Preoperative fasting in children

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In 1948, Digby Leigh, in his textbook Pediatric Anesthesia, suggested that children should fast from clear fluids for 1 h prior to surgery.¹ Yet, in the intervening years, fasting times have increased in the belief that this may reduce the risk of pulmonary aspiration of gastric contents. This article will review the historical context within which preoperative fasting guidelines have evolved, the physiology of gastric emptying, and the emerging evidence for liberalizing preoperative fasting regimens in children undergoing elective surgery.

Historical perspective

For John Snow in 1847, the intention behind preoperative fasting was not to diminish the incidence of aspiration but, rather, to reduce the unpleasantness of vomiting.² A year later, the first paediatric death due to aspiration was reported, possibly due to the anaesthetist pouring brandy into the child’s mouth to relieve ‘syncope’.³ As more reports followed, fasting recommendations emerged. Sir Joseph Lister was the first to make the distinction between fasting from food and fluids and in 1883 recommended no solid matter in the stomach and ‘a cup of tea or beef-tea 2 h previously’. This distinction carried on into the 1960s with paediatric instructions favouring sweetened liquids up to 2 h before operation. However, the years following World War II saw the widespread adoption of the ‘Nil per os (NPO) from midnight’ regimen, especially in North America, ignoring the previous distinction between solids and liquids. A possible reason for this was the work of Curtis Mendelson.

Mendelson’s syndrome

On reviewing 66 cases of aspiration among 44 016 pregnancies, Mendelson found two immediate deaths due to airway obstruction following aspiration of solids and no deaths among those who had aspirated liquids. However, he noted that those patients that aspirated fluid were critically ill, with an acute ‘asthma-like’ attack, and mottling on chest X-ray, which cleared in 7–10 days. Mendelson then demonstrated that hydrochloric acid, or un-neutralized human vomitus, injected into rabbit lungs, reproduced this picture, and concluded that pregnant

Key points

- Prolonged preoperative fasting times for healthy elective cases have been extrapolated from the aspiration risk of ‘full-stomach’ emergency cases.
- Gastric emptying is regulated by hormonal, neuronal, and metabolic feedback.
- Residual gastric volume is a poor surrogate for the risk of aspiration, and there appears to be no causal link or critical volume threshold.
- Perioperative pulmonary aspiration in children is rare. The incidence is 0.07–0.1% and the consequences of clear fluid aspiration are not catastrophic.
- Newer liberal paediatric fasting regimens for elective cases seem to confer no increase in aspiration risk compared with more conservative regimens.
women were at especially high risk of aspiration due to delayed gastric emptying. He subsequently promoted preoperative fasting, alkalization of stomach contents, and the greater use of regional anaesthesia.1

Following Mendelson’s publication, further work on anaesthesia for similarly high-risk patients emerged. The belief that otherwise healthy patients with no risk factors for aspiration were also at risk stemmed from the work of Roberts and Shirley in 1974 who surmised that 25 ml (0.4 ml kg–1) of gastric fluid with a pH < 2.5 increased the risk of serious aspiration. Their work was based on preliminary unpublished data from a single Rhesus monkey which had neither vomited nor regurgitated, but whose right main bronchus was instilled with 0.4 ml kg–1 of acid.5 A relationship between the residual gastric volume and the volume of fluid instilled into the lungs was never established but rather extrapolated to the average weight of a pregnant woman. Subsequent studies challenged these findings by demonstrating gastric volumes >25 ml and pH < 2.5 in 40–80% fasted healthy patients.6 Given the confusion over what constitutes a significant residual volume or pH in adults, it is unsurprising that in the heterogeneous paediatric population the situation is even less clear.

Mechanisms of pulmonary aspiration and risk factors

For pulmonary aspiration to occur, gastric contents must overcome three protective mechanisms: first, they must exceed the lower oesophageal sphincter barrier pressure, then regurgitate up the oesophagus through the upper oesophageal sphincter, and finally pass down the trachea unimpeded by protective airway reflexes such as laryngospasm or coughing. The risk factors predisposing to this sequence of events can therefore be broadly classified into three groups: (i) increased regurgitation, as a result of gastrooesophageal reflux, strictures, and decreased lower oesophageal sphincter tone; (ii) loss of protective airway reflexes, such as those seen in neuromuscular disorders or because of the effects of general anaesthetics and analgesics; and (iii) increased gastric volume, as a result of inadequate fasting or delayed gastric emptying.6 Of these, gastric volume is the only risk factor that can be modified before operation.

Physiology of gastric emptying

The stomach performs both mechanical and chemical breakdown of ingested food into a chyme, which is delivered, at a rate controlled by hormonal, neural, and metabolic mechanisms, to the duodenum for enzymatic degradation into molecular components and absorption through the gut wall. The rate of gastric emptying is a function of the pressure gradient between the stomach (mainly antral contraction) and duodenum (pyloric resistance). Antral contraction is influenced by gastric volume, the secretion of gut hormones, and the composition of chyme entering the duodenum. However, gastric motility differs between the fed and fasting states.

Fed gastric motility

After a meal, gastric distension stimulates a vago-vagal excitatory reflex that enhances antral activity both directly and by the stimulation of gastrin. The composition of duodenal chyme further affects the rate of gastric emptying by influencing the release of inhibitory gut hormones. For example, acidic, hyperosmolar contents stimulate secretin, which directly inhibits gastric muscle contraction; fat and protein by-products stimulate cholecystokinin which inhibits the stimulatory effects of gastrin on the antrum and carbohydrates stimulate gastric inhibitory polypeptide.

In addition to these neural and hormonal regulatory mechanisms, blood glucose also affects emptying. At levels in excess of 8 mmol l–1, the delivery of caloric contents is reduced by a negative feedback mechanism from duodenal receptors to maintain a constant rate of delivery of 1–4 kcal min–1.7

There is a considerable difference in how liquids and solids leave the stomach. For non-caloric liquids, such as water, gastric emptying begins immediately and exponentially, following first-order kinetics, proportional to the volume present in the stomach and thus the gastro-duodenal pressure gradient. For caloric liquids and solids, emptying follows zero-order kinetics, which is linear but biphasic in pattern. The duration of the first phase is related to the caloric content of the food. During this phase, solids are digested in the fundus into particles <2 mm to facilitate passage through the pylorus during the second phase. Motility across the entire gastrointestinal tract peaks at approximately 30 min and continues for about 4 h during which liquids and particles with a size of 1–2 mm are emptied from the stomach. Indigestible solids, such as cellulose-containing vegetables, which do not break down to <2 mm in humans, empty via a different mechanism that occurs later when the stomach is fasting.7,8

Fasting gastric motility

Between meals, a cyclic pattern of motor activity occurs in the stomach every 80–120 min. The first phase is characterized by quiescence, the second by irregular contractions, and the third by continuous phasic contractions lasting up to 5 min. It is during these latter contractions that the stomach empties particles > 2 mm. This process recurs every 2 h and may take up to 6–12 h to complete.7,8

Measurement of gastric emptying

The earliest attempts to observe gastric emptying were made by William Beaumont, an American military surgeon, who in 1822 treated a fur trapper for a gunshot wound to the stomach. The healed wound left a permanent gastric fistula through which Beaumont made direct observations of gastric emptying times, noting that for easily digested food, such as meat, potatoes, and bread, these varied from 1.5 h to 5 h, whereas most fluids passed from the stomach almost immediately.

Today, several methods have been developed to evaluate either gastric volume or emptying. Scintigraphy using radiolabelled meals represents the gold standard for the measurement of gastric emptying either directly or via breath tests; however, differing protocols between centres hamper its interpretation. Ultrasound can be used to evaluate gastric volume and motility with results that correlate well with scintigraphy; however, it requires an experienced operator. Magnetic resonance imaging (MRI) has been used to evaluate gastric residual volume, but its use is limited by expense and availability. Other methods include the paracetamol absorption test, wireless motility capsules, antpyloroduodenal manometry, and impedance monitoring.8

Determinants of gastric volume and emptying

We continue to use residual gastric volume as a surrogate for pulmonary aspiration, although neither a direct link has been demonstrated nor a critical volume accurately determined. Furthermore, despite an empty stomach, aspiration can still
occur due to large volumes of fluid regurgitating from the small and large intestines. Nevertheless, fasting protocols that minimize gastric volume are believed to reduce pulmonary aspiration.9

Gastric volume is influenced by several factors:

(i) Saliva and gastric secretions: During fasting, salivary secretions contribute 1 ml kg⁻¹ h⁻¹ and gastric secretions 0.6 ml kg⁻¹ h⁻¹ to gastric volume.10
(ii) The rate of gastric emptying: Factors affecting emptying are summarized in Table 1. Premature and full-term neonates are often reported to have slower gastric emptying in comparison with older children and adults due to immature neuromodulation of gastric motility. However, a meta-analysis of 1457 patients, from premature neonates to adults, found that age was not a significant determinant of gastric emptying.11
(iii) The timing and type of last oral intake.

**Clear fluids, breast, and formula milk**

Clear fluids rapidly empty from the stomach within 30 min. Sweetened drinks are slower depending upon the type of sugar—fructose, sucrose, and galactose empty faster than glucose. Drinks higher in calories and osmolality delay emptying; however, these differences do not seem clinically relevant.

Breast milk is emptied faster than formula milk due to a higher whey to casein ratio and therefore behaves more like water than cow’s milk. However, its high lipid content slows gastric emptying in comparison with clear fluids. The emptying of formula milk is variable and depends upon its composition. Whey-predominant formulae empty faster than casein-rich formulae and both are significantly faster than cow’s milk. As with clear fluids, an increase in acidity, osmolality, and fatty acid concentration will slow emptying.9,10

**Solids and cow milk**

Cow’s milk separates into liquid and solid (curd) phases on mixing with gastric acid, and therefore, its emptying is biphasic with a rapid initial liquid phase followed by a second-, zero-order, solid phase. This is why it requires a 6 h fast in common with other solids. Full meals, with high fat content, may not empty fully even at 8–9 h.

**Quantifying the risk in children**

Paediatric fasting guidelines are intended to reduce the risk of pulmonary aspiration and facilitate the safe and efficient conduct of anaesthesia. However, there are numerous benefits when children are fasted before operation as briefly as possible, including improved patient and parental satisfaction, increased gastric pH, ingestion of calories, decreased risk of hypoglycaemia, decreased lipolysis, and improved fluid homeostasis.

How long do children actually fast?

Almost all national guidelines advocate the 6, 4, and 2 h regimen for clear fluids, breast milk, and solids, respectively; however, children continue to be fasted for significantly longer. A UK study of 1350 children presenting for dental procedures revealed median fasting times of 12.08 h and 7.95 h for solids and liquids, respectively, with the majority of children reporting feeling ‘extremely hungry’ or thirsty on admission.12 Similarly, a US study of 219 children found that mean fasting from liquids was 10.44 h, breast milk 8.3 h, and solids 10.62 h.13 Possible reasons for these extended fasts may have been the children being fed earlier in the evening on the night before surgery or alterations in the operating schedule. It may, therefore, be better to advise parents to give their children food and drink at specific times rather than instructions for fasting at 2 h and 6 h before

### Table 1 Factors affecting gastric emptying

<table>
<thead>
<tr>
<th>Factors increasing emptying</th>
<th>Factors decreasing emptying</th>
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<tr>
<td>Physiological factors</td>
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<tr>
<td>Large gastric volume</td>
<td>Large duodenal volume</td>
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<tr>
<td>Liquid gastric contents</td>
<td>High-calorie chyme</td>
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<td>Solids &lt; 2 mm</td>
<td>Acidic chyme</td>
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<td>Parasympathetic stimulation</td>
<td>Hypo-/hyper-osmolar chyme</td>
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<td>Secretion of motilin and gastrin</td>
<td>Fatty and amino acid-rich chyme</td>
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<td>Pharmacological factors</td>
<td></td>
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<tr>
<td>Sitting position (for non-caloric liquids)</td>
<td>Secretion of cholecystokinin, secretin, somatostatin, vasoactive intestinal peptide, and gastric inhibitory peptide</td>
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<tr>
<td>Anticholinergics</td>
<td>Opioids</td>
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<td>Metoclopramide</td>
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<td>Domperidone</td>
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<td>Erythromycin</td>
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<td>Patient factors</td>
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<td>Hyperthyroidism</td>
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<td>Pain</td>
<td></td>
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<td>Anxiety and stress</td>
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<td>Trauma</td>
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<tr>
<td>Pregnancy</td>
<td></td>
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<tr>
<td>Alcohol ingestion</td>
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<tr>
<td>Hypothyroidism</td>
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<tr>
<td>Diabetes</td>
<td></td>
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<td>Pyloric stenosis</td>
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<td>Intestinal obstruction</td>
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<td>Vagotomy</td>
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operation, accepting that this may reduce list flexibility. Parents also seem understandably reluctant to wake children for drinks and are anxious about delaying the start of the anaesthetic so err on the side of caution and avoid any intake.

What are the metabolic effects of fasting and surgery?
During fasting, metabolism slows and the primary source of glucose gradually becomes hepatic glycogenolysis. As hepatic glycogen stores are depleted, hepatic gluconeogenesis and lipolysis ensue with subsequent fatty acid beta-oxidation and ketogenesis becoming the main energy sources. Indeed, ketoacidosis has been demonstrated in children less than 3 years of age fasted more than 7 h with a subsequent reduction in ketone bodies and hypotension on induction of anaesthesia when an optimized fasting schedule was introduced.14

In contrast to the reduction in metabolic rate seen with fasting, the trauma of surgery triggers a neuroendocrine stress response that increases metabolism, which further depletes hepatic and skeletal muscle glycogen stores and releases free fatty acids and amino acids from the adipose tissue and skeletal muscle, respectively. A key feature of this perioperative shift of metabolism has been found to be the development of insulin resistance, the severity of which is proportional to the degree of surgical trauma.15 The development of insulin resistance impairs its anabolic effects and is a known risk factor for the development of postoperative complications and increasing length of hospital stay.15,16

Preoperative carbohydrate drinks
Providing non-caloric clear fluids, such as water, 2 h prior to surgery does not provide the substrates required to change the metabolic effects of fasting and surgery. Therefore, the main objective of preoperative carbohydrate drinks is to stimulate an insulin response similar to that of a regular meal and therefore switch the preoperative fasted state described above into a fed state with normal postprandial insulin levels and minimal glyco-
gen store depletion. While there are physiological data to support preoperative carbohydrate drinks, studies investigating the type of drink and its clinical impact in children are limited.16

How common is aspiration in children?
Perioperative pulmonary aspiration in children remains infrequent, is more likely in emergency rather than elective surgery, and serious respiratory complications are rare. Table 2.3,6,17–20 An updated Cochrane review of 25 trials involving 2543 children found only one reported incidence of perioperative aspiration. Furthermore, children allowed to drink 2 h before operation were not found to have higher gastric volumes or lower gastric pH than those fasted longer. These children were also less thirsty, less hungry, and less irritable than those who fasted for more than 6 h.21

Should children fast at all?
From a practical perspective, the 6-4-2 fasting regimen is only possible for the first child on the list as the subsequent children are given only approximate fasting times. With emerging evidence of the safety of liberalizing clear fluid ingestion to either 1 h or up to the time of anaesthesia, fasting times can be reduced even further. In a review of 10 015 children allowed unlimited intake of clear fluids up to the time of general anaesthesia, Andersson et al.19 found the incidence of pulmonary aspiration to be 0.03% with an average fasting time of 1.7 h. This compares very favourably with the aspiration incidence for the less liberal regimens quoted above and allows greater flexibility in the operating list. Also, 1 h clear fluid fasting may not significantly influence gastric volume or pH compared with 2 h,22 with gastric emptying occurring with a median half-life of <30 min when measured by MRI.23 Furthermore, fasting status may not be an independent predictor of aspiration or related adverse events such as unplanned admission, cardiac arrest, or death according to a prospective analysis of 139 142 children anaesthesitized or sedated outside the main operating complex by different practitioners, including anaesthetists, emergency physicians and paediatric intensivists.24

Finally, compliance with preoperative fasting by children and parents is incomplete due to a variety of reasons such as misunderstanding what fasting entails, the reason for fasting, inadequate supervision, or deliberately misleading to avoid delays. Liberalizing preoperative oral intake may reduce these breaches.24

Summary
There is increasing recognition that a prolonged preoperative fast is not desirable let alone advantageous. Gastric physiology is under a complex set of control factors that combine to ensure a steady release of nutrients to the small bowel and beyond. For clear fluid, there is good evidence in children that emptying can occur well within the advocated 2h guidelines. Even when a rare clear fluid aspiration occurs, the consequences do not appear to be severe or long term. These same guidelines, when strictly adhered to, often result in much longer clear fluid fasting times than are desirable. More liberal clear fluid regimens for elective cases seem to confer no increased risk of aspiration.

Table 2 Studies examining the incidence of paediatric aspiration and its complications. All studies considered aspiration to have occurred if non-respiratory material was visualized in the larynx or tracheobronchial tree on laryngoscopy, bronchoscopy, or suctioning or, alternatively, if clinical and/or radiological signs of aspiration developed. No deaths were reported in any study.

<table>
<thead>
<tr>
<th>Study</th>
<th>Time period</th>
<th>Study design</th>
<th>Study size</th>
<th>Incidence of aspiration events (%)</th>
<th>Incidence of postoperative ventilation among children who aspirated (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borland et al.17</td>
<td>1988–93</td>
<td>Retrospective</td>
<td>50 880</td>
<td>52 (0.1%)</td>
<td>4 (7.7%)</td>
</tr>
<tr>
<td>Warner et al.18</td>
<td>1985–97</td>
<td>Prospective</td>
<td>56 138</td>
<td>24 (0.04%)</td>
<td>6 (25%)</td>
</tr>
<tr>
<td>Walker3</td>
<td>2010–11</td>
<td>Prospective</td>
<td>118 371</td>
<td>24 (0.02%)</td>
<td>5 (20.8%)</td>
</tr>
<tr>
<td>Andersson et al.19</td>
<td>2008–13</td>
<td>Retrospective</td>
<td>10 015</td>
<td>3 (0.03%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Tan and Lee6</td>
<td>2000–13</td>
<td>Retrospective</td>
<td>102 425</td>
<td>22 (0.02%)</td>
<td>2 (9.1%)</td>
</tr>
<tr>
<td>Beach et al.20</td>
<td>2007–11</td>
<td>Prospective</td>
<td>139 142</td>
<td>10 (0.007%)</td>
<td>Not reported</td>
</tr>
</tbody>
</table>
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without subjecting large numbers of children and carers to the distress of a prolonged fast.

Declaration of interest
None declared.

MCQs
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Podcasts
This article has an associated podcast which can be accessed at https://academic.oup.com/bjaed/pages/Podcasts.

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