GASTRO-ENTEROSTOMY AND PYLOROPLASTY.

AN EXPERIMENTAL STUDY BY MEANS OF THE RÖNTGEN RAYS.

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THE purposes of the operations most frequently performed on the stomach are relief from the distress and disturbed functioning that arise from pyloric obstruction, control of intragastric hæmorrhage, and removal of malignant pathological tissue, usually from the pyloric region. The two prominent methods for the relief of non-malignant pyloric obstruction are the surgical anastomosing of the intestine with the stomach at some point other than the pylorus,—gastro-enterostomy; and the artificial enlargement of the pyloric opening, —pyloroplasty. For the removal of growths in the pyloric region pylorectomy is the natural procedure, but with pylorectomy and the special treatment of gastric hæmorrhage this paper is not concerned. What is here presented is a discussion of gastro-enterostomy and pyloroplasty as surgical methods of obviating non-malignant pyloric stenosis. In this discussion evidence is brought forward from clinical sources, from recent physiological investigation, and from observations on animals on which gastro-enterostomy or pyloroplasty has been performed.

THE TECHNIQUE OF THE OPERATIONS AND THE METHOD OF EXAMINATION.

The animals used were large cats, preferably females, since they are usually more quiet than males when fastened down for X-ray examination. The last feeding was at least

twelve hours before the operation. The animals were always completely etherized. The hair over the mid-abdomen just below the ensiform cartilage was clipped closely with scissors, but not shaved. This area was then washed with soap and water, scrubbed with a sponge of sterile absorbent cotton wet with ether, and occasionally with alcohol. The cat was then covered with a large square of sterile cotton cloth, with a slit over the site of operation. The instruments were boiled for five minutes. The sponges were bits of absorbent cotton, sterilized in mass, and torn into pieces of suitable size; a few sterile gauze strips were used. Suture material was either silk or linen thread, white or black; the threaded needles were immersed in alcohol without boiling. The operator's hands were prepared by scrubbing with a wood-pulp brush, common soap, and running water, followed by immersion in alcohol for two minutes. Gloves were not used.

Every effort was made to avoid unnecessary manipulation of the abdominal contents. The incision was invariably in the median line just below the sternum. The anastomoses were all made by continuous suture and without clamps, though in another series of cases clamps would be used at least in some of the operations. Before closing the wound, the omentum was always replaced in as nearly its normal position as possible. The peritoneum was usually closed separately, with catgut, and the fascia and skin together, either with catgut or silk. The dressing consisted of sterile cotton and collodion. The cats were given boiled water after eight hours, and gradually returned to their usual diet.

In spite of efforts to obtain an empty alimentary canal at the time of operation, food of some sort was usually present either in the stomach, the intestine, or both; and small worms (Ascarides) almost invariably emerged from the incisions in the intestine. Three cats died as a result of the operations; the others lived for months and grew fat. In the fatal cases death was due to obstruction from kinks at the distal end of the anastomosis, once from a twist in the mesentery, and in another case from beginning local gangrene of the gut in the

region of attachment. The gangrene was perhaps due to the fact that the incision in the intestine was made accidentally on one side and too near the mesenteric border, thus possibly interfering with the blood-supply of the gut. Neither in these cases, nor in any of the autopsies on the other cats, was there a sign of peritonitis. The junctions were invariably found tight, and the anastomoses patent. In one of the early experiments, when food was seen to leave the stomach always through the pylorus and never through the new opening, it was supposed that the anastomosis had in some way closed. The abdomen was opened, the gut opposite the site of the anastomosis incised, the aperture demonstrated to be patent, the gut returned, and the wound closed; then the food was observed as before to leave by the pylorus and not by the artificial way. The difficulty of forcing food to leave the stomach through a gastro-enterostomy opening, when the pylorus is patent, had not at that time impressed itself upon us as it did later.

In considering operations of this character, it must be remembered that the cat does not have a retroperitoneal duodenum; the only part of the small intestine of the cat which is not freely movable is at the end of the duodenum which is anchored by a rather delicate fold of mesentery; and the cat, walking upon all fours, and sleeping usually upon its side, presents conditions in regard to anterior and posterior gastro-enterostomy which are almost the reverse of those which obtain in man. For practical purposes, an anterior gastro-enterostomy in a cat corresponds to a posterior operation in man.

The gastro-enterostomy operation was varied by placing the anastomosis, or *stoma*, as we shall call it, at different points on the front and back of the stomach, by making the aperture large or small, and by uniting the gut with the stomach, so that gastric and intestinal peristaltic waves corresponded in direction, or were opposed. The two pyloroplastic operations employed were the Heinecke-Mikulicz operation[1] and that devised by Finney.[2] These two classes of surgical method will be considered in turn.

For purposes of observation, two varieties of food were fed the operated animals. Thin boiled starch (three or four grammes potato starch to 100 cubic centimetres water) was used to test the passage of fluid contents from the stomach. This food was introduced into the stomach by a rubber tube. Canned salmon was used as a more natural food to test the passage of a semisolid substance from the stomach. The salmon was always eaten voluntarily. Before the food was given, it was mixed with a small amount of subnitrate of bismuth, which rendered the mass opaque to the Röntgen rays. The course of the food in the alimentary canal could then be easily watched by means of a fluorescent screen.

With this method, the effects of the two classes of surgical procedure, gastro-enterostomy and pyloroplasty, on the passage of food from the stomach, were studied.

GASTRO-ENTEROSTOMY.

The advantages said to arise from the performance of gastro-enterostomy are several. First of all, the new opening, if made at the most dependent part, is supposed to act as a drainage outlet for the gastric contents. This drain, in offering a new exit for the food, is thought to relieve the pressure on the pylorus and to decrease the amount of food going through the pyloric passage, or even to put that passage entirely out of function. With this new and easier way for the food to emerge from the stomach the work of the gastric musculature in forcing the food onward is diminished. And, finally, the shorter stay of the food in the stomach decreases the chances of fermentation and its attendant distress.

In the consideration of gastro-enterostomy which follows, the subject will be presented under five heads: drainage, the vicious circle, kinks, the disturbance of digestive processes, and the formation of jejunal ulcers.

DRAINAGE.—In stating that the presence of an opening between the most dependent parts of the stomach and a loop of intestine "drains" the stomach, it is assumed that the stomach is a relatively passive bag, and that the food, which is swal-

lowed in a semisolid condition, somehow becomes liquid and runs into the intestine through the hole at the lowest point in this bag. There are a number of facts which should be taken into consideration before credence is given to the idea that the stomach is emptied by simple gravity drainage.

1. *The Stomach not a Passive Bag.*—First of all, the stomach is not at any time during digestion in the condition of a passive reservoir.[3] Within a few minutes after food is ingested peristaltic waves begin to pass over the pyloric half of the stomach, and these waves continue sweeping up to the pylorus so long as food remains in the stomach. The statement is repeatedly found in surgical literature that a gastro-enterostomy opening relieves the pylorus of the irritation from food and gastric juices. It seems to be assumed that a gastro-enterostomy midway in the stomach renders the region between the opening and the pylorus unnecessary for digestion and inactive. There is no reason for believing that peristalsis does not persist under these circumstances, and that the food is not thoroughly churned in the pyloric end by the peristaltic waves. No one should deceive himself by supposing that there is relief from the presence * of motor activity or acid secretions near the pylorus, after a gastro-enterostomy. We have seen the waves passing over the pyloric end of the stomach ceaselessly for long periods when the pyloric sphincter was externally ligated or completely closed by sutures. In short, then, the pyloric end of the stomach serves to mix the food with the digestive juices, to triturate the larger lumps of food, and, under normal conditions, to propel the chyme into the intestine whenever the pylorus opens and allows the chyme to pass.

The cardiac end of the stomach is the reservoir part of the organ. But this reservoir is not a passive reservoir. The muscle fibres extend in all directions over the cardiac end, and during digestion these muscles are in a state of tonic contrac-

* It is, of course, certain that gastro-enterostomy performed after pyloric obstruction shortens the duration of the presence of peristalsis and acid juices in the pyloric end of the stomach.

tion, pressing on the food within and forcing it into the churning process in the antrum as rapidly as it can be received.[4] Finally, as the food is pushed more and more into the intestine the stomach becomes gradually shorter. As might be expected from the prevalence of longitudinal muscles along the greater curvature, the shortening is more noticeable there than along the lesser curvature.

2. *As the Stomach empties, the Pylorus becomes the most Dependent Point.*—An important result of the shortening of the stomach as it empties is the change of position of the most dependent part. The greater curvature of the stomach in the cadaver or in a living person relaxed in anæsthesia commonly reaches a point considerably lower than the pylorus. But the shape and position of the stomach under such circumstances are not the same in the functioning organ. Observations with the Röntgen rays on the normal human stomach containing food mixed with bismuth subnitrate[5] prove that the shortening of the stomach takes place just as if the longitudinal and oblique fibres[6] passing over the surfaces to the greater curvature lifted the organ up towards the one fixed point of the contracting fibres,—the cardia. Since the pylorus is more or less fixed, it does not rise with the rest of the stomach. The consequence is that in the last stages of digestion, when the gastric contents are more fluid than in the earlier stages, the pylorus becomes the lowest point in the stomach,* and the contents therefore do not have to be moved upward in order to be passed out (Fig. 1).

Doubtless it may be argued that observations on a normal person do not hold good for abnormal conditions. It may be said that the attachment of the intestine to the stomach acts as a drag, keeping the stoma at the most dependent point, and that then the stomach must be merely a passive reservoir

* Bettman (*Philadelphia Monthly Medical Journal*, 1899, i, p. 133) has made post-mortem observations on the human stomach in a state of contraction after several days' fast. The pylorus is then the lowest point. He finds that as the stomach is slowly filled with water the greater curvature gradually becomes lower than the pylorus.

with its contents drained by gravity. Or it may be urged that when the stomach is dilated, toneless, and flabby, it cannot act normally, and the part observed to be lowest when the abdomen is opened must remain so. In answer to the first argument, that the point of union of stomach and intestine does not change position, the freedom and ease of movement of the intestinal coils may be cited as evidence against any firm fixation of the united parts in one place. If, however, the stomach is purposely attached to a *fixed* portion of the gut with the object of making the stoma permanently the most dependent point, it may be questioned, in the light of the evidence which is to follow, whether such a procedure, as a ready

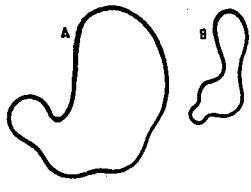

FIG. 1.—Tracings of the outlines of the gastric contents, made by means of the Röntgen rays, one hour (*A*), and four and three-fourths hours (*B*), after eating bread and milk mixed with bismuth subnitrate. Peristaltic waves are passing over the stomach. The line below the figures indicates the level of the umbilicus. The subject was a girl of seven years. The tracings are one-fourth original size.

means of clearing the stomach, is justifiable. In case the stomach is dilated and toneless the lowest point may remain the lowest point if there is no improvement in the condition of the stomach after the operation; but as the tonicity of the gastric musculature returns, the lowest point chosen by the surgeon is as little likely to remain the lowest point as is the case in the normal functioning organ.

Thus far, then, we may say that any point on the surface of the stomach, *not near the pylorus*, that is chosen as the lowest or most dependent point for purposes of "drainage" is in danger of being lifted, as the stomach shortens in emptying, until it occupies a position considerably above the part nor-

mally lowest towards the end of digestion, namely, the pylorus. This fact, coupled with the fact that so long as food remains in the stomach peristaltic waves move continuously towards the pylorus, argues strongly in favor of placing the stoma, not at what happens to be the most dependent point when the abdomen is opened, but near the pylorus, towards which the food is normally pushed and from which the food is most readily passed on into the intestines.

3. *Intra-abdominal Pressure Relations make Gravity Drainage impossible.*—The most important factor which must be considered in coming to a decision regarding the question of "drainage" is the factor of pressure relations within the abdominal cavity, and especially in the two parts of the stomach. The intra-abdominal pressure, *i.e.*, the pressure exerted on the outer surface of the stomach and intestines, is much less than is commonly supposed, for it varies only a few centimetres of water from the atmospheric pressure.[7] The pressure within the alimentary canal, when the canal is inactive, depends on the weight of the overlying organs. This fact was proved by Weisker [8] by measuring the pressure in stomach and rectum by means of manometers. He found that in dorsal decubitus the water in each manometer rose to the highest point of the abdominal cavity. In the upright position the water in the gastric manometer stood at the level of the xiphoid process; but in the head-down position, when the stomach was subjected to the pressure of the freely movable abdominal contents, the water in this manometer rose to the level of the anterior superior spine of the ilium. Similar changes of pressure can be observed in the inactive stomach as the subject lies either on the right or on the left side: on the right side the intragastric pressure varied between one and five centimetres water; on the left side, with the liver above the stomach, the pressure varied between thirteen and nineteen centimetres water.[9] Kelling has shown also that the intragastric pressure increases only slightly even with a large increase of contents, so rapid is the adaptation of the organ to different quantities.[10] The pressure inside the resting stomach and outside the stomach in the

abdominal cavity or in neighboring coils of intestine is approximately the same unless the body is resting on the left side or head downward.

The importance of the considerations in the foregoing paragraph lies in the bearing of these considerations on the question of drainage. The weight of the alimentary canal, as such, must be approximately that of water, which is approximately the weight of the swallowed food. The alimentary canal is not a rigid tube; its walls, unless contracting, are limp and flabby. The limpness and flaccidity of the walls cause the food contained within the canal to be pressed upon by a medium of about the same density as the food itself. To be sure, food pushed into a vertical loop held open by gas would fall by gravity through that loop, but such a condition is not to be regarded as at all usual. Under normal circumstances, therefore, with the walls of the canal in contact or closely surrounding the contents, gravity cannot act, and "drainage" in the common sense of that term is impossible.* In order that the food may be moved onward through the alimentary canal, muscular contraction is necessary to create a difference of pressure.

4. *Intragastric Pressure is greatest at the Pylorus.*—In the digesting stomach a difference of pressure would naturally be expected between the less active cardiac end, holding the food in a tonic grasp, and the more active pyloric end. As the pylorus is approached the pressure should be greater, for the peristaltic waves run downward in a series of several distinct constriction rings, and these rings, as they approach the

* Kelling (*Archiv für die Verdauungs-Krankheiten*, 1900, vi, pp. 455, 456) has also pointed out this fact. He writes: "The stomach is so well supported by the intestinal loops, which surround it, which adapt themselves to its form, and which have a specific gravity about that of water, that we may assume without essential error that it floats completely in water. Thus the labor of the stomach is relieved of the weight of the ingesta. . . . If we fill a gastro-enterostomized stomach with water, the water does not run out by itself, even with the patient in the upright position—because of the hydrostatic relations in the abdomen gravity can have no effect."

pylorus, squeeze deeper and deeper into the gastric contents. So great is the pressure under which the food is forced up to the pyloric sphincter that, when the sphincter does not relax, the food is squirted back through the advancing ring of peristalsis sometimes half the length of the antrum; and when the sphincter does relax the food is shot for some distance along the duodenum.[11] Actual measurement of the pressure in the cardiac and pyloric ends of the human stomach have been made. Von Pfungen[12] found in a boy with a gastric fistula eight centimetres to the left of the linea alba that the intragastric pressure near the fistula was upward from nineteen centimetres water, whereas directly in front of the pylorus the pressure was 162 centimetres water. Moritz has studied a normal individual, and, although his figures are lower than von Pfungen's, they show a similar difference between the two ends of the stomach. The average pressure in the cardiac end was six to eight centimetres water, while in the pyloric end there were rhythmic recurrences of pressure amounting in some cases to thirty-eight, forty, and even sixty centimetres water, though, as a rule, ranging from twenty to thirty centimetres.[13] The evidence is conclusive that the peristaltic waves sweeping towards the pylorus cause the pressure on the food in the antrum to be much greater than it is in the less active cardiac end.

5. *Food goes through the Pylorus rather than through the Open Stoma.*—The difference between the pressure at the pylorus and the pressure elsewhere in the stomach is important in its bearings on the discharge of food into the intestines. If there are two ways from the stomach to the intestines, the pylorus and the stoma, does the food pass out naturally by the pylorus, by both ways, or more readily by the stoma? Observations were made on ten cats on which gastro-enterostomy had been performed and the pylorus left untouched. In these cases the new aperture between the stomach and intestine was placed as follows: two in the anterior wall; one in the posterior wall, near the middle of the stomach; five in the anterior wall; one in the posterior wall, just before the narrowing of the

stomach that forms the antrum; and one in the posterior wall of the antrum. The stoma was varied in size: in two cases it was found at autopsy to be oval and about one and a half centimetres in length, in other cases it has two, two and a half, and even three centimetres in length.

When fluid boiled starch was given to the ten animals above enumerated, this fluid, instead of running through the stoma into the intestines, was forced out naturally by peristaltic waves, through the pylorus. Only two exceptions were observed, one in the animal with the stoma in the posterior wall of the antrum close to the pylorus, and the other in an animal with a large anterior stoma (three centimetres long) about half-way between the two ends of the stomach. The food left by both exits. But in the latter case canned salmon, less fluid, went out by the pylorus alone; it was not observed to pass through the stoma at any time during four and a half hours after feeding.

In one instance the pylorus was partly occluded. A tape was passed through the walls of the stomach in front of the pylorus, and tied; then the gastric wall was sewed tightly over the entrance and exit of the tape. The food still passed out by the pylorus. In another instance a linen ligature was tied snugly about the pyloric sphincter. A week later liquid boiled starch was fed, and, although peristaltic waves were continually sweeping up to the pylorus, the food was observed to pass out wholly by way of the stoma. Still later, when thick salmon was fed, the stomach was watched for the first three-quarters of an hour, and from two to two and a half hours after the feeding. No food was seen going from the stoma, but it was seen leaving in small amounts through the pylorus. At autopsy the ligature was found partially embedded, and the pyloric opening was about a third of a centimetre in diameter. These cases clearly show that even when the pylorus is narrowed so as to offer difficulty to the passage of the chyme, the chyme is forced through the natural way into the intestine rather than through an opening remote from the point of greatest pressure.

When salmon was fed, the food, with the one exception

above mentioned, was never observed to leave the stomach through the stoma if the pylorus was patent. The salmon, a more solid food than the starch paste, adds to the greater pressure in the pyloric region still another factor which causes the pyloric exit to be the easiest exit; this factor is the greater fluidity of the food in the pyloric end of the stomach. As long ago as 1834, Eberle noted that the food in the cardiac end of the stomach was relatively dry, while the contents of the pyloric end were mushy and fluid.[14] This observation is readily confirmed by examination of the stomach of a dog or cat after an hour or two of digestion. It is natural that a relatively fluid material under a general pressure should pass more readily from the stomach than a drier and more solid mass. For this reason alone the chyme should go out through the pylorus sooner than the unchymified food through an opening in the middle of the stomach. And when this difference of consistency, favorable to the pyloric passage, is combined with the greater pressure in the pyloric region, the reasonableness of the results observed in the cases above reported is manifest.

No difference was noted in the results from anastomoses on the front and from those on the back of the stomach. It may be that the operations were not sufficiently numerous to justify conclusions as to the relative merits of anterior and posterior anastomoses. But the evidence from the pressure relations in the abdominal cavity and in the stomach—the fact that the stomach is a muscular bag resting practically as if surrounded by water—indicates that the position of the stoma, anterior or posterior, has not the importance generally ascribed to it.

In the evidence presented in the foregoing paragraphs the physiology of the gastric movements has been considered with reference to its bearing on the emptying of the stomach after gastro-enterostomy operations. It has been made clear that peristalsis is seen only in the pyloric end of the stomach, that the pressure in the stomach is greater as the pylorus is approached, that the food in the pyloric end is much more fluid

than the food in the cardiac end, and that as a result of all these factors the food is more readily forced into the intestines through the pylorus than through the stoma, when these two exits are both offered. It should be observed that there is in these statements no slighting of the fact that improvements have resulted in clinical cases from gastro-enterostomy operations. The larger opening possible between stomach and intestine in the human subject may render the artificial passage-way relatively easier than it is in the small animals used for experiment; but the factors of peristalsis, pressure relations, and the difference of food consistency in the two ends of the stomach are as true for human beings as for these animals, and must make the pyloric passage in human beings an easier and more natural exit for the food than any artificial opening in other parts of the stomach. A justification of this conclusion is found in the experience of Mayo,[15] who observes that when gastro-enterostomy is performed with the pylorus unobstructed, the food seems to take its natural course and the operation is of little use.

THE "VICIOUS" CIRCLE.—In the animals on which gastro-enterostomy has been performed and the pylorus left unclosed or only partly occluded, a circulation of the food has been repeatedly observed. The food was forced through the pylorus, was pushed thence through the duodenum (never in the opposite direction), and entered the stomach again through the stoma. Animals have been watched a half-hour at a time, and over and over again at short intervals during this period food has entered the duodenum from the pylorus, and gone through the regular course, only to merge once more with the mass in the stomach. Usually at these times no food was observed to pass into the intestine beyond the stoma. It is of interest and of practical importance to note that the circulation of the food described above was seen especially when the stomach was stretched either by large amounts of food or by the application of pressure to the abdomen when moderate amounts of food had been given. The reason for this result is clear when the stomach wall in the region of the stoma is

stretched post-mortem. The stretching separates the edges of the opening to which the intestine is attached, and as the edges separate the intestine becomes drawn tight between them (Fig. 2). Thus the intestine forms a flat covering to the opening; it becomes, in short, practically a part of the gastric wall.* In the flattening of the intestine against the stomach, the opening into the intestine in either direction is merely a narrow slit, and these slits become still more narrowed to complete occlusion when pressure is applied to them from within

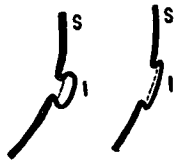

FIG. 2.—Diagram showing how stretching the stomach may cause the part of the intestine sewed to the stomach to become almost continuous with the gastric wall, and the openings into the intestine from the stomach to become mere slits. *S*, stomach; *I*, intestine.

the stomach. The effectiveness of these "valves" was tested in the excised stomach by tying the pylorus and filling the organ with water. As the gastric wall became stretched and the internal pressure increased, almost no water escaped through the stoma into the intestine. And when the cardia was closed and the stomach and its fluid contents further pressed by hand the "valves" were still more effective in preventing leakage.

Evidently the narrow slit-like openings into the intestine, which result from stretching the gastric wall, fully explain

* Kelling (*Archiv für klinische Chirurgie*, 1900, lxii, p. 35) thinks that the vicious circle is due to making too large a hole, so that when the stomach stretches the hole, a spur of the intestine is formed, projecting into the gastric cavity and preventing easy exit. But even with a small stoma, the contraction of the circular fibres of the intestine must cause the gut to lie flat between the lines of ligature and bring about the condition described in our experiments; and, furthermore, a small stoma from its smallness is less likely to be an effective exit. In this connection it is interesting to note that Moynihan strongly advocates a large opening, even four inches in length (*Journal of the American Medical Association*, 1904, xliii, p. 1971).

the prevalence of the circulation of the food from pylorus to duodenum and back to stomach again through the stoma, when large amounts of food are given. These narrow openings act like valves. The slit on the duodenal side of the stoma permits food which has passed the pylorus to return without hindrance to the stomach, but both slits offer a distinct obstacle to the forcing of food outward from the stomach into the intestine. The obvious moral that meals should be moderate in amount in gastro-enterostomy cases need only be mentioned.

The circulation of the food described in this section has never resulted in the clinical symptoms of a "vicious" circulation. The animals have never vomited as a consequence of the repeated passage of the food from the duodenum into the stomach. Indeed, the recent observations of Boldireff [16] render it probable that in the stomach a certain amount of bile and pancreatic juice may be found quite normally. Kaiser [17] cites numerous observers who found after gastro-enterostomy in human beings that bile was almost invariably present in the stomach, and he does not regard its presence there as of unfavorable significance. Retention of food in the stomach, with subsequent repeated vomiting, such as attends the so-called "vicious circle," have been associated usually, in our experiments, with kinks and demonstrable obstacles to the easy passage of the food.

KINKS.—By far the greatest number of failures in our experimental gastro-enterostomies have been due to the formation of kinks. When the ease of movement of the intestinal coils one on another is regarded, the possibility of difficulties arising from the permanent fixation of a coil at any point is easily comprehended. Evidence of such difficulties is found in the acute obstructions caused by the kinks and flexures from adhesions between the intestines and the more stationary abdominal viscera.

In the cases of fatal kinking of the intestine observed by us, the trouble has invariably been located at the distal point of that part of the intestine which is attached to the stomach. The intestine beyond this point is ordinarily more

freely movable than the loop between pylorus and stoma. It may be that this freedom of movement favors the kinking, or that the shortening of the stomach as it empties, with the consequent forward pull on the attached intestinal loop, brings about a sharp turn of the gut at the point of junction with the stomach.

Sharp turns in the intestine in normal conditions are undoubtedly readily straightened by the push of intestinal peristalsis. Bayliss and Starling [18] have described a local reflex of the intestinal wall, which requires peristalsis always to be a forward movement. Stimulation of the gut at any point causes contraction behind and relaxation in front of the point of stimulation. A mass of food in the gut must therefore move forward, and as it does so it causes a new region back of it to contract, a new region in front to relax. Thus the mass

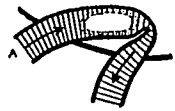

FIG. 3.—Diagram showing kink just beyond attachment of intestine to stomach. Note the interruption of the circular fibres at the stoma.

progresses. A mass of food driven forward by a peristaltic constriction must therefore act under normal conditions like the forcible injection of a flaccid rubber tube, in obviating kinks and bends and in making the way passable. It is important to note that conditions for straightening a kink at the end of a gastro-enterostomy attachment are not present. At the stoma there is an interruption of the circular fibres (Fig. 3). The interruption of these fibres makes it impossible to apply to the turn in the gut a force which would make the gut straight. It is evident that the contraction of the interrupted circular muscle can result in no other effect than that shown in Fig. 2, *i.e.*, a shortening of the intestinal wall between the attachments to the stomach. The circular fibres in this region cannot get a grip behind a mass of food and push that mass forward straightening the gut. The only force tending

to obviate the kink is the pressure of the food from the stomach, which in the cardiac end has been proved to be relatively slight. The persistence of kinks near the stoma is thus readily understood. Their effects in producing retention of food in the stomach, vomiting, and death have been observed several times in our experiments.*

Foods leaving by Stoma are not mixed with Important Digestive Juices in the Duodenum.—Food which emerges from the stomach through the pylorus accumulates in the duodenum, and there undergoes the process of rhythmic segmentation.[19] The rhythmic segmentation of the food serves to mix it thoroughly with the pancreatic juice and the bile. The great physiological importance of these secretions, especially the pancreatic secretion, in the digestion of all three classes of food-stuffs—carbohydrates, proteids, and fats—need not here be emphasized. The fact that the presence of the acid chyme in the duodenum is the normal stimulus to the flow of the pancreatic juice[20] is not so widely recognized by surgeons. Thus the food in taking its natural course causes the flow of the digestive secretions and becomes thoroughly mixed with them. If the food, instead of going through the duodenum, passes directly from the stomach into the jejunum or ileum, these functions are seriously interfered with. It is conceivable that a certain amount of pancreatic secretion may be carried into the jejunum and the ileum and there mixed with the food. And food may pass for a short distance into the proximal loop from the stoma. In our experiments food has repeatedly been seen passing from the stroma into the proximal loop (towards A, Fig. 3), only to be swept into the stoma again by a peristaltic wave. Since the circular fibres were not complete at the stoma, the food was not pressed past it into the distal gut, but was forced into the stomach. And no

* We have never observed a reversed peristalsis in the small intestine returning intestinal contents to the stomach. Rosenberg (*Archiv für die gesammte Physiologie*, 1898, lxxiii, p. 419) has assumed this perversion of normal intestinal activity as the cause of vomiting after gastro-enterostomy.

sooner had the wave gone by than the food was pressed back into the proximal loop. Thereupon a new peristaltic wave once more pushed up the food, but back it was pressed when the wave came to the cut fibres. This process, which we have seen repeated again and again, must have the effect of mixing some of the food, at least, very thoroughly with the digestive secretions poured into the duodenum.* But only a relatively small part of the food may be treated in this manner, and at best this is a poor makeshift for the kneading process which normally mixes the juices and the food together.

JEJUNAL ULCERS.—An occasional occurrence in connection with gastro-enterostomy operations is the formation of an ulcer in the jejunum opposite or near the stoma. The cause of such ulceration is not known, although it is commonly ascribed to a digestive process too active for the tissue to resist. When it is remembered that there is a mechanism between duodenum and stomach which prevents fresh food from leaving the stomach until the acid in the food already in the duodenum has been neutralized by bile and pancreatic juice,[21] the presence of ulcers in the jejunum in cases of gastro-enterostomy might well be due to the constant presence of acid in a region in which inorganic acid is not normally found.[22] In this connection it is interesting to note that no case of ulcer of the duodenum after pyloroplasty has been reported.[23]

CONCLUSIONS AS TO THE BEST COURSE IN GASTRO-ENTEROSTOMY.

From the observations detailed in the previous division of this paper, certain conclusions can be drawn as to the best course in gastro-enterostomy.

DRAINAGE.—It has been shown that there is no reason to suppose that "drainage" from the stomach occurs, in the sense of gravity drainage, but that food is pushed from the stomach,

* Kelling (*Deutsche Zeitschrift für Chirurgie*, 1901, lx, p. 157) has recorded a surgical case in which he was able to observe through a fistula the passage of some of the food into the duodenum from a gastro-enterostomy opening.

as it is pushed elsewhere in the alimentary canal, by pressure due to contraction of muscles in the wall of the canal. In the stomach the most effective muscular activity, peristalsis, is seen only in the pyloric end. Consequently, pressure is greater near the pylorus than anywhere else in the stomach; and food leaves through the pylorus, even the partially obstructed pylorus, rather than through an open stoma some distance away.

The obvious conclusion from these considerations is that the union of stomach and intestine should be made in that part of the stomach in which there is the greatest intragastric pressure, *i.e.*, as close to the pylorus as possible. In the animals observed by us the usual semisolid food invariably left by the pylorus rather than by the stoma, when the pylorus was open and the stoma was near the middle of the stomach. And the only case in which food left invariably by the stoma as well as by the pylorus was a case of gastro-enterostomy in the antrum pylori. If the stoma is to be placed in the most favorable position for use, therefore, it should be placed as close to the pylorus as possible.

The repeated observation of food forced from the stoma into the proximal loop, *i.e.*, in the direction of the gastric peristalsis but opposite to the direction of the intestinal peristalsis (see p. 698), is suggestive of advantages to be derived from a coincidence in the direction of gastric and intestinal peristalsis in the region of the junction. The only case in which this coincidence was followed by an earlier discharge through the stoma than through the pylorus was the case already mentioned on page 690. In this instance the stoma was about midway in the stomach, but the opening was large,—three centimetres in length. In other similar cases with openings only half as large, the food passed out by the pylorus rather than by the stoma. It is impossible to conclude from our cases that the coincidence in direction of gastric and intestinal peristalsis is of great advantage, but a large opening is evidently favorable for use.

"Vicious" Circle.—It has been shown in the previous division of this paper that in simple gastro-enterostomy a

circulation of the food, from stomach through pylorus and back to stomach through stoma, was a frequent occurrence. Especially was this circulation seen when the stomach was well filled. The lips of the opening were thereby widely separated, and the attached intestine stretched so as to become practically a part of the gastric wall. The openings into the intestine at the stoma were then only narrow slits. These are good inlet valves from intestine to stomach, but they prevent easy exit.

The circulation of the food can be rendered less probable by Wölfer's second method (practically the Roux operation) or by a combination of gastro-enterostomy and entero-enterostomy, although in the latter case the circulation is still possible by direct forward peristalsis. One animal on which Roux's operation was performed was observed at intervals for almost three months. Whenever fluid food was given, it invariably passed out both by the pylorus and by the stoma. Proteids combined with fats are very slow in beginning to leave the normal stomach;[24] at one time when salmon was fed to this animal the salmon was seen going out by the stoma earlier than by the pylorus. Never was the law of forward intestinal peristalsis[25] violated, never was there a passage of the food back into the stomach.

With simple gastro-enterostomy and an open pylorus the circulation of the food from stomach to intestine and back to stomach again cannot be prevented. The continuance of such a circulation is clearly favored by stretching the stomach with food. The taking of moderate quantities of food at a time is therefore advisable.

KINKS.—It has been pointed out that intestinal kinks were repeatedly found at the point where the intestine leaves the stomach after being joined to it. These kinks are not readily straightened, because peristaltic pressure cannot be brought to bear upon them, the circular fibres, rendered ineffective by the incision necessary to make the stoma, lie too close to the obstacle.

It is evident that if this reasoning is correct, the rational procedure is to attach a narrow band of the distal gut con-

tinuously to the stomach wall for several centimetres beyond the stoma. The gut is thus prevented from making a sharp turn within a distance in which peristalsis is not effective. Food getting into this region which is kept relatively straight may now be clutched from behind by a peristaltic constriction, and possible bends lying further on in the intestine may thus be straightened by the force of the peristaltic movement.*

FOOD NOT MIXED WITH DIGESTIVE JUICES IN THE DUODENUM.—Food which passes out by the stoma is not mixed with the bile and pancreatic juice in the duodenum. And furthermore this food is not neutralized in the natural manner by the alkaline duodenal fluids. The occurrence of jejunal ulcers near the stoma may be thus explained.

These objections to gastro-enterostomy cannot be avoided, if the operation does what it is intended to do and entirely supersedes the pyloric passage as an outlet. On the other hand, if the food still goes wholly or chiefly through the pylorus the gastro-enterostomy is of little use.

All our observations on experimental animals, and the data collected from the literature, directed us to the pyloric region as the most advantageous location for an artificial outlet from the stomach. The difficulties arising from the circulation of the food by the so-called "vicious" circle, and from the non-mixture of food with the digestive and neutralizing fluids in the duodenum, are practically impossible to avoid in a simple gastro-enterostomy. And the danger from kinks when a movable part of the alimentary canal is fastened as a loop to a less movable or immovable point must always be present. Is not pyloroplasty in cases in which it can be used a much more rationally defensible operation for the relief of

* Kappeler (*Deutsche Zeitschrift für Chirurgie*, 1898, xlix, p. 129) has noted in his cases the passage of food into the proximal loop of the attached intestine, and the failure of the distal loop to function because of the formation of a spur at the stoma. It is interesting to note that from clinical considerations Kappeler recommends (p. 144) fastening both the proximal and distal loops for four to six centimetres horizontally along the stomach for the purpose of avoiding spur formation.

pyloric obstruction than we have found gastro-enterostomy to be?

PYLOROPLASTY.

The two forms of pyloroplastic operations are the Heinecke-Mikulicz and the Finney operations, although Finney's procedure is sometimes wrongly classified as a gastro-duodenostomy. Both these operations have been performed on animals, and the movements of the food studied by the method already described. As the results, so far as the passage of food from the stomach is concerned, were the same with both operations, a separate consideration of each of them is not necessary.

By the normal mechanism of the pylorus the food is prevented from leaving the stomach until it has undergone gastric digestion. Thus, proteid food, digested in the stomach, does not begin to leave the stomach till later, departs more slowly, and is retained longer, than carbohydrate food of the same amount and consistency, not digested by the gastric juices.[26] And the reflex from the duodenum prevents the chyme from being discharged from the stomach in quantities so great as to overwhelm the important digestive processes begun near the opening of the pancreatic and bile ducts. The chyme emerges at irregular intervals in small amounts, and when a mass of food has accumulated in the duodenum rhythmic segmentation churns the food with the juices.

It is natural to suppose that by cutting the pyloric sphincter the digestive mechanisms controlling the exit of food from the stomach must be entirely destroyed. This supposition is not wholly correct.

When the animals on which pyloroplastic operations had been performed were fed either carbohydrate or proteid food, the discharge from the stomach began earlier and continued in greater abundance than under normal conditions. And although in some cases the duodenum became filled with food, the peristaltic waves continued running over the pyloric end of the stomach. But the discharge into the intestine was not entirely uncontrolled, for the operation does not interfere with the process of rhythmic segmentation in the duodenum (see

p. 702). This rhythmic contraction of the circular fibres of the intestine just beyond the stomach has been again and again observed in these cases of pyloroplasty. It is clear that the process of segmentation alone would check the discharge from the stomach, for the circular constrictions of the gut assume the function of the pylorus, and the gastric peristalsis cannot force the food past them. There is, therefore, in the duodenum a mechanism which serves to control the discharge from the stomach and to continue the mixing of the chyme with the pancreatic juice and the bile in the normal manner.

In favor of the pyloroplastic operations, the facts to be adduced are mainly the obverse of the disadvantages of gastro-enterostomy. In the first place, the food is pressed out of the stomach normally by peristalsis. And after the pyloroplastic operations no circulation of the food is possible,—there is no way back into the stomach except in opposition to the normal movement of intestinal peristalsis. Kinks and sharp turns in the gut have no reason for existence or persistence,—there is no fixation of a free loop of the intestine. And, finally, foods are mixed in a normal manner with the digestive fluids poured into the duodenum. This mixing, by rhythmic constrictions of the intestine, prevents a too rapid discharge from the stomach, promotes the important digestive functions performed by the bile and pancreatic juice, and serves to neutralize the acidity of the chyme with these alkaline secretions.

SUMMARY.

The stomach is not a passive bag. During digestion the cardiac end slowly contracts, pressing its contents into the pyloric end. Over the pyloric end during digestion peristaltic waves are continually running, churning the food with the gastric juices and forcing the chyme into the intestine. Observations on the functioning human stomach show that as it empties it shortens, especially along the greater curvature. Therefore the part of the stomach lowest when the organ is full or relaxed is not lowest as it empties. The pylorus then becomes the lowest point. Even if "gravity drainage" oc-

curred, the pylorus is the natural outlet so long as the stomach retains its power of contracting.

The pressure within the abdomen is approximately atmospheric pressure. The pressure in any part of the passive alimentary canal depends on the weight of the overlying abdominal organs. If the canal is inactive, the food therefore is as if surrounded by water. Gravity cannot act, and gravity drainage does not occur.

After an ordinary meal, the peristalsis of the pyloric end of the stomach makes the contents of this part more fluid than the contents of the cardiac end. Because peristaltic waves move towards the pylorus, the intragastric pressure is three or four times greater at the pylorus than in the cardiac end. Observations on large cats with gastro-enterostomy openings of various sizes at various parts of the stomach showed that unless the opening, or stoma, was in the antrum (*i.e.*, close to the pylorus) the food, even when fluid, was pushed through the pylorus rather than through the stoma.

With peristalsis only in the pyloric end of the stomach, with the intragastric pressure much greater at the pylorus than elsewhere in the stomach, and with the food in the pyloric end normally more fluid than that in the cardiac end, the food is forced into the intestine through the pylorus and not through the artificial opening, when both ways are offered.

Circulation of the food through the pylorus to the duodenum and back to the stomach through the anastomosis has been repeatedly observed, but it was not followed by the clinical symptoms of the "vicious circle." The circulation was observed best when the stomach was very full. The stretching of the stomach separates the lips of the stoma and draws the intestinal wall into line with the gastric wall. The openings into the intestine at the stoma then become mere slits, and act like valves, permitting the entrance, but preventing the exit, of the food.

The clinical symptoms of the "vicious circle" have been observed in animals in which a kink of the intestine has been found just distal to the anastomosis. Kinks at this point can-

not be straightened by peristaltic activity because the circular fibres of the intestine are cut at the nearby stoma.

It is important that food be mixed with the secretions poured into the duodenum; these juices are highly effective in digestion, and also neutralize the acid chyme. If food leaves the stomach by the stoma, it is not mixed with these secretions. Jejunal ulcers after gastro-enterostomy may be due to the presence of acid in a region in which inorganic acid is not normally found.

From the above considerations, it was concluded that the stoma should be large and as near to the pylorus as possible; that the circulation of the food be rendered less probable by avoidance of overeating, and that so far as possible kinks be obviated, by attaching a narrow band of the distal gut to the stomach for several centimetres beyond the stoma, thus permitting peristalsis to become an effective force.

The probability of a circulation of the food whenever the pylorus is left open, the non-mixture of the food with the digestive and neutralizing fluids in the duodenum, and the ever-present danger from kinks in gastro-enterostomy make the operation not an ideal one.

In pyloroplasty (preferably the Finney operation) these objections are avoided. And a too rapid exit of the food through the pylorus is prevented by rhythmic segmentation of the food in the duodenum, an activity which in part replaces the functions of the pylorus, and also mixes the food with the pancreatic juice and the bile.

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