Review

Vomiting and Aspiration During Anesthesia

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THE first documented anesthetic death was not caused by aspiration of vomitus, but James Simpson believed aspiration was a closely related cause. He insisted that the patient was strangled by brandy poured into her throat for the purpose of resuscitation. Simpson appears to have stood alone in his opinion, others agreeing that death was due to an overdose of chloroform.[9] This case is cited because it indicates that Simpson must have been familiar with the dangers of strangulation during anesthesia in the year 1848 when the art of general anesthesia was fifteen months old. The first reliable report of a death due to vomiting and strangulation during chloroform anesthesia states that it occurred in 1853.[33]

In more recent times the anesthetic literature has been replete with reports of deaths from vomiting and aspiration. Several of these reports have attempted to survey all deaths due solely to anesthetic causes, which occurred in particular hospitals or regions. Although these surveys are widely scattered in time and place, they give some idea of the magnitude of the problem of vomiting during general anesthesia. Fourteen per cent of all anesthetic fatalities reported in these compilations resulted from aspiration of vomitus. When the obstetric deaths due to anesthesia are reviewed, one finds that thirty-four per cent of them were caused by vomiting.[20,25,30,38,43,46,55,59,66,67,73] The total number of aspiration deaths reported in the medical literature total several hundred, and one may presume that thousands have gone unreported.[2,24,45,54,69,72] Lest one should assume that these figures are merely of historical interest, a report of anesthetic deaths which occurred in five Connecticut Hospitals during 1957 and 1958 should be considered. Virtually all of the 121,000 anesthetics reviewed in this survey were given by full time anesthesiologists or residents, yet three of the thirty deaths attributed directly to anesthesia were caused by aspiration of vomitus.[25]

There is small wonder that obstetricians, surgeons and pathologists, as well as anesthesiologists, have come to view vomiting during anesthesia with something akin to horror. One can sympathize with the obstetrician who wrote in 1947, "The second stage of anesthesia is bristling with hazards."[36] And one cannot fail to be impressed by the terse description of one anesthetist who wrote, "All went well until the surgeon introduced his hand into the abdomen. Immediately there was a violent regurgitant vomiting of the stomach contents: it was like pouring water out of a jug. I tried to mop out the mouth and introduce an endotracheal tube, but failed completely. The patient died in a few minutes."[21] Here, in four sentences is summarized the sudden and unexpected tragedy of death by aspiration of vomitus.

Etiology

Although the early anesthetists recognized the obvious fact that vomiting could cause sudden death by strangulation, the recognition of chemical pneumonitis as a sequela of vomiting was delayed until recently. Probably the earliest description of the effects of chemical irritants on the lungs was made by Winternitz while studying the effects of war gases immediately after World War I. He was able to reproduce the pathologic changes caused by phosgene by the instillation of hydrochloric acid solutions into the lungs of rabbits, and described the cellular changes in the lung in detail.[90] His work, however, went unnoticed, and clinical students of surgical pathology insisted for years that the aspiration of vomitus was merely another route whereby microorganisms might enter the lungs and produce pneumonia.[3,7,32,52,56] In 1940 two writers independently speculated that aspiration pneu-

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monitis had a chemical, rather than a bacterial etiology, because of its distinctive clinical syndrome.[40, 52]

The etiology of aspiration pneumonitis was finally established in 1946 when Mendelson published a paper in which he described the aspiration syndrome in detail, and reported the results of extensive experiments.[65] Mendelson injected stomach contents recovered from patients into the lungs of rabbits. He found that when the injected liquids were chemically neutralized pneumonitis could not be produced. On the other hand, he found that unaltered human gastric contents did produce lung lesions similar to those found in human autopsies. He was also able to produce the same pathologic changes by injecting 0.1*N* hydrochloric acid solution into animals' lungs.

Teabeaut several years later investigated the problem further.[80] He found that hydrochloric acid solutions and liquid vomitus must have a hydrogen ion concentration below *p*H 2.5 in order to produce pneumonitis. Acid solutions having a *p*H above 2.5 produced minimal pathologic changes, completely unlike aspiration pneumonitis. Teabeaut also found that various foods, partially digested and recovered from the stomachs of human volunteers, produced pneumonitis in animal lungs regardless of their *p*H. He was also able to show that peptic activity and bacterial infection played no part in producing the aspiration lesions.

The etiology of aspiration pneumonitis is, thus, twofold. The lesions can be caused by food particles and by liquid vomitus having a *p*H of less than 2.5. Gastric enzymes, bile and liquids of a *p*H greater than 2.5 are relatively innocuous.

Pathology

Most authors who have described the pathologic changes found in fatal cases of aspiration pneumonitis have emphasized the extensiveness of the lesions.[32, 40, 65, 80] On gross inspection the lungs are found to be heavy and doughy in texture with dark mottled areas due to hemorrhage. The lungs may be almost completely consolidated and airless.

When highly acid liquid vomitus is the etiologic agent the microscopic changes consist primarily of extensive areas of peribronchial infiltration. In the initial stage the infiltrating cells are largely polymorphonuclear in type. After a time mononuclear cells predominate, many of which are large phagocytic cells probably derived from the alveolar epithelium. In the infiltrated areas the lung parenchyma appears to be completely destroyed. In other areas the alveoli are filled with hyaline exudate and extravasated red cells. The bronchial epithelium may be partially or completely sloughed. The remaining functional alveoli are emphysematous.

The presence of partially digested food in the lung produces a somewhat different pathologic response.[80] Food particles evoke a foreign body reaction in the lung tissue. In the early stage of the reaction the particles are surrounded by polymorphonuclear cells and macrophages, and multinucleated giant cells are present. Eventually the cellular exudate evolves into a foreign body tubercle composed of epithelioid cells surrounded by macrophages and lymphocytes.

Physiology

Vomiting is one of the most primitive of protective reflexes, and it can be initiated by a variety of stimuli: revolting sights and odors, fear and many pathologic states can cause vomiting. It has been said that almost any type of stimulus, central, visceral or peripheral, can trigger this reflex.[16]

The act of vomiting is preceded by a prodromal pattern which includes nausea, increased salivation, swallowing, spasmodic respiration, tachycardia, hypotension and pallor. Emesis is produced by maximal descent of the diaphragm and forceful contraction of the abdominal muscles. The stomach is, thus, squeezed by the diaphragm and abdominal muscles, and partially emptied. Simultaneously the esophagus and cricopharyngeal sphincter relax, the soft palate rises, the glottis closes, and the mouth opens. Emesis, thus, depends on action of respiratory and somatic muscles, while the stomach and esophagus are passive.[23]

The duodenum, unlike the stomach, plays an active part in vomiting. During the prodromal phase it undergoes a series of contractions which climax in a sustained, tonic

contraction immediately preceding evacuation of the stomach.[51,84]

The pylorus appears to remain open throughout this process. Atkinson concluded that the pyloric sphincter is rarely closed,[5] and there is good evidence that it is patent during emesis. While it has been impossible to prove that reverse peristalsis takes place in the duodenum, it is known that there is a reflux of duodenal contents into the stomach, which explains the frequent presence of bile in vomitus. Abbot, Mack and Wolf have shown that the same type of duodenal activity occurs during mental and physical distress,[1] which probably causes the delay in gastric emptying often observed during periods of anxiety following injury. Jejunal contractility also increases during vomiting.[59,72]

This complicated set of visceral and somatic motor responses requires an integrating mechanism, if it is to be coordinated into an effective reflex pattern. Borison and Wang have been able to demonstrate such an integrating mechanism deep in the dorsolateral border of the reticular formation of the medulla.[14,83,84] The precise location of the vomiting center has been fixed by electrical stimulation experiments and by ablation with radon seeds of small, circumscribed portions of the medulla. Stimulation of this area consistently causes vomiting in dogs, cats and monkeys, and its ablation inhibits vomiting. The center was found to be strategically placed, since stimulation of areas adjacent to it produce several of the components of vomiting: salivation, forced inspiration, spasmodic respiration, and vasomotor changes.[74,82,85]

The vomiting center does not directly trigger all the motor activity of vomiting. It should be regarded, rather, as a group of neurones sensitive to emetic stimuli, and sends out simultaneous impulses to specific motor areas which finally transmit impulses to the necessary smooth and striated muscle groups. The center integrates but does not directly stimulate motor activity.[16]

Borison and Wang have also located a superficial area in the floor of the fourth ventricle near the ala cinerla, which they call a chemoreceptor trigger zone. This superficial group of neurones relays the stimulus of emetic drugs, such as apomorphine, digitalis glycosides and ouabain, to the vomiting integrating center deep in the medulla. The trigger zone is refractory to electrical stimuli, but when emetic drugs are applied to it locally, vomiting occurs. Ablation of the chemoreceptor trigger zone inhibits the effects of the centrally acting emetics, and prevents motion sickness, as well.[15]

The vomiting integrating center is sensitive to numerous pathologic stimuli such as enteric toxins and increased intracranial pressure. The center is especially sensitive to stimuli arising in the small bowel. Herrin consistently provoked vomiting in dogs by distending exteriorized loops of jejunum and found that the reflex could be interrupted by destroying the sympathetic nerve supply of the bowel loops.[4] Walton, studying the emetic effects of peritonitis, found that both vagotomy and sympathectomy were necessary to inhibit this reflex path.[81] Distention of the biliary tract has also been said to cause vomiting.[16]

The means by which general anesthesia triggers the vomiting mechanism has never been scientifically studied. As a result of this surprising lack of curiosity on the part of anesthesiologists, we can only speculate on the role which anesthesia plays in stimulation of the vomiting center. The usual explanation of the phenomenon is that light planes of anesthesia sensitize the vomiting center. This statement implies that anesthetics can selectively strychninize the vomiting center and thus render this small group of neurones more sensitive to stimulation. It would seem to be more consistent with the known facts of neurophysiology, however, to speculate that the vomiting center shares the state of general reflex excitability produced by second stage anesthesia. During this phase of hyperexcitability, the vomiting center, like other motor areas of the central nervous system, may react to weak levels of stimulation. Thus, during second stage anesthesia, the presence of a full or partially full stomach or any of the pathological mechanisms mentioned above would be more likely to trigger the vomiting mechanism than they would in the conscious state.

Regurgitation

Regurgitation of stomach contents presents noteworthy problems to the anesthesiologist.

Regurgitation is so poorly understood that it is impossible to distinguish its role in causing anesthetic mortality, because it is often included under the term of vomiting. The two processes of emptying the stomach, however, are different in their mechanics. Regurgitation is not a highly integrated reflex act, such as vomiting. It is a passive effect which occurs when physiologic mechanisms fail under undue stress.

The incidence of regurgitation during anesthesia is high. Five investigations of this problem have been carried out, employing the introduction of dye into the stomach before induction of anesthesia and then searching for traces of the dye in the pharynx and trachea after operation.[12,22,58,62,87] The consensus of these reports is that regurgitation occurs frequently in patients well prepared for surgical procedures and often goes unrecognized by the anesthesiologist.

Gastric distention occurs frequently in surgical patients. Swallowed air and gastric secretions accumulate in massive amounts when peristalsis is impaired or obstructed. Olson found that patients suffering from duodenal ulcers can secrete as much as two liters within twelve hours.[70] Anesthesia and surgical manipulation can produce gastrointestinal atony lasting for long periods following operation.[13,53] Before modern methods of stomach and bowel decompression were understood, postoperative pneumonia frequently resulted from aspiration of stomach contents.[3,7,56] Even today gastric distention is encountered, especially in patients undergoing emergency procedures.

Passive regurgitation from the stomach obviously requires opening of the cardiac "sphincter." The gastroesophageal closing mechanism has been the subject of several recent studies, and consequently it is now well understood. Use of the term "cardiac sphincter" is incorrect, for no sphincter muscle in the region of the cardia has ever been identified with certainty.[61] The only muscular mechanism which might effect the closure of the cardia is a group of the oblique muscle fibers of the stomach which arise on its anterior and posterior walls, and pass in a U-shaped pattern around the superior portion of the cardial opening. Although the function of this group of muscle fibers has never been determined, it is possible that they tend to kink the gastroesophageal junction when the stomach is distended.[37] The theory that the diaphragm acts as a pinch-cock, which was widely believed for many years, has been disproved.[17]

Most investigators now believe that the closure of the gastroesophageal opening is effected by a valvular mechanism probably consisting of flaps of gastric mucosa. Dornhorst, after investigating pressure gradients in the esophagus and stomach, concluded that the cardial opening had "the characteristics of a valve—namely, small resistance to forward passage, with the ability to resist retrograde flow in spite of large inverse pressure differences."[27] Marchand performed experiments upon the stomachs of cadavers which reinforce the theory of the valve mechanism. Normally the esophagus enters the fundus of the stomach at an acute angle. Marchand pumped water into cadavers' stomachs through the pylorus and found that alterations in the angle of entry of the esophagus markedly altered the competence of the closing mechanism. In its normal position the valve withstood pressures of 28 cm. of water. When he removed the left diaphragm, allowing the fundus to distend upward, thus rendering the esophageal-fundal angle more acute, Marchand found that the valve was competent up to a pressure of 42 cm. of water. When the esophagus was mobilized so that it entered the stomach at approximately a right angle fluid leaked into the esophagus at a pressure of only 3 cm. of water.[61] O'Mullane was able to render the valve mechanism incompetent by applying traction to a large balloon inflated in the lower end of the esophagus, presumably by pulling the mucosal folds flat.[71] Robson and Welt observed the cardia through a cystoscope during gradual distention of the stomach with water, and described the flattening of the mucosa around the cardia and the appearance of an opening into the esophagus. They also found that when distention of the stomach lumen was prevented by encasing the organ in polyethylene film pressures as high as 67 cm. of water were required to produce leakage into the esophagus.[76] Thus, it appears that distention of the stomach lumen is an important factor in causing regurgitation.

Factors which alter intragastric pressure

were studied by O'Mullane. He found that patients with normal scaphoid abdomens had relatively low intragastric pressures which were not significantly altered during anesthesia or by changes in position. Pregnant women whose abdomens were distended by the gravid uterus, however, had much higher intragastric pressures which could be further increased by change to the head down or lithotomy positions. High intragastric pressures were also observed when weights were placed upon the relaxed abdomen and when the stomach was manipulated during surgical procedures.[71]

Leakage from the stomach into the esophagus occurs during airway obstruction. O'Mullane demonstrated this when he deliberately obstructed inspiration during anesthesia.[71] Sinclair repeated this maneuver while he observed the lower esophagus through an esophagoscope. He saw the gastroesophageal junction, which was tightly closed during quiet breathing, open when inspiration was obstructed, and took color photographs of his observations.[70] This phenomenon does not take place often in conscious subjects. Dornhorst recorded a gastroesophageal pressure gradient of 80 mm. of mercury during a Valsalva experiment, but was unable to detect leakage from the stomach.[27]

Most students of this subject believe that although an anatomical cardiac sphincter has not been demonstrated, a functional neuromuscular mechanism must play some part in closing the cardia. Scattered pieces of evidence point to such a conclusion. Atkinson demonstrated an area of increased tonus just above the gastroesophageal junction, which relaxed only during the act of swallowing.[5] Robson and Welt found that intravenous doses of atropine reduced the tonus in this region from 12 to 8.5 mm. of mercury.[76] They also found that when the stomach was distended with 0.2 per cent hydrochloric acid solution the pressure required to cause leakage into the esophagus was more than twice as high as when distention was produced with 0.5 per cent soda bicarbonate solution.

On the basis of the evidence one must conclude that regurgitation is favored by gastric distention, increased intragastric pressure and by airway obstruction. A woman in the lithotomy position whose delivery is being assisted by means of fundal pressure and who is struggling to breathe against a partially obstructed pharynx would appear to be the ideal candidate for regurgitation. All these factors, however, are probably inoperative unless gastric distention is present, and this factor is difficult for the anesthesiologist to detect in advance.

Regurgitation can also be caused by esophageal distention. O'Mullane found that the esophagus of an anesthetized patient could retain as much as 200 ml. of fluid without leakage into the pharynx. When the cricopharyngeal sphincter was paralyzed by a relaxant the fluid immediately escaped from the esophagus into the mouth.[71] The cricopharyngeal sphincter must be regarded as the last line of defense against regurgitation, and there are undoubtedly occasions when it is the only defense against massive escape of esophageal or stomach contents.

Secretion of Hydrochloric Acid by the Stomach

The acidity of the stomach contents is one of the primary causes of aspiration pneumonitis. Therefore, the factors which influence the secretion of acid by the stomach are of interest. Hydrochloric acid is secreted in a virtually pure state by the oxyntic cells of the gastric mucosa, the undiluted secretion having a titrimetric acidity of 0.17*N* and *p*H of 0.87.[49,65]

It has been accepted that gastric acid production is primarily controlled by the vagus nerves.[63] Leonsins and Waddell, however, have supplied evidence that H ion secretion by the oxyntic cells is controlled by the volume of blood flow in the gastric mucosa, and believe that neurogenic control operates by altering this mechanism.[57] Alcohol stimulates the production of large amounts of acid, whether ingested orally or administered intravenously. The stimulus of intravenous alcohol may be inhibited by atropine and vagotomy, but the presence of alcohol in the stomach probably stimulates the cells directly.[48] Personality and emotion play an important part in gastric secretion. Relaxed or sedated individuals secrete small amounts of acid. Anxiety states, however, are conducive to high rates of acid secretion. Olson measured fasting acid secretion in a large group of prisoners, and found that these emotional and tense subjects secreted acid in

amounts comparable to subjects suffering from duodenal ulcers.[70] The ability of the oxyntic cells to secrete hydrochloric acid varies directly with the carbon dioxide content of the blood, which indicates that during periods of hypoventilation and hypercarbia acid secretion may increase.[69] Shay and Sun have reported a prompt increase in acid secretion during insulin induced hypoglycemia, which suggests that acid secretion may increase during prolonged fasting.[78] The fact that the stomach contents can be highly acid during fasting has been amply demonstrated. Shay and Sun reported finding gastric contents of *p*H 2 to *p*H 1.3 during fasting,[78] and Holmes found that some women in labor had gastric contents of *p*H 2.0 to *p*H 1.0.[50] Three disease states, peptic ulcer, cholecystitis and gastric neurosis, are characterized by high rates of acid secretion.[18]

Although the hydrogen ion concentration of gastric contents can be high in extreme cases, such high concentrations do not occur often. The acid secretions are usually diluted by swallowed saliva, and buffered by mucus and regurgitated duodenal contents. The anesthesiologist should be on guard, however, when he obtains a history of alcohol ingestion, peptic ulcer and abnormal periods of fasting.

Gastric Emptying

The ability of the stomach to empty itself assumes importance when considering vomiting during anesthesia. If the stomach could be assumed to empty within a predictable period after a meal, vomiting could be avoided simply by a standard period of waiting. Many factors, however, alter the normal gastric emptying period.

It is widely taught that a meal is evacuated from the stomach within two to four hours, and normally this is true, but there are exceptions. There can be wide differences in evacuation time in the same individual. Chase, who studied the evacuation time for barium in dogs, found a wide range in the time required for gastric emptying when the test was repeated several times in each animal. One dog's evacuation time varied from one and a half to six hours.[19] Under abnormal conditions the stomach can retain food for long periods, and the vomiting of partially digested food twelve to twenty-four hours after eating has been observed frequently. The swallowing of blood from an oozing tonsil fossa and bleeding directly into the stomach from an ulcer crater can impose further difficulties in predicting whether or not the stomach is empty.

Gastric emptying can be delayed by drugs commonly used for preanesthetic medication and for pain relief. Chase has studied the effect of several of these drugs on the evacuation of barium from the stomach of dogs.[19] He found that barbiturates were without significant effect on evacuation time, and that clinical doses of meperidine and methadon caused only moderate delay. Single doses of morphine and repeated doses of scopolamine, however, doubled and even tripled the emptying time, and combinations of scopolamine with meperidine or morphine caused extreme slowing of evacuation. Atropine in doses of 0.4 mg. probably does not alter gastric emptying time, and antagonizes the effect of morphine. Larger doses of atropine in the range of 0.8 mg. markedly decrease the tonus and motility of the stomach.[35]

The stomach is known to empty poorly during high intestinal obstruction and when mechanical obstruction such as scarring of the pylorus exists. Displacement of the stomach by large tumors may retard evacuation of stomach contents. This situation is encountered in pregnant women at term when the uterus presses the pyloric portion of the stomach upward and backward.

The gastrointestinal tract is more sensitive to psychic influences than any other organ system. Anxiety and pain have been universally believed to retard gastric emptying. Abbot's finding, cited above, that pain and fear cause duodenal spasm in dogs lends evidence to support this observation.

The widely held belief that gastric emptying stops during labor is not supported by the evidence available. Crawford observed the evacuation of barium meals during labor, and found that in only two of his 12 subjects was there marked delay in gastric emptying.[47] Hirscheimer, January and Daversa in a similar study found delayed evacuation of barium in only one out of nine subjects in labor.[47]

Vomiting in Obstetrical Patients

It is impossible to review the factors which predispose to vomiting during anesthesia with-

out being impressed by the number of these factors encountered in parturients. The nausea and vomiting which afflicts so many women in the first trimester can persist to varying degrees to the end of pregnancy in some women. Many obstetrical patients enter the hospital in labor after having recently eaten. On the other hand, when labor and fasting are prolonged acid gastric secretions and swallowed air can collect in the stomach and cause vomiting or regurgitation during anesthesia for delivery. Drugs commonly used for analgesia and amnesia during labor are known to slow gastric emptying. Waters, writing at a time when total pain relief by means of drugs was fashionable, pointed out that some women were so depressed that they did not even turn their heads to empty their mouths when vomiting occurred during labor.[46] Fortunately such deep narcosis is not common today, but semicoma is still occasionally observed when tranquilizing drugs are added to routine narcotic and scopolamine medication. Anxiety and pain and mechanical displacement of the stomach can also contribute to retention of food or secretions in the stomach. It is small wonder that vomiting has caused so many maternal deaths.

Prevention of Vomiting During Anesthesia

After the foregoing discussion one might assume that few patients could survive general anesthesia without vomiting. Such assumption is obviously wrong. The danger of vomiting and aspiration has grown less, and continues to diminish as anesthesiologists replace technicians. The gains of the past, however, must be protected by constant vigilance. Some measures of prevention of vomiting are fundamental. Many authorities agree that general anesthesia should not be administered within six hours following a meal, and in the presence of pain or anxiety the waiting period should be twelve hours.[59, 66, 92] The practice of feeding women while in routine labor should be abandoned.[21, 59, 66, 73] When an operation must be performed in the presence of a full stomach, regional anesthesia is most appropriate.

Danger still exists, however, for the patient with a full stomach for whom regional anesthesia is unsuitable. When the danger of vomiting while under general anesthesia must be assumed as a calculated risk, a number of preventive measures have been proposed. Perhaps, the most widely practiced measure is that of attempting to empty the stomach before induction of anesthesia. Small caliber stomach tubes are useless for the removal of solid food, and are unreliable even for the aspiration of liquids.[20] The small tube is valuable for gradually decompressing the stomach over a period of hours, but reliance cannot be placed upon one when the stomach must be emptied quickly before an emergency operation. Large caliber, rigid gastric suction tubes are far more reliable, but are difficult to use unless the patient is completely cooperative.[21, 92] It seems unlikely that such tubes are widely used, because patients are unwilling to submit to them.

A more reliable method of emptying the stomach is to induce vomiting by means of apomorphine. This procedure has been recommended for obstetric patients, and in two recent studies it appears to have been effective and safe.[50, 88] Holmes recommended a maximum dose of apomorphine of 3 mg. White used doses as high as 6.5 mg., but warned that a hypnotic effect may result when the larger doses are required. The apomorphine is diluted in 10 ml. of diluent and administered intravenously in not less than three minutes. Vomiting usually begins before a dose of 4 mg. has been reached. The injection is stopped as soon as vomiting occurs. Not all patients vomit when given apomorphine. White admitted that seven of his 75 patients failed to vomit after receiving 6.5 mg.

Mechanical blockade of the vomiting pathway has had several advocates. Macintosh devised a double lumen tube with a large balloon seven inches from the tip. He inserted the tube into the esophagus so that the balloon lay eighteen inches below the incisor teeth.[60] The balloon, when inflated, thus served as an obstruction to the expelling of vomitus, and the tube was available for gastric suction. Wulfsohn has described a method in which a Levine tube is attached to a Foley catheter, and is used in the same manner as the Macintosh tube.[91] Gilman and Abrams, using a similar device, inserted the balloon into the stomach, inflated it and pulled it back snugly against the cardia, thus hoping to obstruct passage of vomitus.[24] The Miller-

Abbott tube has been used in a similar manner.[92] It should be borne in mind that the esophagus is a highly distensible organ, and that its muscular coat relaxes during vomiting. Consequently blockade of the esophagus is probably not completely reliable.

While these methods may be fairly effective, it seems doubtful that they are widely used. Anesthesiologists faced with the danger of vomiting more likely rely on the customary tools of their specialty. Endotracheal intubation of the conscious patient under topical anesthesia of the larynx has been advocated by Wycoff.[92] He believes that topical anesthesia can be quickly and effectively performed by the transtracheal injection of the topical agent combined with regional block of the superior laryngeal nerves. There is no doubt that this procedure is both effective and practical for the prevention of aspiration during general anesthesia, and all anesthesiologists should cultivate skill in performing it. Many, however, take the slightly greater risk of rapidly inducing both anesthesia and paralysis by injecting large doses of thiopental and a muscle relaxant, followed by insertion of a cuffed endotracheal tube. This procedure is safe so far as avoiding the danger of vomiting is concerned. Large doses of thiopental depress the central vomiting mechanism rapidly, and paralysis of the diaphragm and abdominal muscles makes vomiting impossible. The danger of the method lies in the fact that it does not prevent regurgitation from a stomach distended by food, alcoholic beverages or gastric secretions. Regurgitation can occur simultaneously with the injection of the relaxant, and render insertion of the endotracheal tube difficult. Use of the head-up position may decrease the possibility of reguritation.

Some authors have pointed out that oropharyngeal airways, manipulation of stomach tubes and obstruction of airway can stimulate vomiting during the induction of anesthesia.[2,87] If vomiting is so imminent that it will be triggered by these stimuli, however, a better method of prevention should be employed than their avoidance.

Evaluation of the effectiveness of antiemetic drugs lies beyond the scope of this study. It should be sufficient to point out that although these drugs may be relatively effective in depressing the vomiting reflex,[23,77] it is probably unreasonable to hope for complete suppression of vomiting by any drug. Borison and Wang have stated the case against severe depression of the vomiting center, as follows: "Since it has become apparent that the central vomiting mechanism cannot be depressed without concurrent depression of closely associated vital functions, the most intelligent therapeutic approach to clinical vomiting is elimination of the specific cause rather than the general effect."[16] Bellville and his associates have reported observations of the side effects of antiemetic drugs which support this statement.[10,11]

Finally, the role which the cough reflex plays in preventing aspiration should be discussed. Some believe that the maintenance of the activity of this reflex by utilizing a light plane of anesthesia will protect the patient from aspiration. There are dangers inherent in reliance upon the cough reflex. First, effective coughing requires deep inspiration which provides entry into the tracheobronchial tree. Although the presence of vomitus in the hypopharynx causes glottic spasm for a time, the spasm eventually relaxes because of hypoxia, and is followed by gasping and aspiration. Second, clenching of the jaw handicaps clearing of the airway. Third, in some patients the cough reflex may be inactive. Pontoppidan and Beecher have demonstrated that patients above 50 years of age require stronger stimuli to trigger the reflexes of the upper respiratory tract than do younger persons.[75] It has been shown that some elderly patients aspirate even when awake.[33]

The aspiration of liquid vomitus is as dangerous as is aspiration of solid material. Edwards reported that in a group of 118 deaths caused by aspiration, the aspirated material was liquid in 92 cases.[30] Mendelson reported that liquid vomitus was aspirated in 40 of 45 fatal cases.[65] While we do not minimize the dangers of aspiration of solid or semisolid vomitus, the danger of aspirating liquid vomitus should be emphasized. Liquids disperse rapidly throughout the tracheobronchial tree when the patient is struggling to avoid strangulation, and coughing probably assists in this process. Hartzell and Mininger pointed out that when a patient undergoing a bronchogram coughs the opaque oil can be seen to spread immediately into the alveoli.[41]

Archibald demonstrated that in animals radiopaque oil spread into the alveoli more rapidly during coughing than during quiet respiration.[4]

Management of Patients Following Vomiting

Since complete prevention of vomiting during anesthesia appears to be impossible, procedures for handling this emergency should be mastered. Vomiting is easily detected because of the prodromal signs which precede it. Irregular respiration, breath holding, swallowing and salivation interfere with smooth induction of anesthesia. Although some believe that a stormy induction causes vomiting, it seems just as likely that the prodromal stage of vomiting causes the stormy induction. On the other hand, regurgitation of stomach contents may take place so insidiously that cyanosis is the first sign of its having occurred.

As soon as vomiting or regurgitation is recognized the first step in clearing the airway is to tilt the patient head down, and, if possible, to turn him on his side to allow vomitus to drain from the mouth, thus decreasing the possibility of aspiration. Suction apparatus, which should be available and ready, can then be used to clear liquids from the pharynx. If solid food is vomited, it is best to clear the mouth with the finger wrapped in gauze. As soon as the airway has been partially cleared oxygen should be administered by mask to relieve cyanosis.

As simple as these procedures are, they may be rendered difficult by the struggling of a partially anesthetized patient. The jaws may be tightly clenched making it impossible to remove solid food or to aspirate liquids thoroughly. Whenever there is difficulty in clearing the airway, the use of short-acting relaxant drugs in paralyzing doses is justified. With their aid the mouth may be opened and cleared, the trachea can be aspirated, and laryngospasm can be relieved so that oxygen may be given under intermittent positive pressure. Relaxants are not recommended for every episode of vomiting. Small amounts of liquid vomitus may be aspirated easily via the nose in the head-down position.

Whenever there is a suspicion that solid food has been aspirated, bronchoscopy should be attempted as soon as the patient is cooperative. If the vomitus is liquid, however, there is little to be accomplished by use of the bronchoscope. Water is absorbed rapidly from the lung, and by the time bronchoscopy is possible the tracheobronchial tree is empty.

Fortunately, few patients who aspirate vomitus develop pneumonitis. Berson and Adriani failed to observe a single case of pneumonitis among 66 patients who were known to have aspirated during anesthesia.[12] The likelihood of pneumonitis occurring after aspiration of liquid vomitus can be determined by testing a small sample of vomitus with pH indicator paper. If the pH is not below 2.5, pulmonary complications are unlikely to occur.

When pneumonitis does result from aspiration, it presents a pathognomonic syndrome which is easily recognized. The syndrome includes cyanosis which may persist in spite of vigorous oxygen therapy. Accompanying the cyanosis are severe tachypnea and tachycardia. Rapid, shallow respirations at a rate of 40 or more per minute are observed, and the pulse ranges from 120 to 160 per minute. The patient exhibits severe prostration after awakening from anesthesia. The triad of symptoms: persistent cyanosis, tachypnea and tachycardia observed in a patient who has vomited or regurgitated must be accepted as proof of pneumonitis, at least, until a chest roentgenogram can be obtained. Another sign of pneumonitis is coarse asthmatic rhonchi, which may occur as late as two hours following aspiration. Emphasis has been placed upon this sign by most writers, but it is not always notable. In some cases only mild wheezing is observed.

The clinical diagnosis of aspiration pneumonitis can be confirmed by roentgenogram, which reveals areas of density in the lung fields. The diagnosis cannot be made by roentgenograms alone, however, since the consolidation of the lung revealed by roentgenograms does not have distinctive features. The right lower lobe is the lobe most frequently and extensively consolidated, because the right main bronchus offers the easiest pathway for aspiration. The right upper lobe is usually involved secondarily, probably due to drainage of vomitus into this lobe, when the patient is positioned head-downwards. In severe cases the left lung has large areas of consolidation, as well.

Cardiovascular failure, evidenced by hypo-

tension and pulmonary edema, may be observed during the asthmatic stage of the syndrome. The seriousness of this need not be emphasized other than to point out that many patients have died during this period of crisis. In those who do survive, the hypotensive episode usually lasts two to four hours, after which improvement occurs. No one has reported observing enough cases of this type of shock to speak with authority on its causes. It may be, as Simonds suggested in 1940, that the hypotension is precipitated by loss of blood volume caused by pooling of blood in the pulmonary vascular bed and exudation of plasma into the alveoli.[52] On the other hand, it may be due to cardiac failure brought on by hypoxia and tachycardia. In view of the ignorance which exists concerning shock following aspiration, measures for combating it have been adopted haphazardly. Fortunately, shock after aspiration does not occur often. No accurate statement can be made concerning its incidence aside from mentioning that shock occurred in only three of nine cases of extensive aspiration pneumonitis known to the authors.

While the symptoms of aspiration pneumonitis usually become apparent immediately after aspiration takes place, three authors have reported a total of six cases in which there was a significant delay in diagnosis by the anesthesiologist.[29, 42, 49] In fact, the period of delay was as long as five and one-half hours in one of these cases.[42] It is impossible to explain the long period of quiescence on the basis of the facts related in any of these reports. Although such cases must certainly be rare, one cannot dismiss the possibility of their occurrence in view of these reports.

Management of Aspiration Pneumonitis

The treatment of aspiration pneumonitis begins with the measures already described for the prevention of strangulation and restoring oxygen to the patient. The patients who develop pneumonitis, however, require careful and protracted treatment. The tracheobronchial tree is partially obstructed by thick mucoid material which requires repeated aspiration especially during the first hour following aspiration. The practice of injecting 5 to 10 ml. of normal saline into the trachea for loosening these secretions has been widely employed. It has been shown experimentally, however, that large amounts of liquid instilled into the tracheobronchial tree in the hope of diluting the aspirated acid served only to force the acid into larger portions of the lungs. Some caution, therefore, should be observed in employing this method. Single intratracheal injections should probably be limited to 10 ml. and the saline solution should be aspirated promptly.

During the period immediately after aspiration occurs oxygen by mask should be given. When the airway is relatively clear and the patient can be transferred to bed, nasal oxygen at a flow of 5 or 6 liters per minute appears to be the best form of oxygen therapy. The need of the patient for frequent care and examination militates against the efficiency of an oxygen tent. High concentrations of oxygen given by mask for prolonged periods present the hazard of oxygen toxicity and further irritation of the lungs. If the patient exhibits signs of severe air hunger, oxygen under intermittent positive pressure may be given by means of any of the devices suitable for this purpose. This type of assisted respiration can give needed periods of rest to the patient who is exhausting himself by his efforts to breathe. The danger of oxygen toxicity, however, requires that this form of oxygen therapy be limited to fifteen minutes in each hour. If continuous intermittent positive pressure respiration is used, oxygen concentrations should be limited to 40 per cent. Respiratory exchange is likely to be embarrassed by copious bronchial secretions, which may require removal by bronchoscopy. Expectorants have been advised for the purpose of liquefying such secretions,[62, 66] but the patient may be so debilitated that his efforts to cough are ineffective. Broad spectrum antibiotic therapy should be instituted early to minimize the possibility of secondary infection of the inflamed lungs.[63]

Although shock constitutes one of the gravest of the crises following aspiration, no dogmatic statements can be set down concerning its management. If shock is brought on by a fall in blood volume caused by the impounding of blood and plasma in the injured lung, the methods of combating it would be obvious. Unfortunately there is no proof that loss of blood volume is the cause,

and it seems even more reasonable to believe that cardiac failure may be the cause of hypotension and pulmonary edema. In view of the severe tachycardia and hypoxia it would seem most logical to support the coronary circulation and cardiac muscle function. Raising of the aortic pressure by use of vasoconstrictor drugs and rapid digitalization might be lifesaving. On the other hand, increasing the blood volume by transfusion would further embarrass the failing heart. Those patients who can be supported during the period of shock have been known to go on to full recovery.

Pulmonary edema can occur during the period of shock, and may be the immediate precursor of death. While it is possible that pulmonary edema may be precipitated by some unknown factor peculiar to aspiration pneumonitis, it seems more likely that the immediate causes are pulmonary hypertension and acute cardiac failure. Rotation of tourniquets on the extremities and breathing under a continuous pressure of 6 to 8 cm. of water are probably the most effective measures which can be taken to reverse the edema.[6]

As mentioned earlier, the critical period of shock is often accompanied by marked bronchoconstriction and asthmatic wheezing. The severity of this symptom varies with the severity of the pneumonitis, and may require little attention in milder cases. It can, however, cause serious impairment of respiratory exchange, and thus necessitate the use of bronchodilator drugs. Aminophyllin has been recommended as the best drug for this purpose.[62, 66] One-half gram of aminophyllin injected intravenously in not less than three minutes should give at least partial relief from bronchoconstriction. Other bronchodilator drugs, such as isoproterenol, may be used for this purpose.

A promising approach to the treatment of aspiration pneumonitis has been provided by the employment of adrenocortical steroids. Hausman and Lunt reported in 1955 that they had successfully treated two patients with hydrocortisone.[42] Marshall and Gordon in 1958 reported giving hydrocortisone to eight patients following aspiration of vomitus, and gained the clinical impression that these patients were greatly benefited.[63] Dines and his associates have described a case in which aspiration pneumonitis was not diagnosed until profound shock and pulmonary edema occurred. They noted that the patient's symptoms were dramatically relieved within three hours after receiving hydrocortisone intravenously.[26] The present authors have observed similar results in four patients who had radiologic evidence of extensive aspiration pneumonitis.

Animal experiments support the clinical impression that hydrocortisone is of value in the treatment of aspiration pneumonitis. Chemical pneumonitis has been produced in rabbits by instilling hydrochloric acid solution of *p*H 1.5 to 1.8 into the lungs. In those animals which received hydrocortisone, the extent of the lesions found at autopsy after forty-eight hours were much less extensive than the lesions found in animals which did not receive cortisone. Peribronchial infiltration was found to occur in the treated animals but the lesions were well circumscribed, and the surrounding portions of lung were relatively unaffected.[5] Thus, it appears that both experimental and clinical observations support the efficacy of adrenocortical steroids in treating aspiration pneumonitis.

Numerous experiments have been performed which have shown that administration of cortical steroids diminishes the inflammatory response of animal tissues to injury. It is reasonable to assume that hydrocortisone by inhibiting the inflammatory response of the lungs to chemical irritation alleviates the acute symptoms of aspiration and hastens recovery. Although the physiological mechanism whereby inflammatory tissue responses are altered is not known, it seems possible that the adrenocortical hormones inhibit the release or enhance the removal of phlogistic substances from injured cells.[26] It should be remembered that hydrocortisone also alters the tissue response to infection, and its use in aspiration pneumonitis should always be accompanied by antibiotic therapy.

Clinical experience in the use of hydrocortisone for the treatment of aspiration pneumonitis has not been extensive, and the dosage schedules reported have not been uniform. A regime which has been found to be satisfactory by the authors consists of hydrocortisone 100 mg. given intravenously as soon as chemical pneumonitis is diagnosed. Hydrocortisone 50

mg. is then given intramuscularly every six hours for three days and 25 mg. every six hours during the fourth and fifth days following aspiration. ACTH may be given for a day or two following discontinuance of steroid therapy.

Information concerning late sequelae of aspiration pneumonitis is meager. Authors who have obtained serial chest roentgenograms of their patients following aspiration report that in most patients the lung lesions disappear within seven to ten days.[41,63,65] There are, however, some patients who continue to have moderate to severe peribronchial infiltration as evidenced by chest films. Hartzell and Mininger state that three of 18 patients had a prolonged convalescence following aspiration,[41] and Marshall and Gordon report that in one of their patients resolution of the lung pathology was incomplete seven weeks after aspirating vomitus.[63] It appears that in patients who fail to complete their convalescence promptly chronic bronchitis is the cause of persistent symptoms. Whether or not pulmonary fibrosis occurs as a result of aspiration pneumonitis has not been determined.

Conclusion

There has been slow but steady progress in gaining understanding of the aspiration problem. The etiology and pathology of aspiration pneumonitis have been established. Physiological mechanisms which operate during vomiting and regurgitation have been studied, and the knowledge gained should aid in the prevention of emesis during anesthesia. The management of patients who aspirate vomitus shows promise of improvement.

There are still areas of ignorance in this field. The effects of general anesthetic agents on the vomiting centers are poorly understood, and no experiment has been devised for studying these effects. Consequently there is no rational approach to mitigation of the emetic effects of general anesthetic agents.

Inability to detect the presence of a full stomach renders the complete prevention of vomiting during anesthesia difficult. Unsuspected gastric distention can persist for many hours after the ingestion of food. A reliable, clinical test to determine whether the stomach is empty would lead to a major break-through in this field, since it would eliminate the uncertainty and wishful thinking which lead to trouble.

Finally, ignorance persists concerning the treatment of aspiration pneumonitis. The cause of the post aspiration shock syndrome is uncertain, and consequently no definitive method of treating this entity exists. The effects of aspiration pneumonitis upon cardiac function have not been studied, so it is not known whether digitalization is advisable or not. The use of adrenocortical steroids for restricting the inflammatory effects of aspiration now appear to be of value. Further clinical experience with this type of therapy, however, may reveal limitations of its usefulness.

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