the left-hand side, all likely to reduce refractory GER symptoms.

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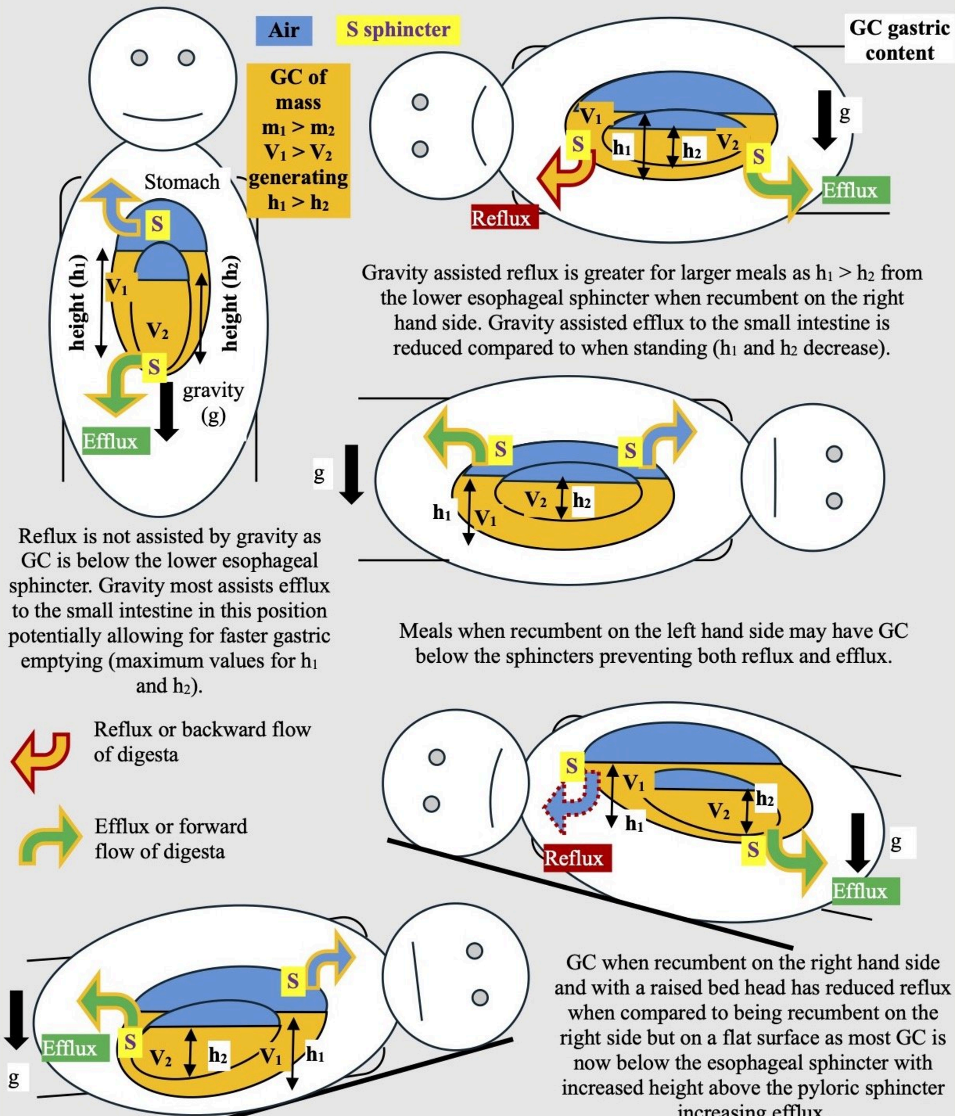
Graphical Abstract

Hypothetical models show how gastric content (GC) and body orientation change the hydrostatic pressure on the lower esophageal sphincter influencing the risk of gastroesophageal reflux in the fed state

Larger meals of mass m_1 and volume V_1 increase the height h_1 of the GC in the stomach more than smaller meals (m_2, V_2, h_2) such that $h_1 > h_2$, $V_1 > V_2$ and $m_1 > m_2$. This can result in increased hydrostatic pressure on the lower esophageal sphincter, increasing reflux (the backward flow) of GC into the esophagus and on the pyloric sphincter, increasing efflux (the forward flow) of GC into the small intestine.



Gravity assisted reflux is greater for larger meals as $h_1 > h_2$ from the lower esophageal sphincter when recumbent on the right hand side. Gravity assisted efflux to the small intestine is reduced compared to when standing (h_1 and h_2 decrease).

Reflux is not assisted by gravity as GC is below the lower esophageal sphincter. Gravity most assists efflux to the small intestine in this position potentially allowing for faster gastric emptying (maximum values for h_1 and h_2).

Meals when recumbent on the left hand side may have GC below the sphincters preventing both reflux and efflux.

Reflux or backward flow of digesta

Efflux or forward flow of digesta

GC when recumbent on the right hand side and with a raised bed head has reduced reflux when compared to being recumbent on the right side but on a flat surface as most GC is now below the esophageal sphincter with increased height above the pyloric sphincter increasing efflux.

When recumbent on the left hand side and with a raised bed head GC is now further from the esophageal sphincter compared to being recumbent on the left side and on a flat surface. Gravity assists both efflux and reflux on the right hand side. For those with reflux sleeping on the left hand side is preferable.

Hydrostatic Pressure (P) = density (ρ) x gravitational acceleration (g) x height (h)

ρ = density of the GC approximated to that of water as 993 kg/m^2 at 37^o C; $g = 9.8 m/s^2$; h = height of liquid or GC and 1 N/m^2 $\approx$ 0.0075 mmHg then: $P \approx 993 \times 9.8 \times 0.0075 \times h \approx 73 \times h$ (mmHg).

For pre-meal to meal volumes of 1000 ml, the minimum and maximum h $\approx$ 2.4 to 32 cm or (0.024 to 0.32m) then $P \approx 73 \times (0.024 \text{ to } 0.32) \approx 2\text{-}23$ mmHg, the same order of magnitude as the tonically or sustained contracted average pressure for the lower esophageal sphincter of 15-30 mmHg [37-40].

1. Introduction

Gastro-oesophageal reflux (GER) occurs when gastric content (GC) refluxes back into the oesophagus, but it can also enter the larynx, throat, mouth or lungs and, if frequent and severe, can develop into gastro-oesophageal reflux disease (GERD) [1]. Laryngopharyngeal reflux (LPR) is an inflammatory condition of the upper aerodigestive tract tissues and can be related to the effects of GER, GERD or gastroduodenal reflux [2]. In this case report, a patient developed significant pre-bedtime and nocturnal GER with a late-night or early-morning sore throat and cough, symptoms that can be associated with LPR, that were not responding to antacid treatments [2][3][4]. The patient was concerned that a course of proton pump inhibitors (PPIs) would need to be commenced, despite a previous course taken several years earlier having had limited benefits. The patient knew from experience that early meals and smaller meals were beneficial in reducing pre-bedtime reflux, but changing mealtimes and food volumes consistently over several days as a treatment option had not been considered. It was decided to consume a larger lunch and an earlier, smaller dinner 5 (4–6) hours before bedtime over several consecutive days. The frequency and severity of any changes in reflux, sore throat and cough symptoms would be recorded.

A recent consensus paper for the diagnosis and management of refractory GERD has recommended that patients avoid eating dinners close to bedtime, elevate the head end of the bed by at least 20 cm and preferably sleep in the left lateral position [5].

A brief review of the literature to determine how the development of GER and GERD may be influenced by changes in meal timing, volumes, body position, the rate of gastric emptying, circadian rhythm and air swallowing was undertaken (Tables 1–3). Gravity-induced hydrostatic pressure values were calculated in mmHg to compare with reported tonically or sustained contracted average oesophageal sphincter values to help explain why meal volume and body orientation (upright and recumbent) could contribute to GER and LPR.

2. Case Report

A 63-year-old male with no underlying health conditions had experienced GER over the past 8 years and 3 years previously was diagnosed with laryngopharyngeal reflux following laryngoscopy after noting a sore throat on waking during the night or in the morning with changes in his voice. An 8-week course of twice-daily PPIs was undertaken, with symptom relief initially but with benefits reducing slowly over time and worsening on cessation, and so was considered refractory to PPIs.

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Intermittent gastric reflux symptoms usually occurred after dinner while preparing to go to sleep at night. If reflux symptoms were present before sleep or on waking at night a few hours after sleep, they were effectively managed by taking one antacid tablet containing mixtures of sodium bicarbonate (up to 100 mg) and calcium carbonate (up to 300 mg). The bed head had been raised by 12 cm (20 cm has been recommended) and sleeping, preferably in the left lateral position, had already been adopted and was considered of benefit in reducing nocturnal reflux symptoms.

For an unknown reason, symptoms developed over 5 days where the usual antacid medications did not resolve pre-bedtime and nocturnal reflux symptoms, sometimes with a sore throat and cough, occurring early in the morning or on waking.

The patient was reluctant to undergo a second course of PPIs and so decided to increase the time between dinner and bed as a possible treatment option. This would be achieved by consuming the main meal of the day at lunchtime, 9 (8–10) hours before bedtime, and a small-sized meal at dinnertime, 5 (4–6) hours before bedtime, over several consecutive days, ending if symptom relief was obtained. Previously, lunchtime was usually around 1–2 p.m., with a larger dinner around 6–7 p.m.; bedtime and sleep were usually at 10.30 (10–11) p.m., with the time between the main meal and bedtime being approximately 4 (3–5) hours.

The smaller-sized evening meals often consisted of soup and small portions of rice or bread, approximately 50 (40–60)% of the volume of the usual main meal at dinnertime, with animal fats and protein avoided. Hunger was often felt prior to sleep, with a disciplined approach needed to avoid further eating. On waking at night, a dry mouth, a sore throat and sometimes a cough, often without prior reflux symptoms, were noted, relieved by drinking water or taking an antacid tablet.

Reflux was defined as either feeling the stomach contents could reflux into the oesophagus or heartburn, with symptoms generally difficult to differentiate at the time of occurrence. Reflux symptoms were scored pre-bedtime, on waking during the night as nocturnal reflux, and for sore throat and cough. Symptoms were scored on a linear scale from 0–3, with 0 meaning no symptoms, 1 mild, 2 moderate and 3 significant symptoms; although an apparently simple scoring system, it has been found to be more accurate than more complex scoring systems often used in the past [6]. After 5 days, symptom relief was obtained, and dinnertimes and food volumes returned to usual times and quantities.

Three months later, for an unknown reason, symptoms returned, and again the main meals were consumed at lunch, this time 7.5 (7–8) hours before bedtime, and with a smaller-sized dinner, approximately 40 (30–50)% of the usual size, 5 (4–6) hours before bedtime. After 8 days, reflux symptoms were relieved, although the early-morning sore throat and cough persisted, with mealtimes and food volumes again returning to the usual times and quantities.

Changes in meal timing resulted in a loss of pleasure associated with preparing and sharing the same evening meals with others and so would be used on demand if required, rather than becoming a lifestyle change.

3. Results

3.1. Pre-bedtime and nocturnal reflux with sore throat and cough scores

The pre-bedtime reflux, nocturnal reflux, and sore throat and cough scores were initially recorded before changes in meal timing and volume were undertaken for days 1–5, where symptoms were not resolved by antacid treatment, followed by 5 days (days 6–10), Fig. 1, and then again 3 months later for 8 days (days 8–13), where changes in meal timing and meal volume were undertaken, Fig. 2.

For Fig. 1A-C, over days 6-10, the main meal was consumed at lunchtime about 12–1 pm, 9(8–10) hours before bedtime with a small dinner at about 4–5 pm, 5(4–6) hours before bedtime. Pre-bedtime reflux symptoms improved rapidly and any symptoms that did arise were now responsive to antacid treatment. Average symptom scores over days 6–10 reduced from the pre-bedtime reflux score of 3 on days 1–5 to 0.4±0.55 for days 6–10, nocturnal reflux from 2 on days 1–5 to 1.0±1.0 for days 6–10 and cough and sore throat scores on days 1–5 to 0.2±0.45 for days 6–10. The number of nocturnal reflux and sore throat and cough events was also reduced, compared to the previous 5 days (days 1–5) before the early main meals at lunch and smaller dinners were initiated.

On days 7 and 8, reflux symptoms occurred during the night at about 4 am with a dry mouth, up to 10–11 hours after a main meal when in a more fasting state. On day 9 a sore throat score was recorded early in the morning at 3–5 am, despite no reflux symptoms being scored, possibly occurring due to "silent reflux" [7].

It cannot be known for certain if the reduction of reflux and sore throat and cough scores over the 5 days was due to consuming the main meal at lunchtime with earlier and reduced meal volumes at dinnertime, or would have occurred naturally anyway over time. From the patient's perspective, having a main meal at lunch and a smaller early meal for dinner over 5 days resulted in a reduced frequency and severity of reflux symptoms from previous values; the reflux symptoms that did occur were now more manageable with antacids and an 8-week course of PPIs had been avoided.

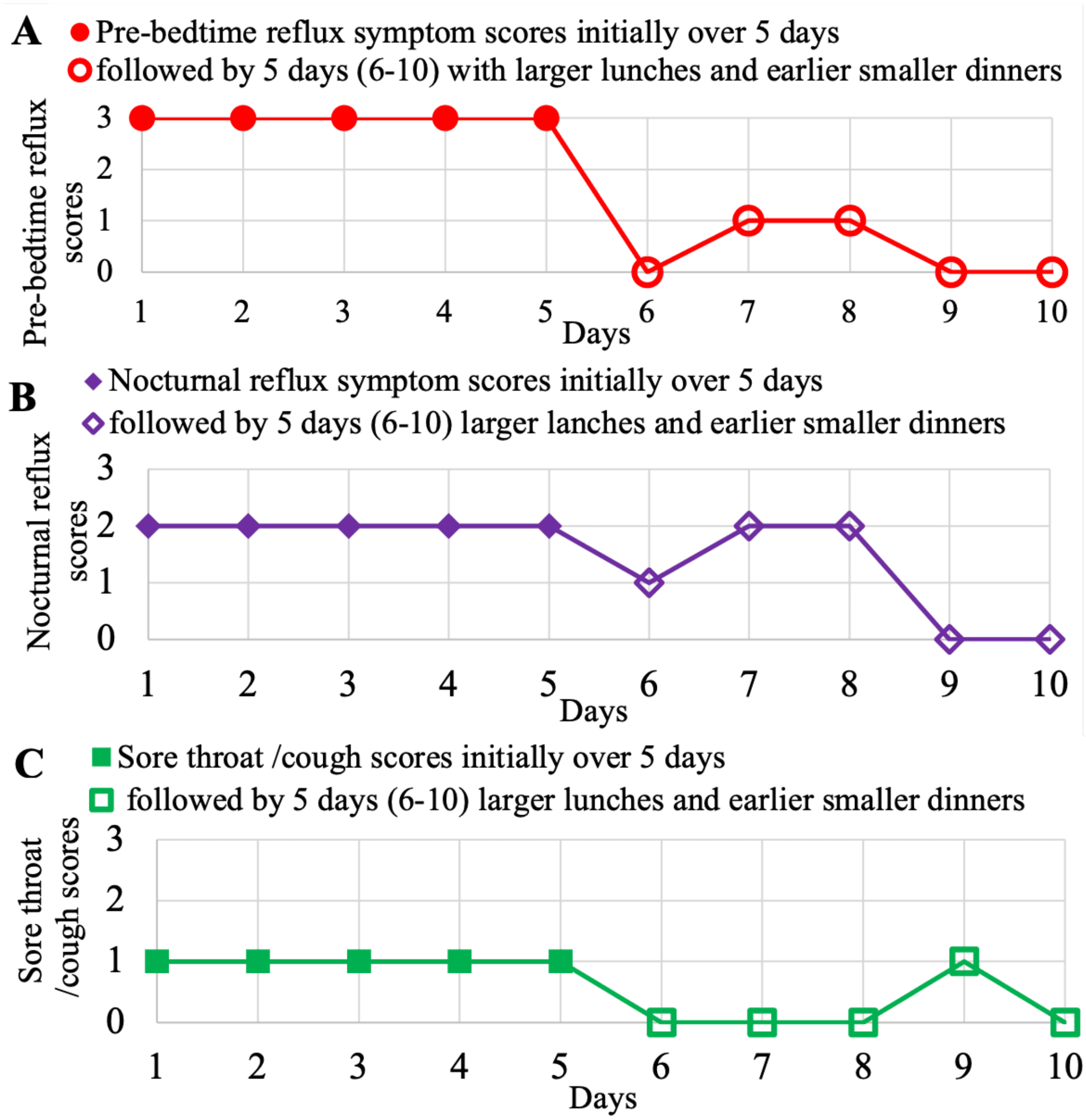

Figure 1. A, B, C. For the first 5 days, estimated initial pre-bedtime reflux scores were 3/3 (days 1–5), nocturnal reflux 2/3 (days 1–5) and sore throat and cough 1/3 (days 1–5). These days were followed by days 6–10 (5 days) where the main meal was at lunch, giving a main meal to bedtime time of 9(8–10) hours followed by a smaller meal of 50(40–60)% of the volume 5(4–6) hours before bedtime. The most rapid change in symptom severity over the 5 days (days 6–10) was for pre-bedtime reflux. A connecting line was used to join the data points rather than using the slope of the line of best fit and the coefficient of determination or R^2 values, as caution is needed in the evaluation of trends in this way [8].

After 3 months, reflux symptoms were again unresolved by antacids as described previously, Fig. 1D-F. Larger lunches 7.5(7–8) hours before bedtime and earlier dinners 5(4–6) hours before bedtime of approximately 40(30–50)% of the usual main meal were consumed, but this time for 8 days, before symptoms were thought manageable, Fig. 2.

Symptom scores over the 8 days (days 6–13) reduced for pre-bedtime reflux from 3 on days 1–5 to 0.13±0.35 for days 6–13, nocturnal reflux from 1 on days 1–5 to 0.5±0.76 for days 6–13, and cough and sore throat scores from 2 for days 1–5 to 1.3±0.89 for days 6–13. Again, pre-bedtime reflux scores improved rapidly from a score of 3 (days 1–5) to 0 within 1 day (day 6); nocturnal reflux symptoms improved more slowly, reducing from a score of 1 (days 1–5) to a score of 0 from day 9. Sore throat and cough scores on waking during the night or in the morning reduced from 2 (days 1–5) to a score of 1 from days 10–13, showing some resistance to the influence of changes in meal timing on symptoms. The sore throat and cough scores were always recorded early in the mornings at around 3–5 am, and for days 10–13 occurred with a score of 1 without a score for pre-bedtime or nocturnal reflux, again suggesting “silent reflux”.

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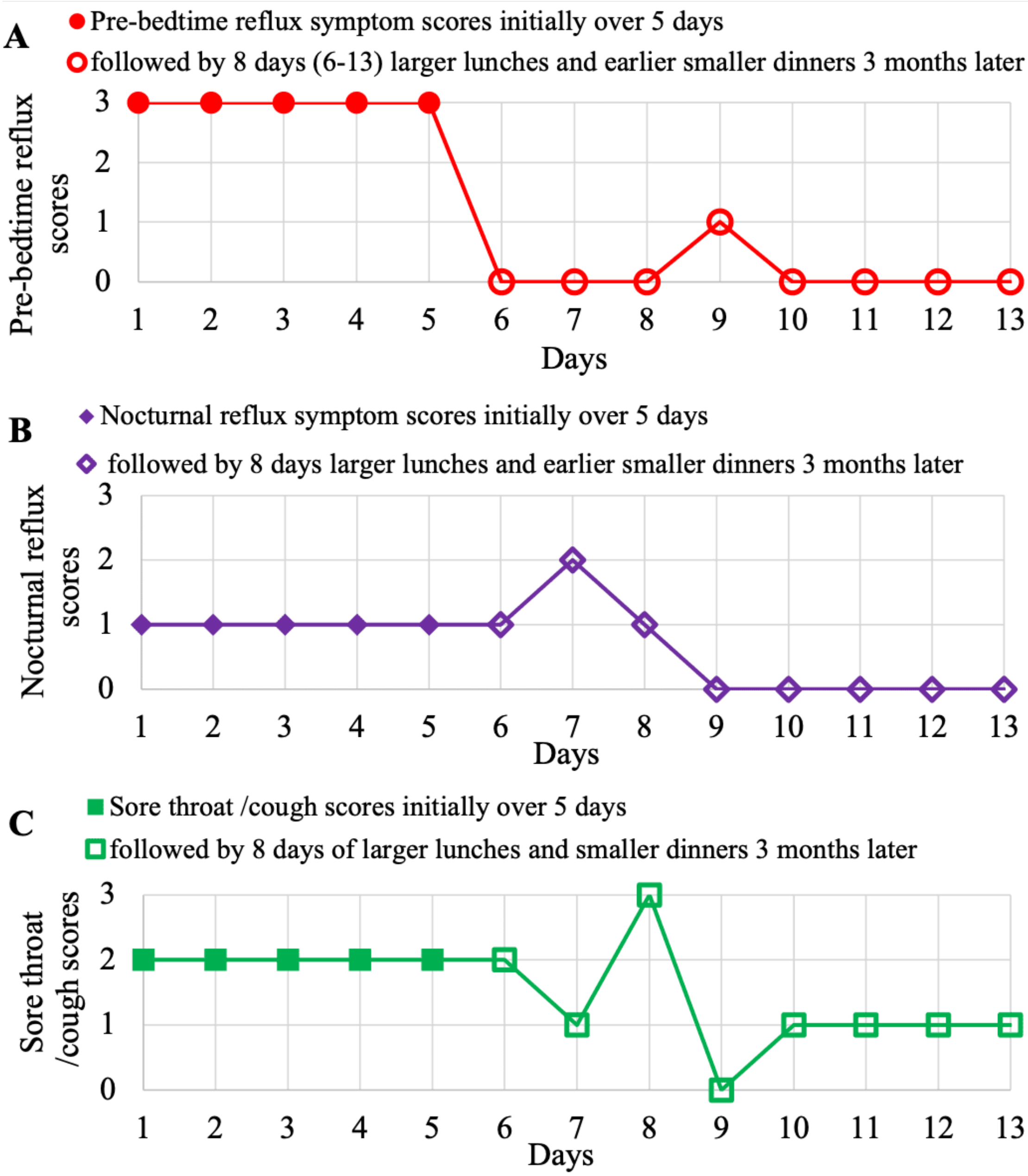

Figure 2. A, B, C. Three months later reflux symptoms returned and again for the first 5 days, the estimated initial pre-bedtime reflux scores were 3/3 (days 1–5), nocturnal reflux 1/3 (days 1–5) and sore throat and cough 2/3 (days 1–5). These days were followed by days 6–13 (8 days) where the main meal was at lunch, giving a main meal to bedtime time of 7.5(7–8) hours followed by a smaller meal of 40(30–50)% of the volume 5(4–6) hours before bedtime. The most rapid change in symptom severity over the 8 days (days 6–13) was for the pre-bedtime reflux scores with less change for nocturnal reflux and a full reduction in sore throat and cough scores not obtained. For both the 5 days (Fig. 1) and 8 days (Fig. 2),

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where meal timing and volumes were changed, a trend towards lower symptom scores, as supported by anecdotal evidence that symptoms had significantly improved, was found.

The early morning LPR symptoms occurred when in a more fasting state, suggesting different mechanisms than for the GER symptoms, which occurred sooner after meals, when in the fed state.

If the change in scores over 5 days (days 6–10) and 8 days (days 6–13) are averaged, then pre-bedtime reflux scores reduced from 3 (days 1–5) to 0.23±0.44, nocturnal reflux scores from 1 or 2 (days 1–5) to 0.69±0.85 and sore throat and cough scores from 1–2 (days 1–5) to 0.85±0.90.

It is not certain if symptom reduction was primarily due to consuming the main meals at lunch, 9(8–10) hours and three months later 7.5(8–9) hours before bedtime, or simply from the reduction of meal volumes by 40–50%, 5(4–6) hours before bedtime, rather than the usual 4(3–5) hours, or both.

4. Discussion

4.1. Dinner to bedtime meal volumes and time between meals

Fourteen reports investigating the influence of meal timing on GERD were found, with three reports relating to other medical conditions (Table 1) [9][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25]. In one of the 14 reports, having dinner at 9 pm rather than 6 pm resulted in increased acidity in the stomach overnight [9]. In 11 of the remaining 13 reports, dinners close to bedtime resulted in an increased risk of GERD and gut cancers [11][12][13][14][15][16][18][19][20][21][22]. In only two of the remaining 13 reports, no change in GERD symptoms was found for meals between two, 3.5 or four hours before bedtime or for meals < 3 hours or ≥ 3 hours before bedtime [10][17]. Regarding non-GERD-related diseases, shorter dinner-to-bedtimes were associated with an increased risk of colorectal cancer, being overweight or obese, and asthma (Table 1) [23][24].

The terms 'early dinners', 'late evening meal', 'eating dinner close to bedtime', 'dinner to bedtime', 'short meal to bedtime' and 'timing between sleep and meals' are used in the literature, with bedtime assumed to be approximately the time sleep begins at night, when adopting a recumbent position [9][10][11][14][15][16][20][21].

The influence of meal volume for 15 patients with GERD found that three larger-volume liquid meals of 600 ml per day (1800 ml in total) were associated with distension of the gastric fundus and increased

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reflux compared to six smaller meals of 300 ml per day (1800 ml in total) [26].

The time between meals and the number of meals per day may also be a significant factor in reducing GER [27]. The consumption of two meals per day 10–12 hours apart (morning and evening), with only liquid in between meals, was found for 44 patients with GERD to result in a highly significant improvement in heartburn, reflux, nausea, vomiting and dyspepsia after two weeks (p=0.001) based on patient responses [27]. It was suggested that a contributing factor could be changes in the migrating motor complex (MMC) developed during the inter-digestive state or the fasting phase, clearing the stomach of unwanted waste material and pushing chyme towards the small intestine [27]. This suggestion may be supported by the reported findings from scintigraphy using technetium-labelled lactulose solutions where meal transit time for constipation-predominant patients with IBS was 2.2 times greater than for diarrhoea-predominant patients (p=0.0023), indicating that meal loading in more distal regions of the gut may influence transit times in more proximal regions [28].

In summary, increasing the time between dinner and bed, having smaller meals and increasing the time between meals are all likely to reduce the risk of GER and developing GERD.

4.2. Body position and reflux

Reports comparing digestion in either the sitting or supine positions during the day and while awake found differences in the intragastric distribution of food, slower emptying times when supine, reduced absorption post-prandially and reduced digestion in numerical models of the duodenum, as summarised in Table 2 [29][30][31][32][33].

Bed head elevation by 20 cm at the head end of the bed while asleep has been recommended in a recent consensus and likely lowers the risk of reflux, with gravity suggested as an opposing factor for reflux and aiding the clearance of reflux content, Table 2 [5][34][35].

In relation to body position and GER, ingested ^{13}C-labelled phenylalanine milk protein and paracetamol from blood samples collected 5 hours post-prandially showed both protein and paracetamol levels were higher when sitting upright compared to when supine, suggesting the sitting position preferentially accelerates gastric emptying and increases absorption rates, Table 2 [32].

For 500 individuals, 238 with GERD, acid exposure time in the oesophagus when recumbent during the day was found to be no different for individuals recumbent at night, suggesting body position, rather than being awake in the day or asleep at night, was the more significant factor for GER [36].

In summary, when recumbent compared to upright, whether during the day or night, meals are digested and absorbed more slowly, suggesting a biochemical basis for GER with body position. For meals close to bedtime or for large meals, there is an increased force of gravity for the backflow of GC into the oesophagus or throat when recumbent, suggesting a biophysical basis also exists for GER with body position.

4.3. Hydrostatic pressure and models for gastric reflux

Hydrostatic pressure can be defined as the pressure (P) resulting from a fluid of density (ρ), gravitational acceleration (g) and the fluid height (h) for a static fluid as:

$$P = \rho g h \tag{1}$$

showing P has a linear relationship with h and does not depend on the volume (V) of fluid present, only if V influences the value of h. Liquids also exert pressure in all directions, not only downward but sideways and upwards (buoyancy). The hydrostatic pressure on the sphincters in the stomach depends on the height (h) of liquid or GC above the sphincter, which depends on the mass or volume of food consumed, the GC density and the gravitational acceleration. If the density of the GC can be averaged to approximately that of water (oils and fats less dense with some solids of greater density) at 37^{0} C as ≈ 993 kgm^{3} and g = 9.8 m/s^{2} then:

$$P \approx 993 \times 9.8 \times h(\mathrm{N/m^2}) \tag{2}$$

with 1 N/m^{2} ≈ 0.00750 (mmHg) then:

$$P \approx 993 \times 9.8 \times (0.0075) \times h \approx 73 \times h(\mathrm{mmHg}) \tag{3}$$

[37]. This would suggest for water or GC in the stomach of h ≈ 1 cm = 0.01m then:

$$P \approx 73 \times 0.01 \approx 0.73 \text{ (mmHg) per 1 cm height of GC} \tag{4}$$

Note that this pressure adds to the existing atmospheric pressure (1.01 x 10^{5} N/m^{2} ≈ 760 mmHg) that the body is under such that:

$$P_{\text{total}} = P_{\text{atmosphere}} + P_{\text{liquid or GC}} \approx 760.00 + 0.73 \approx 760.73(\mathrm{mmHg}) \tag{5}$$

for GC of height 1 cm and although this pressure seems small compared to atmospheric pressure, it is still a significant addition, particularly if the value of h increases.

Models of the stomach have reported that volume (V) changes from a pre-meal value to a meal of 1000 ml as V ≈ 113–1,173 ml with length (L) changing to L ≈ 27–32 cm and diameter (D) as D ≈ 2.4–7.2 cm [38]. Note

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the stomach length changes (32-27/32) x100 ≈ 16% while the diameter changes (7.2-2.4/7.2) x100 ≈ 67%, suggesting the stomach is more like an expanding tube that only slightly increases in length relative to diameter.

For V ≈ 113-1000 ml the minimum and maximum values for h ≈ 27-32 cm and from the diameter, give values for h ≈ 2.4-7.2 cm. From pre-meal to meal volumes of 1000 ml, water or GC have heights from a minimum to a maximum value of ≈ 2.4-32 cm and with P ≈ 0.73 mmHg per cm, then from eq. 4:

$$P_{\text{liquid or GC}} = 0.73(2.4 - 32) \approx 2 - 23 \text{ mmHg} \tag{6}$$

The lower oesophageal sphincter (LES) has been reported to be tonically contracted to an average pressure of 15 to 30 mmHg [39][40]. The pyloric sphincter resting pressure has been determined as 5.0±0.5 mmHg, increasing to 17.2±1.4 mmHg during duodenal acidification with 0.1 M HCl, but can peak at 66±40 mmHg in those with delayed gastric emptying [41][42].

Based on these values, it is possible that GC at a height in the stomach of 2.4-32 cm can produce hydrostatic pressures of ≈ 2-23 mmHg, the same order of magnitude as the LES sphincter pressures. This suggests large meal volumes could create pressures that allow pressure-related reflux events to occur.

Larger meals close to bedtime would result in more liquid or GC in the stomach and on sleeping, the changes in posture from upright to recumbent would also result in variations of GC height. Earlier meals would be partially digested and result in a reduced GC volume and therefore GC height in the stomach. Simple models can be developed to show how meal volume and body position influence the height of GC above the oesophageal and pyloric sphincters as shown in the Graphical Abstract.

Increased height of the GC above either sphincter in the stomach will increase the gravity-induced hydrostatic pressure and for the oesophageal sphincter, the potential for backflow or reflux of GC into the oesophagus. For the pyloric sphincter, hydrostatic pressure can increase the forward or outflow of GC into the small intestine and with no descriptive term found in use in relation to the gut, the word efflux could be used to describe the forward flow of liquids in the gut.

Based on hydrostatic pressure values, the volume, which changes the height of the meal in the stomach, and density of the food are the only determinants for reflux, with early meals or smaller meals before bedtime being beneficial solely from the reduced meal volume in the stomach. Reflux is best avoided by standing or sleeping on the left-hand side, while emptying of a full stomach is best supported by standing or sleeping on the right-hand side to increase efflux and the gastric emptying rate.

In summary, the hydrostatic pressure in the stomach depends on the height of the liquid or GC present, which depends on the meal volume consumed, with early dinners to bedtimes beneficial due to the resulting reduced meal volume, lowering the height of GC in the stomach pre-bedtime and during the night when recumbent, reducing the risk of reflux when in the fed state.

4.4. Gastric emptying circadian rhythm and air swallowing

The rate of gastric emptying has been considered a possible contributing factor towards developing reflux symptoms (Table 3) [7][43]. A 220% difference in the half-life of gastric emptying for meals consumed at 8 am compared to meals consumed at 11 pm, while awake and supine, may demonstrate the role of the circadian rhythm with increased activity in the morning and during the day and quiescence at night, with digestion slowing at night even before sleep (Table 3) [43][44]. A lack of nocturnal air swallowing may potentially be associated with reflux due to the inadequate digestion of food from reduced aerobic digestion of meals close to bedtime and reduced carbon dioxide swallowing, potentially reducing bicarbonate production for acid neutralisation (Table 3) [45][46].

In summary, gastric emptying is likely faster in the morning and slower in the evening. Slower digestion prolongs the presence of food in the stomach and so increases the risk of gastric reflux; a lack of air swallowing during the night, particularly for large meals close to bedtime, also has a potential effect.

5. Conclusion

An early dinnertime, which results in a smaller meal volume in the stomach pre-bedtime, or a smaller volume of dinner, which also results in a smaller meal volume pre-bedtime, over several consecutive days, are both likely to be beneficial in reducing the severity of pre-bedtime reflux and nocturnal reflux, but LPR symptoms, like early morning sore throat and cough, could persist.

Biochemical and biophysical (gravity) processes in the human body are influenced by meal timing (day or night) and body position (sitting or recumbent), including gastric secretion, gastric emptying and absorption rates, all potentially contributing to the development of GER, GERD and LPR.

Calculated values for the hydrostatic pressure in the stomach after consuming food were found to be in the same order of magnitude as the average tonically contracted lower oesophageal sphincter. Finding that larger meal volumes create more pressure on the lower oesophageal sphincter than smaller meals increases the risk of pressure-related reflux events.

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Research reports associating gastric acidity, gastric reflux and GERD with dinner-to-bedtime intervals	Year and Ref.
For 23 volunteers, intragastric pH measurements found that consuming a meal at 6 p.m. resulted in a less acidic stomach from 12 a.m. to 7 a.m. compared to consuming a meal at 9 p.m.	1989 [9]
Two groups of 20 and 17 symptomatic reflux patients who consumed meals over two non-consecutive nights for 2, 3.5 and 4 hours before sleep found that gastric reflux did not appear to be exacerbated by a standard late-evening meal.	1989 [10]
A comparison between 147 patients with gastro-oesophageal reflux disease (GERD) and 294 controls found that shorter dinner-to-bedtime intervals of < 3 hours were significantly associated with an increased risk of GERD compared to intervals ≥ 4 hours ($p < 0.0001$).	2005 [11]
Oesophageal pH studies for 201 patients with reflux symptoms over 24 hours found that 118 patients who had a meal within 2 hours before retiring were 2.46 times more likely to develop reflux than the 83 patients whose last meal was more than 2 hours earlier.	2005 [12]
For 32 patients with reflux symptoms who consumed a standard meal 6 hours or 2 hours prior to bed over two consecutive nights, it was found that patients consuming a late-evening meal had significantly greater supine acid reflux events, especially in patients who may be overweight, have oesophagitis or a hiatus hernia.	2007 [13]
For 232 patients with oesophageal squamous cell carcinoma and 286 controls, people with shorter dinner-to-bedtime intervals of < 3 hours were at a statistically significant risk of disease ($p = 0.003$) compared to those with longer intervals > 4 hours. A post-dinner walk was also considered beneficial.	2014 [14]
For 146 patients with gastric cardia carcinoma and 116 controls, shorter dinner-to-bedtime intervals of < 2.9 hours or 3–3.9 hours were associated with a statistically increased risk ($p = 0.007$) compared to longer intervals ≥ 4 hours.	2014 [15]
For 452 patients with gastric cancer and 465 controls, dinner-to-bedtime intervals of < 3 hours were more prone to cancer ($p = 0.001$), and the shorter the dinner-to-bedtime interval, the higher the risk ($p = 0.001$). For the gastric cancer group, the average dinner-to-bedtime interval was 2.5±1.1 hours and for controls, 3.2±1.3 hours. A post-dinner walk was also considered beneficial.	2016 [16]
For 17 patients with reflux symptoms, impedance pH monitoring and electroencephalography found no difference in nocturnal reflux symptoms for dinner-to-bedtime intervals of < 3 hours or ≥ 3 hours.	2016 [17]

Research reports associating gastric acidity, gastric reflux and GERD with dinner-to-bedtime intervals	Year and Ref.
For 85 children with GERD and 117 controls, late-night meals and shorter dinner-to-bedtime intervals were found to have a significant correlation with GERD, and unless risk factors were removed, patients were vulnerable to relapse.	2016 [18]
A study with 817 patients who consumed dinner ≤ 2 hours before bedtime at least three times a week found that late-night dinners were positively associated with GERD.	2018 [19]
For 134 patients with GERD, short (≤ 2 hours) meal-to-bedtime intervals were a predominant risk factor in pregnancy.	2021 [20]
For 605 women, the timing of sleep and the timing of meals relative to the sleep/wake cycle were associated with the presence of GERD. It was important to consider the timing of meals relative to the sleep/wake cycle rather than the clock time.	2023 [21]
A study investigating the effects of circadian preferences using the morningness-eveningness questionnaire (MEQ), which classifies individuals according to their biological clock, found for 80 GERD patients a mean score of 31.25±10.04, indicating an evening chronotype (scores 16–41), and for 72 controls, a mean score of 56.07±7.84, indicating an intermediate chronotype (scores 42–58), with evening chronotypes associated with GERD involving circadian regulation of gastric acid secretions, gastrointestinal motility and hormonal fluctuations such as cortisol and melatonin.	2025 [22]
Research reports associating other diseases with dinner-to-bedtime intervals	
For 166 patients with histologically confirmed colorectal cancer and 166 controls, shorter dinner-to-bedtime intervals of 2.0 or 2.9 hours were statistically significantly ($p = 0.05$) associated with an increased risk compared to controls with ≥ 4-hour dinner-to-bedtime intervals. A post-dinner walk was also considered beneficial.	2018 [23]
For 872 adults, a high total daily energy intake consumed ≤ 2 hours before bedtime was associated with increased odds of being overweight or obese, particularly in people with a late chronotype.	2019 [24]
For 60,392 children, shorter (<120 minutes) dinner-to-bedtime intervals had a higher risk of asthma than longer intervals (>120 minutes), but it was not mentioned how reflux symptoms may have been affected.	2025 [25]

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Table 1. For 12/14 reports, an increased dinner-to-bedtime interval was likely beneficial in reducing gastric acid, GER and gut cancers. For 2/14 reports, increasing the dinner-to-bedtime interval was not necessarily beneficial [10][17]. For three reports with non-reflux-related diseases, increased dinner-to-bedtime intervals were associated with a decreased risk of colorectal cancer, obesity and, for children, asthma [23][24][25].

Research reports associating gastric/duodenal emptying with body position as standing, sitting or supine while awake and gravity.	**Year and Ref.**
Technetium-labelled beef stew and orange juice for 8 healthy males over 4 days, found the lying position significantly slowed gastric emptying compared to standing or sitting when awake.	1988 [29]
Technetium-labelled olive oil and soup for 11 volunteers found gravity had a major effect on the intragastric distribution of oil, which was preferentially retained in the proximal stomach when sitting and the distal stomach in the decubitus position ($p < 0.05$), with the aqueous phase emptying more slowly ($p < 0.01$). After 180 minutes, the oil was emptied from the stomach in either position when awake.	1993 [30]
For 12 seated or upside-down volunteers, after ingestion of 300 ml of water, magnetic resonance imaging showed the same rate of gastric emptying over 30 minutes but different emptying patterns (exponential or linear) and a marked difference in intragastric distribution, particularly for gastric gas.	2006 [31]
For 8 males ingesting 20 g of ^{13}C-labelled phenylalanine milk protein and 1.5 g paracetamol, blood samples collected 5 hours post-prandially found both protein and paracetamol levels were higher when sitting upright compared to when supine, finding the sitting position accelerates gastric emptying and increases absorption rates.	2017 [32]
Modelling of starch-based granular food digestion in the duodenum found that, when lying down, digestion was reduced by half due to a higher proportion of particles in the proximal acidic region compared to sitting upright, with the direction of gravitational forces influencing the distribution of both particles and solutions of different pH, which is crucial for the digestive efficiency of the duodenum.	2024 [33]
Research reports associating gastric emptying with the body at an incline with a raised bedhead while asleep.	
For 20 patients, a 20 cm bed elevation at the head end reduced oesophageal acid exposure ($p = 0.001$) and acid clearance time ($p = 0.001$) for nocturnal supine reflux, likely due to gravity increasing the clearance of refluxed content and opposing the reflux compared to when in a supine position.	2012 [34]
For 39 pharmacologically treated patients with GERD, a 20 cm head-of-bed elevation for 6 weeks compared to supine for 6 weeks resulted in a reduction of symptoms as assessed by a reflux symptom score of ≥ 10% but with no increase in the quality-of-life score.	2020 [35]

Table 2. Results show that digestion in the upright position is likely to accelerate gastric and duodenal digestion, increase absorption rates and improve digestive efficiency compared to when supine and awake [29]

[30][31][32][33]. A raised bed head is also likely to reduce gastric reflux symptoms due to an increase in the gravitational force that opposes reflux, relative to the supine position [34][35].

Research reports associating reflux with day/night times, gastric emptying, circadian rhythm, and aerobic digestion.	**Year and Ref.**
Reflux patterns during arousal and sleep are different because of delayed gastric emptying, reduced oesophageal peristalsis, decreases in swallowing and salivary secretion, and prolonged oesophageal clearance, with the avoidance of late-night meals having a role in the prevention of reflux.	2012 [7]
For a male and female, awake and in the supine position, the half-life for gastric emptying after consuming technetium-labelled eggs, toast and orange juice at 8 am in the morning was ≈55-80 minutes and at 11.00 pm at night was ≈125-200 minutes, a 220% difference.	2015 [43]
The gastrointestinal system is governed by a circadian rhythm with quiescence at night and elevated activity on awakening with increased activity through the day, influencing the migrating motor complex, enzyme and fluid production, nutrient absorption, and gastric/gut motility.	2020 [44]
Air in the gut is required to support the aerobic digestion of food, with the air entering the gut through swallowing, which occurs mostly during meals and at other times while awake, with less air swallowed when asleep, possibly contributing to disrupted digestion, particularly for meals close to bedtime. Swallowed air always occurs after the expiration of air from the lungs and so contains ≈5% carbon dioxide, a much higher concentration than in atmospheric air (0.04%), but it is unknown if this has a role in bicarbonate production via carbonic anhydrase for acid neutralisation in the oesophagus or stomach.	2024/5 [45][46]

Table 3. Differences in digestion during the day and night are highlighted. Circadian rhythms elevate the gastrointestinal system on waking with quiescence at night, possibly demonstrated by the difference in gastric emptying rates for meals in the morning and evening while awake [7][43]. Air swallowing to support luminal aerobic digestion and to increase carbon dioxide levels in the oesophagus and stomach for acid neutralisation via carbonic anhydrase may also be relevant [45][46].

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