

Replacement of the Pyloric Sphincter with the Ileocecal Valve:

An Experimental Study

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Abstract

Background: Several surgical methods have been devised and applied to overcome the complications associated with the loss of the pyloric sphincter after distal gastrectomy. However, none of these methods creates an efficient sphincteric mechanism at the anastomotic site. The purpose of this experimental study in dogs was to replace the pylorus with the ileocecal valve and determine whether its sphincteric function would be preserved in its new location without affecting gastrointestinal motility and the health of the animals.

Methods: Thirteen dogs underwent surgical removal of the pyloric sphincter and a partial distal gastrectomy. The ileocecal valve, with a short segment of ileum, was then relocated so that the ileal segment was anastomosed to the stomach while the cecal segment was anastomosed to the duodenum. Intestinal continuity was reestablished by anastomosing the distal ileum with the ascending colon. Intraileal and intracolonic pressures were measured in all animals prior to and following transposition of the ileocecal valve. In 3 of these animals, pre-pyloric (intra-gastric) and post-pyloric (intra-duodenal) pressures were also measured before the pylorus was removed. Pressure measurements on both sides of the transposed ileocecal valve were performed again 4–6 months later. All pressure measurements were made directly with a water manometer. Radiographic and fluoroscopic studies were carried out on all animals to assess gastrointestinal motility, gastric emptying times, and the sphincteric competence of the transposed ileocecal valve. Hematological and biochemical studies intended to assess the nutritional status of all animals were carried out. Also, postoperative measurements were made of gastric basic acid output.

Results: All animals were alive and well 4–6 months after the initial operative procedure. Hematological studies and biochemical tests and studies of liver function remained normal. There was a slight reduction in serum B₁₂ levels and, as expected, a significant postoperative reduction in gastric basic acid output. The intraluminal pressure measurements and the radiographic and fluoroscopic studies all showed that the sphincteric mechanism of the ileocecal valve was preserved in its new location, that gastrointestinal motility was not impaired, and that the healthy condition of the animals was maintained. Gross and histological examination of the transposed segments of the intestinal tract did not reveal any abnormalities.

Conclusion: Because the anatomy and physiology of the human alimentary tract are similar to those of the dog, this technique may be applicable clinically, when indicated, to avoid and/or relieve complications resulting from gastrectomy, when those complications do not respond or have not responded to conservative management. **Key Words:** Pyloric sphincterectomy, ileocecal valve transposition, dumping syndrome, gastrointestinal function.

Introduction

SEVERAL DISEASES of the stomach and duodenum (peptic ulcer and malignant or extensive benign tumors) usually require distal gastrectomy. This approach may involve removal of the pyloric sphincter (1). In such cases, the absence of the pyloric sphincter often results in various compli-

cations such as alkaline gastritis, dumping syndrome and anastomotic ulceration (2–6). A variety of surgical methods have been devised to prevent these postoperative complications. However, none of these creates an adequate sphincteric mechanism at the anastomotic site, and none has been proven to be clinically effective in the vast majority of cases (4–8).

The ileocecal valve impedes reflux of the contents of the large intestine and delays the passage of the contents of the ileum toward the large intestine (9, 10). The purpose of this study was to replace the pyloric sphincter in experimental animals (dogs) with the ileocecal valve and to investigate whether the ileocecal valve, in its new position, could serve as a sphincter to delay the passage of gastric content to the small intestine and prevent reflux of the duodenal content toward the stomach. Additional studies were performed to evaluate the overall impact on gastrointestinal motility and general well-being of the animals.

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Materials and Methods

The experiments were performed on dogs because their digestive system is similar to that of humans (11). Thirteen experimental animals, 1–2 years of age and weighing 8–10 kg were studied. Before surgery, barium X-ray studies of the gastric emptying time and the anatomic condition of the gastrointestinal tract were performed to ascertain the suitability of each animal for the experimental study. Hematological, liver, and biochemical tests (including those for electrolytes and vitamin B₁₂ levels), and measurement of nutritional parameters and hourly basic acid output (B.A.O.) were performed preoperatively.

Prior to surgery, the intestine was cleansed and sterilized with neomycin sulfate and metronidazole. Nembutal (16–20 mg/kg) was given intravenously for anesthesia. A midline abdominal incision exposed the peritoneal cavity. After isolating the terminal ileum, intraluminal pressures on both sides of the ileocecal valve were performed in order to determine the pressure at which the valve opened. The intraluminal pressures were measured as follows:

1. The terminal ileum was obstructed with a ligature about 8 cm proximal to the ileocecal valve.
2. A Foley catheter was inserted into the ileum through a small opening made distal to this ligature. The balloon was then inflated gently to prevent the catheter from slipping or moving.
3. The Foley catheter was connected to the end of the horizontal segment of a T tube used for measurement of the venous pressure (Fig. 1). The other end of the horizontal segment was connected to a water-filled reservoir (a bottle with colored water). The vertical segment of the T tube was calibrated in centimeters. The zero of the calibrated scale was marked at the level of the eminence of the ileocecal valve. Pressure measurements were carried out as follows: After proper turning of the 3-way valve, the colored water in the water-filled reservoir was allowed to fill the calibrated manometer. Subsequently, by proper turning of the 3-way valve, the water in the manometer was allowed to flow into the lumen of the terminal ileum. When flow ceased for a few seconds, the height of the column of water at that instant was considered to be equal to the pressure required to open the ileocecal valve. When the ileocecal valve opened, flow

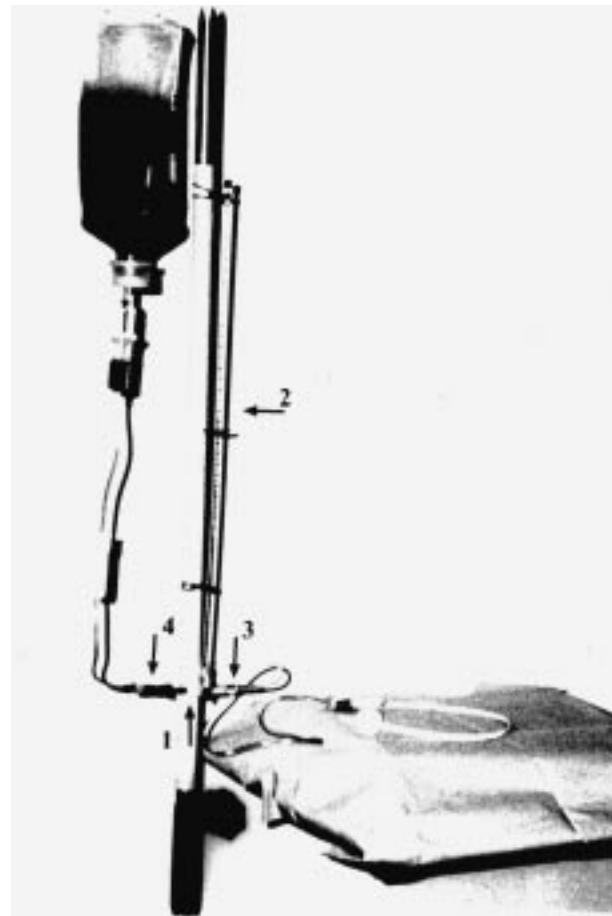


Fig. 1. Apparatus to measure intraluminal pressures. The 3-way valve is marked with arrow 1. The decimal scale in cm is marked with arrow 2. The end of the horizontal segment connected to the Foley catheter is marked with arrow 3. The other end connected to the water-filled reservoir is marked with arrow 4.

resumed and the pressure fell to zero. After measurement of these pressures, the Foley catheter was removed, the opening in the ileum was closed, and the ligature was removed.

Measurement of the intracolic pressure was carried out in a similar manner, except that the Foley catheter was placed in the ascending colon proximal to an occluding ligature positioned about 5 cm distal to the ileocecal valve. The Foley catheter was inserted into the ascending colon through a small incision in the colon, and the procedure described above was repeated.

After all the above measurements had been recorded, a distal gastrectomy with removal of the pylorus and the adjacent segment of the duodenum (1–2 cm) was performed. The proximal segment of the ascending colon, with the cecum and a segment (10–20 cm) of the terminal ileum, (Fig. 2A) was prepared and isolated. This intesti-

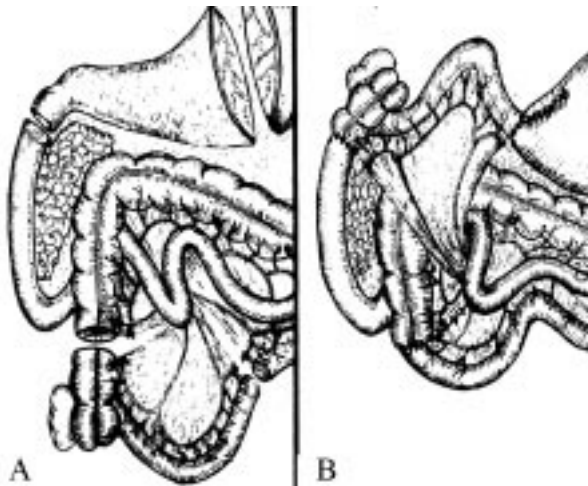


Fig. 2. (A, B) Schematic representation of the surgical technique.

nal segment, with its vasculature and its nerve supply, was then transposed to the site of the excised area of the pylorus. The stump of the transposed portion of the ascending colon was then anastomosed, end to end, with the duodenum. The distal end of the stomach was closed partially and anastomosed, end to end, with the stump of the transposed portion of terminal ileum. The enteric route was then restored by anastomosing the remaining distal end of the ileum, end to end, with the now early portion of the ascending colon (Figs. 2B and 3).

In 3 of the 13 animals, pressures above (intra-gastric pressure) and below (intraduodenal pressure) the pylorus were measured preoperatively in order to compare these pressures with those after



Fig. 3. Final stages of the surgical procedure. The coloduodenal anastomosis is marked with arrow 1; the ileogastric anastomosis is marked with arrow 2; and the ileocolic anastomosis is marked with arrow 3.

excising the pyloric sphincter. To carry out the intragastric pressures, the stomach was obstructed with a ligature about 5 cm proximal to the pylorus, and a Foley catheter was inserted proximal to this ligature. The intraduodenal pressures were measured by obstruction of the duodenum with a ligature about 5 cm distal to the pylorus, followed by insertion of a Foley catheter proximal to this ligature. The manometer was zeroed at the level of the eminence of the pylorus.

To avoid the use of a Levin tube, which is not feasible to place in the dog, a gastrostomy was made and a Foley catheter was inserted into the stomach to overcome the postoperative gastrointestinal paresis. This Foley catheter was also used subsequently to aspirate gastric juice and to infuse barium contrast medium for the X-ray studies of the stomach and gastrointestinal tract. The abdominal wall was finally closed.

During the first few postoperative days, the dogs were hydrated with 5% dextrose solution, administered initially subcutaneously and then by mouth. Prophylactic antibiotics were also given during the early postoperative period. Following this period, a liquid diet was permitted; it was eventually replaced with normal feeding.

Hematological, liver, and biochemical tests, including those of electrolytes and vitamin B₁₂ levels, and measurement of nutritional parameters and hourly Basic Acid Output (B.A.O.) of gastric secretion were performed during the postoperative period. Radiographic and fluoroscopic studies of the sphincteric mechanism of the ileocecal valve and of the peristalsis of the stomach, as well as measurements of gastric emptying time, were also carried out during the postoperative period.

After 4–6 months, the animals were re-explored under general anesthesia. Intraluminal pressures, proximal and distal to the transposed ileocecal valve, were carried out to compare these pressures with those obtained preoperatively. The same protocol for pressure measurements was used as described above.

Following measurement of the intraluminal pressures, the animals were sacrificed. The segment of the terminal ileum and ascending colon which had replaced the area of the pyloric sphincter, together with the adjacent segment of the duodenum and stomach, were removed for macroscopic and histological examination.

Results

The experimental animals were kept alive for 4–6 months. During this time, none presented

with any illness or weight loss. Nor did the animals experience change in the frequency of bowel movements, which remained at 1–2/day, although the stool was looser in the postoperative period. Hematological, liver, and biochemical tests were within normal limits (Tables 1–4). The values for B₁₂ during the postoperative period were slightly lower (0.06–0.07 µg/100 mL) than the preoperative ones (0.08–0.09 µg/100 mL) (normal range of B₁₂ levels is 0.08–0.09 µg/100 mL). The preoperative and postoperative hourly B.A.O. are shown in Table 5. The postoperative

values of B.A.O. were significantly lower than the preoperative ones. In the 3 animals studied before the surgical procedure, mean intragastric and mean intraduodenal pressures were 12 and 19 cm H₂O respectively. The preoperative and postoperative intraluminal pressures of the ileocecal valve are shown in Table 6. After transposing the ileocecal valve, the ratio of the intraduodenal/ intracolic and intragastric/intraileal pressures remained unchanged. Moreover, this ratio of intraluminal pressures was similar to that which existed before replacement of the pyloric sphincter in the 3 ani-

TABLE 1
Hematological Tests

| Experimental Animal No. | Pre-operative hematocrit % | Post-operative hematocrit % | Pre-operative hemoglobin g/dL | Post-operative hemoglobin g/dL | Pre-operative platelet count x 10 ⁵ /µL | Post-operative platelet count x 10 ⁵ /µL | Pre-operative white blood count x 10 ³ /µL | Post-operative white blood count x 10 ³ /µL |
|-------------------------|----------------------------|-----------------------------|-------------------------------|--------------------------------|--|---|---|--|
| 1 | 41 | 39 | 13.2 | 12.7 | 6 | 6 | 7 | 10 |
| 2 | 42 | 40 | 13.6 | 12.7 | 7.5 | 8 | 8 | 12 |
| 3 | 39 | 37 | 12.8 | 12 | 5 | 5.5 | 12 | 14 |
| 4 | 43 | 40 | 14 | 12.8 | 4 | 4 | 10 | 10 |
| 5 | 46 | 43 | 14.8 | 14 | 3.5 | 4.5 | 9 | 9.3 |
| 6 | 41 | 40 | 13.2 | 13 | 8.5 | 8 | 8 | 8.6 |
| 7 | 40 | 38 | 13 | 12.2 | 7.3 | 7.5 | 7 | 7 |
| 8 | 39 | 37 | 12.8 | 12 | 8 | 7.5 | 6 | 6.5 |
| 9 | 47 | 46 | 15.2 | 14.8 | 7 | 7 | 13 | 11 |
| 10 | 42 | 39 | 13.8 | 12.6 | 6 | 6.5 | 11 | 9.5 |
| 11 | 40 | 37 | 14 | 12.3 | 4 | 3.5 | 12 | 12 |
| 12 | 47 | 44 | 15.2 | 14 | 6 | 6 | 15 | 15.5 |
| 13 | 42 | 39 | 13.6 | 12.8 | 5 | 5 | 16 | 16 |

Normal range: hematocrit 37–55%; hemoglobin 12–18 g/dL; platelet count 2–9 X 10⁵/µL; white blood count 6–17 X 10³/µL.

TABLE 2
Hematological Tests of Animals

| Experimental Animal No. | Pre-operative ALT U/L | Post-operative ALT U/L | Pre-operative AST U/L | Post-operative AST U/L | Pre-operative ALK phosphatase U/L | Post-operative ALK phosphatase U/L | Pre-operative GGT U/L | Post-operative GGT U/L | Pre-operative bilirubin mg/dL | Post-operative bilirubin mg/dL |
|-------------------------|-----------------------|------------------------|-----------------------|------------------------|-----------------------------------|------------------------------------|-----------------------|------------------------|-------------------------------|--------------------------------|
| 1 | 9 | 14 | 10 | 14 | 20 | 22 | 3.4 | 3.6 | 0.2 | 0.4 |
| 2 | 12 | 17 | 9 | 11 | 16 | 19 | 2.6 | 2.2 | 0.3 | 0.5 |
| 3 | 8 | 10 | 12 | 14 | 17.2 | 18.5 | 4.5 | 4.3 | 0.2 | 0.4 |
| 4 | 11 | 12 | 9.5 | 10.3 | 13 | 15.5 | 7.2 | 5.5 | 0.3 | 0.3 |
| 5 | 13 | 18 | 11 | 13 | 12 | 12 | 6.4 | 3.2 | 0.1 | 0.2 |
| 6 | 10 | 9.5 | 14 | 17 | 19 | 18.2 | 3.7 | 3.5 | 0.3 | 0.2 |
| 7 | 8.5 | 8 | 13 | 12 | 20 | 20.4 | 5.2 | 4.8 | 0.2 | 0.2 |
| 8 | 13 | 12.5 | 11 | 10.2 | 18 | 15 | 3.5 | 3.2 | 0.3 | 0.2 |
| 9 | 14 | 13 | 12.6 | 12 | 21 | 14 | 2.8 | 3 | 0.2 | 0.2 |
| 10 | 9.5 | 9 | 16.2 | 15 | 18 | 19 | 4.3 | 3.8 | 0.1 | 0.1 |
| 11 | 10.5 | 12 | 18 | 18 | 11.5 | 11 | 5.6 | 4.7 | 0.2 | 0.1 |
| 12 | 11 | 11.5 | 15 | 14 | 16.3 | 14 | 3.8 | 3.4 | 0.1 | 0.2 |
| 13 | 14 | 12 | 12 | 12.2 | 15.5 | 16.5 | 6.2 | 5.4 | 0.3 | 0.2 |

Normal range: ALT 8.2–57.3 units; AST 8.9–48.5 units; Alk phosphatase 10.6–100.7 units; GGT 1.0–9.7; bilirubin 0.1–0.6 mg/dL.

TABLE 3
Biochemical Tests

| Experimental Animal No. | Pre-operative calcium mg/dL | Post-operative calcium mg/dL | Pre-operative sodium mEq/L | Post-operative sodium mEq/L | Pre-operative potassium mEq/L | Post-operative potassium mEq/L | Pre-operative glucose mg/dL | Post-operative glucose mg/dL | Pre-operative urea mg/dL | Post-operative urea mg/dL | Pre-operative creatinine mg/dL | Post-operative creatinine mg/dL |
|-------------------------|-----------------------------|------------------------------|----------------------------|-----------------------------|-------------------------------|--------------------------------|-----------------------------|------------------------------|--------------------------|---------------------------|--------------------------------|---------------------------------|
| 1 | 8.5 | 9.2 | 142 | 138 | 3.6 | 3.4 | 70.2 | 100.2 | 12.2 | 16.8 | 0.6 | 0.8 |
| 2 | 8.8 | 8.5 | 145 | 135 | 4.2 | 3.7 | 80.4 | 90 | 18.2 | 19.4 | 0.7 | 0.7 |
| 3 | 9.2 | 10.4 | 143 | 140 | 4.8 | 4.6 | 100.2 | 107 | 13.8 | 12.4 | 0.6 | 0.7 |
| 4 | 9.3 | 9.4 | 146 | 146 | 4.2 | 4.4 | 90 | 98 | 17.2 | 15.4 | 0.9 | 0.7 |
| 5 | 10.5 | 10.7 | 152 | 150.5 | 5.2 | 5.5 | 95 | 100.3 | 20.2 | 16.7 | 0.6 | 0.6 |
| 6 | 11.2 | 11.4 | 146 | 145.7 | 3.8 | 3.8 | 97.4 | 100.6 | 18.6 | 14.5 | 0.9 | 0.8 |
| 7 | 8.7 | 9.2 | 140.8 | 140.2 | 4.2 | 4.4 | 88 | 90.2 | 11.8 | 9.5 | 0.7 | 0.6 |
| 8 | 9.6 | 9.7 | 149 | 150.8 | 4.6 | 4.8 | 90.4 | 100 | 14.8 | 12.5 | 0.8 | 0.7 |
| 9 | 10.3 | 10.5 | 150.2 | 152 | 5.2 | 5 | 90.6 | 102 | 17.2 | 14.8 | 1.2 | 0.9 |
| 10 | 10.6 | 10.3 | 144.8 | 150 | 4.5 | 4.8 | 90.3 | 107 | 16.5 | 11.8 | 0.9 | 0.8 |
| 11 | 11.4 | 11.4 | 138 | 145 | 3.9 | 4.1 | 100.7 | 111 | 22.6 | 17.3 | 1.2 | 0.8 |
| 12 | 11.2 | 11 | 140 | 142.8 | 4.3 | 4.7 | 100.2 | 108 | 20.8 | 18.3 | 1.4 | 0.9 |
| 13 | 9.6 | 10.2 | 139 | 141.8 | 5.2 | 5.5 | 98 | 106 | 17.6 | 12.8 | 1.2 | 0.8 |

Normal values: calcium 8.7–11.8 mg/dL; sodium 140.3–153.9 mEq/L; potassium 3.8–5.6 mEq/L; glucose 61.9–108.3 mg/dL; urea 8.8–25.9 mg/dL; creatine 0.5–1.6 mg/dL.

TABLE 4
Nutritional Parameters

| Experimental Animals No. | Pre-operative Albumin g/dL | Post-operative Albumin g/dL | Pre-operative Protein G/dL | Post-operative Protein G/dL |
|--------------------------|----------------------------|-----------------------------|----------------------------|-----------------------------|
| 1 | 2.7 | 3.2 | 4.2 | 4.8 |
| 2 | 2.5 | 3.7 | 5.3 | 6.2 |
| 3 | 2.8 | 4.2 | 5.6 | 7.2 |
| 4 | 3.0 | 3.8 | 5.8 | 7.0 |
| 5 | 3.2 | 4.2 | 6.2 | 7.4 |
| 6 | 2.8 | 3.8 | 5.5 | 7.3 |
| 7 | 2.5 | 3.7 | 5.3 | 6.8 |
| 8 | 2.6 | 3.6 | 5.6 | 7.1 |
| 9 | 3.2 | 4.5 | 5.8 | 7.8 |
| 10 | 2.5 | 3.7 | 5.5 | 7.2 |
| 11 | 2.4 | 3.5 | 5.2 | 6.8 |
| 12 | 2.8 | 4.2 | 5.7 | 7.8 |
| 13 | 3.3 | 3.8 | 6.2 | 7.4 |

Normal values: albumin 2.6–4.0 g/dL; total protein 5.5–7.5 units.

mals in which these measurements were carried out. For this reason, no reflux of duodenal contents was observed fluoroscopically in any animal. The radiographic (Fig. 4) and fluoroscopic studies showed preservation of both the sphincteric mechanism of the ileocecal valve in its new position and of the peristalsis of the stomach. Preoperative and postoperative gastric emptying times, measured until the stomach was virtually free of barium, were similar in all animals (Table 7) (13). No abnormal findings were noted in either the macroscopic (Fig. 5) or histological examinations.

Discussion

The results of the present study demonstrate that when the pyloric sphincter of the dog is replaced with the ileocecal valve, the sphincteric mechanism of the ileocecal valve is preserved in its new position. This serves to prevent rapid gastric emptying as well as duodenal reflux. Moreover, Dozois and Kelly have reported that gastric emptying time of dogs with distal antrectomy did not differ significantly from that of control animals (14).

The consequences of removing the ileocecal valve from its normal location (impairment of

TABLE 5
B.A.O. Measurements

| Experimental Animal No. | Hourly pre-operative B.A.O. * mEq/L | Hourly post-operative B.A.O. ** |
|-------------------------|--|---------------------------------|
| 1 | 6.7 | 4.5 |
| 2 | 6.5 | 3.8 |
| 3 | 6.4 | 3.0 |
| 4 | 6.4 | 2.8 |
| 5 | 6.5 | 3.2 |
| 6 | 6.6 | 4.0 |
| 7 | 6.5 | 3.4 |
| 8 | 6.6 | 3.5 |
| 9 | 6.7 | 4.2 |
| 10 | 6.6 | 4.0 |
| 11 | 6.5 | 3.8 |
| 12 | 6.6 | 4.6 |
| 13 | 6.4 | 3.8 |

Normal range: 6.4–6.8 mEq/L.

* Mean \pm S.D. = 6.07 ± 0.1 ; ** 3.73 ± 0.54 ; $p < 0.001$ (paired t-test)

the absorptive function of the small intestine and loose stool), can be managed effectively with medical treatment (12), in contrast to the clinical difficulties which often arise following gastrectomy.

Vitamin B₁₂ deficiency is expected in the long term, and this should be considered as one disadvantage of the procedure. However, B₁₂ deficiency can easily be corrected with periodic B₁₂ injections. Reduced B.A.O. follows distal gastrectomy, but this could be helpful in preventing ulceration at the anastomotic site.



Fig. 4. Radiologic depiction of ileocecal valve function in one of the experimental animals. The fluctuations in the opening of the ileocecal valve confirm preservation of its sphincteric mechanism. Preservation of peristalsis of the stomach is also shown. The ileocecal valve is marked with arrow 1; the coloduodenal anastomosis is marked with arrow 2; and the ileogastric anastomosis is marked with arrow 3.

Conclusion

The healthy condition of the dogs after the procedure, the normal blood and serum laboratory

TABLE 6
*Intraoperative Intraluminal Parameters **

| Experimental Animal No. | Pre-transposition | | Post-transposition | |
|-------------------------|-------------------|----------------|--------------------|----------------|
| | Intrailiac | Intracolonic | Intragastric | Intraduodenal |
| 1 | 14 | 31 | 12 | 28 |
| 2 | 25 | 38 | 20 | 35 |
| 3 | 16 | 30 | 15 | 32 |
| 4 | 20 | 40 | 18 | 37 |
| 5 | 13 | 27 | 10 | 25 |
| 6 | 20 | 36 | 17 | 34 |
| 7 | 14 | 32 | 14 | 30 |
| 8 | 15 | 31 | 13 | 28 |
| 9 | 14 | 34 | 15 | 33 |
| 10 | 13 | 28 | 10 | 23 |
| 11 | 14 | 29 | 12 | 26 |
| 12 | 16 | 30 | 15 | 30 |
| 13 | 21 | 40 | 18 | 38 |
| Mean \pm S.D. | 16 ± 3.8 | 32.8 ± 4.4 | 14.5 ± 3.1 | 30.7 ± 4.6 |

* In 3 animals, mean *in situ* intragastric and intraduodenal pressures prior to the surgical transposition of the ileocecal valve were 12 and 19 cm respectively.



Fig. 5. Macroscopic presentation of the area of the ileocecal valve with the adjacent duodenal and gastric segments in one of the experimental animals. The coloduodenal anastomosis is marked with arrow 1 and the ileogastric anastomosis is marked with arrow 2. The clamp shows the position of the cecum.

TABLE 7
Gastric Emptying Time

| Experimental Animal No. | Preoperative | Postoperative |
|-------------------------------|--------------|---------------|
| | min | min |
| 1 | 60 | 60 |
| 2 | 80 | 70 |
| 3 | 70 | 65 |
| 4 | 80 | 75 |
| 5 | 45 | 45 |
| 6 | 70 | 70 |
| 7 | 50 | 50 |
| 8 | 60 | 60 |
| 9 | 45 | 40 |
| 10 | 40 | 40 |
| 11 | 50 | 45 |
| 12 | 80 | 80 |
| 13 | 90 | 90 |

Normal range: 30–60 minutes (13).

values, the radiographic and fluoroscopic studies, and the macroscopic and histological examinations all showed that this technique is feasible and effective in the animals studied. Because the

anatomy and physiology of the alimentary tract in the dog is similar to that of humans, this method might provide better clinical outcomes following gastrectomy than those achieved with the present-day techniques. This method might also be useful in relieving postgastrectomy complications which do not repond or have not responded to conservative treatment.

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