Reconstruction of the Common Bile Duct with an Acrylate-Amide Prosthesis *

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DESPITE many ingenious experimental attempts, efforts at bridging a gap in the common bile duct have been nearly uniformly unsuccessful. While it is virtually always possible to reconstruct a channel between a bile carrying remnant of the biliary tree and the gastro-intestinal tract in man, stricture at the site of anastomosis, cholangitis, and choledocholithiasis commonly ensue. Relatively satisfactory bile duct reconstruction has been limited to those cases in which direct anastomosis of proximal to distal common duct has been possible.

Previous experimental attempts to bridge a gap in the common bile duct include variations of four basic approaches: free tissue grafts (homogenous and autogenous), vascularized tissue grafts, anastomosis of the proximal duct to the gastro-intestinal tract by direct (choledochoduodenostomy) or indirect (Roux en Y) methods, and insertion of prosthetic materials. Free tissue grafts of veins, arteries, bile duct, ureters, skin grafts or fascia have been totally unsatisfactory.[11, 12, 14–16, 19, 20] Split thickness skin tubes, veins, etc. vascularized by subcutaneous or omental implantation prior to use in bridging a gap in the common bile duct has been somewhat more promising, but the common complications of stricture, concretion, and cholangitis have been the rule rather than the exception.[1, 13, 18, 21] Direct anastomosis of the proximal common bile duct to the gastro-enteric tract, with and without T-tubes as internal splints, has provided the only reasonably reliable results in man. These technics, utilized by the most experienced surgeons, result in no more than 60 to 70 per cent satisfactory bridging of the gap.[3] Results obtained with these methods by the average surgeon are considerably less satisfactory.

Development of prosthetic tubes for bridging gaps in blood vessels have stimulated experimental use of these materials for common bile duct reconstruction.[2, 6, 7, 9, 10, 18] Common bile duct grafts made of Teflon have been reported to be functioning satisfactorily as long as one year after implant, without evidence of obstruction or impairment of liver function.[6] These encouraging results prompted a study of a previously reported acrylate-amide vascular prosthesis,*** modified for use in bridging a gap in the common bile duct.[5]

Acrylate-Amide Common Bile Duct Prosthesis

The basic attributes of tissue acceptance without toxicity or appreciable foreign body reaction, easy handling, autoclava-

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*** Developed by the U. S. Army Prosthetic Research Laboratory.

bility, and capability for *biologic fixation*, demonstrated by the acrylate-amide vascular prosthesis are equally important in common bile duct prostheses.

Previously reported failures due to duct obstruction from granulation tissue or scar formation at the anastomotic site and from slough of the prosthesis into the bile duct lumen suggested the need for improvement in methods of graft fixation. Fixation by ingrowth of fibrous tissue into the interstices of a porous prosthetic device (biologic fixation) obviates the necessity of reliance on through-and-through sutures for fixation of bile duct grafts. Three types of acrylate-amide tubes for common bile duct replacement have been designed, each successive model incorporating improvements suggested by experimental trials. Acrylate-amide elastomer is a polyacrylic ester rubber; a terpolymer of butyl acrylate, methyl methacrylate and methacrylamide with ethyl methacrylate filler. All of the grafts were designed and fabricated in the Army Prosthetic Research Laboratory.

The first (soft design) acrylate-amide prosthesis (Fig 1, top) consisted of an impervious tube of the terpolymer intimately bound to an outer veneer of foam. Pore size of the outer foamed layer was too small to permit adequate ingrowth of fibrous tissue and true *biologic fixation* did not occur (Fig. 2). Lack of rigidity of this type tended to produce *kinking* and mechanical obstruction of the common bile duct.

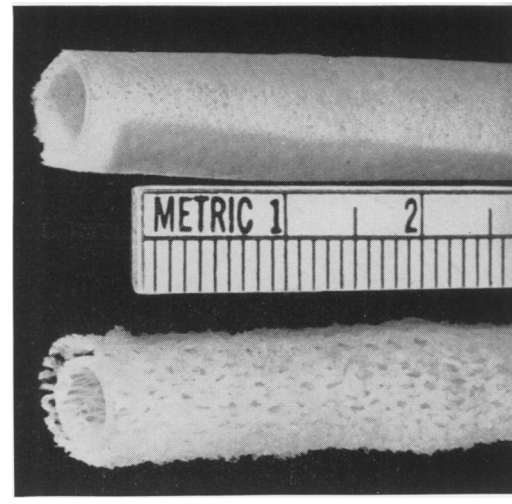

FIG. 1. Top: Soft design acrylate-amide common duct prosthesis. Bottom: Rigid design, Dacron mesh imbedded in inner impervious lining increasing rigidity and enlarged pore size of the outer layer for improved fibrous tissue ingrowth.

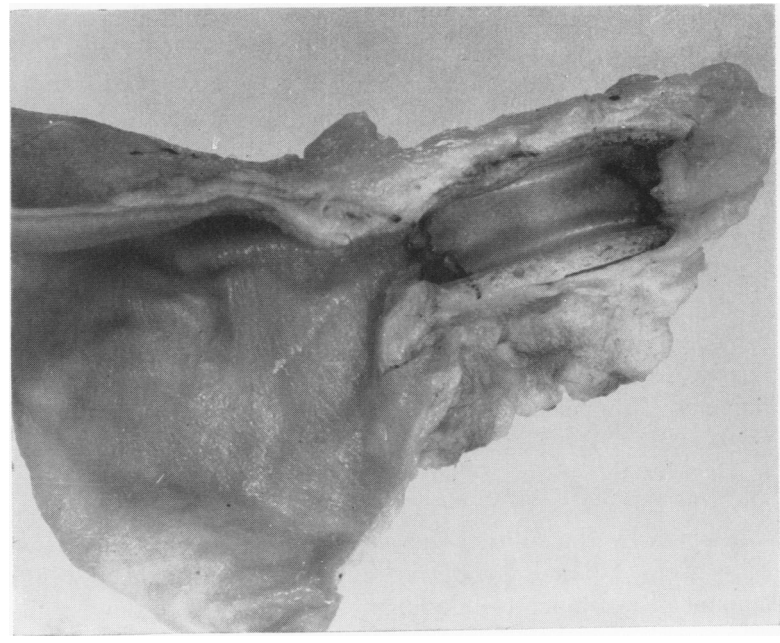

FIG. 2. Note lack of ingrowth or *biologic fixation* by fibrous tissue surrounding the prosthesis. Marked proximal duct dilatation and total distal occlusion by scar.

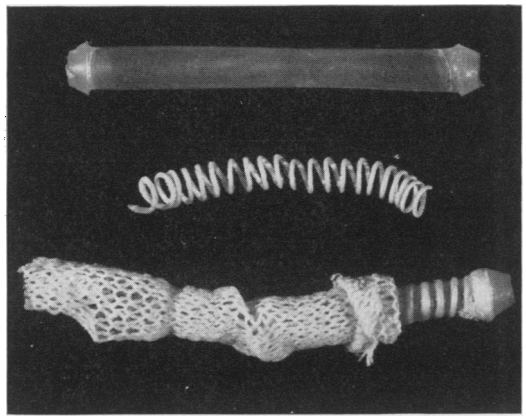

FIG. 3. Combined design permitting implantation without sutures entering the lumen and external support of the suture line.

The second (rigid design) which was developed (Fig. 1, bottom) was designed to overcome the problem of small pore size and subsequent lack of *biologic fixation* and the tendency to *kink* after implant. Coarse Dacron mesh was imbedded in the inner impervious tube and the outer layer fabricated from similar mesh impregnated with acrylate-amide polymer. Penetration of the lumen by sutures was still necessary for insertion of the graft.

The third (combined design) provides a more rigid tube that will not collapse or kink but still retains flexibility. This was accomplished by utilization of a coil or helical structure to support the impervious inner wall. The coil was made from 300 denier Dacron thread impregnated with a thermosetting acrylic resin which was attached to the acrylate-amide tube.

To preclude the necessity for penetrating the lumen by the suture needle, the ends of the tube were tapered and a shoulder provided with rather loose Dacron-Fluflon, lightly impregnated with acrylate-amide polymer. This permits easy penetration by the needle and at the same time prevents tearing by the suture. This suturing ring obviates the necessity for penetration into the lumen by the suture. The ends of the tube were tapered permitting the least amount of resistance to bile flow.

Finally the whole prosthesis was covered with a coarse tubular Dacron mesh impregnated with acrylate-amide polymer. The ends of the mesh were allowed to extend beyond the tube, and slit to allow the operator to draw the mesh back over the tube during insertion and then draw it back over the anastomosis followig insertion (Fig. 3).

Methods

Experimental animals were 10 to 18 kg. mongrel dogs operated under Nembutal anesthesia through a midline incision. The distal half of the common bile duct was dissected from the gastrohepatic ligament and a segment of duct varying from 1.5 to 3.5 cm. was resected. Diligent search for accessory bile ducts was made with division and ligation of all such ducts encountered. The prosthesis was sutured between the cut ends of the common duct by continuous through and through 6-0 silk suture. No intraluminal splints were used. The grafted area was covered with omentum, and the abdomen closed without drainage. A single intramuscular injection of procaine penicillin was given immediately postoperatively and regular dietary intake permitted as soon as recovery from anesthesia was complete. All animals were closely observed for postoperative jaundice and weight loss. Serial alkaline phosphatase and serum bilirubin levels were determined in all dogs.

Technical Problems

The small caliber of the common bile duct in dogs has prompted other investigators to employ cholecystectomy or ligation or the common bile duct prior to common duct grafting in an effort to increase the diameter of the duct. Preliminary attempts to increase the diameter of the common bile duct by distal ligation 10 to 14 days prior to insertion of the graft in our hands was met by high morbidity and mortality. Accordingly, all of the dogs in this report

TABLE 1. *Length of Survival and Cause of Death 33 Bile Duct Grafts*

Survival	No. Dogs	Death Related to Graft	Principle Causes of Death
1 Week or less	7	Yes—4 No—3	Suture line leak—peritonitis Pneumonia—heart worms—Aspiration
1 Month or less	7	No	Pneumonia (distemper)
2–4 Months	12	No	Pneumonia (distemper)
4–8 Months	3	No—2 Yes—1	Malnutrition Duct obstruction
8–12 Months	2	No	Pneumonia-unknown
12–24 Months	2	No	Malnutrition-sacrificed
Totals	33	5	—

had primary grafting of the common bile duct without any prior operation designed to increase the diameter of the duct. Early postoperative mortality was limited to the first few dogs operated upon and did not occur later in the series, after suitable operative technics had been developed.

Further technical difficulties were encountered as a result of discrepancies between the bile duct lumen and the graft, since only one diameter (5–6 mm.) prosthesis was available. The lumen of the bile duct was approximately equal in diameter to that of the graft in 25 per cent, smaller than the graft lumen in 50 per cent, and variably disproportionate in the remainder.

Results

Thirty-seven dogs had replacement of resected segments of the common bile ducts by the soft design acrylate-amide prosthesis. Seven dogs died within the first postoperative week. Four from peritonitis secondary to suture line leaks or tearing of the soft prosthesis by the suture. Three died from causes unrelated to the bile duct graft (pneumonia, heart worms, acute gastric dilatation). Seven dogs died after the first postoperative week, but within one month of operation. All seven died of histologically proven pneumonia (distemper), without gross or histologically demonstrable difficulty related to bile duct reconstruction. Nineteen dogs died one to 24 months post grafting. One of these was sacrificed 21 months postoperatively for gross and histologic study (Table 1). Only one death in this group could be related to the common duct graft. Total obstruction of the duct with marked proximal dilatation in this dog resulted from granulation tissue at the site of the distal anastomosis eight months after grafting (Fig. 2). This animal was the only one in the series who became clinically jaundiced at any time after common bile duct replacement.

Four animals are still alive 19 to 31 months after grafting. Duration of survival, evidence of hepatic dysfunction, and present condition are summarized in Table 2. Serum bilirubin levels were within normal range in all animals with the exception of two animals who demonstrated a rise above normal in the first postoperative week and the dog with total duct obstruction eight months after graft. Serial alkaline phosphatase levels revealed a marked rise in all animals between the second and seventh postoperative day, returning toward normal by the second week, and within normal range by the fourth postoperative week. Mean alkaline phosphatase levels at intervals up to two and a half years post grafting are illustrated in Figure 4.

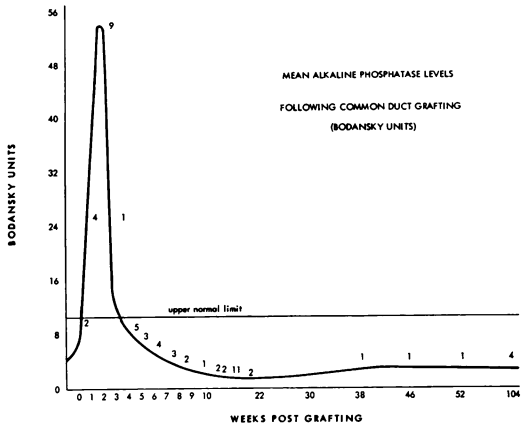

FIG. 4. Mean alkaline phosphatase levels post common duct graft. Numbers along the curve represent the number of dogs studied at each period postoperatively.

Dilatation of the common bile duct proximal to the graft of variable degree was present in all dogs, ranging from minimal (Fig. 5) to marked (Fig. 6). No correlation between extent of dilatation of the proximal duct, alkaline phosphatase, serum bilirubin or histologic appearance of the liver was evident. Failure to demonstrate concretions within the common bile duct in any of the experimental animals is in contrast to the experience of others.

TABLE 2. *Time Post Implant and Condition of Survivors*

Survival (Mo.)	Evidence of Liver Disease	Condition	Totals
31	No	Poor	1
22	No	Fair	1
21	No	Fair	1
19	No	Fair	1
Totals	0	—	4

Histologic examination of the major organs of all animals dying after common bile duct replacement was done. Causes of death as listed in Table 1 were established by this method. Only two animals had histologic evidence of liver disease. One dog dying nine weeks after graft revealed microscopic findings which could not be differentiated from those resulting from canine hepatitis. Gross examination revealed a patent common duct in this dog. The other, dying at eight months with total obstruction of the duct (previously mentioned) was shown to have marked biliary cirrhosis.

Normal biliary ducts, hepatic cellular structure, minimal inflammatory cell infil-

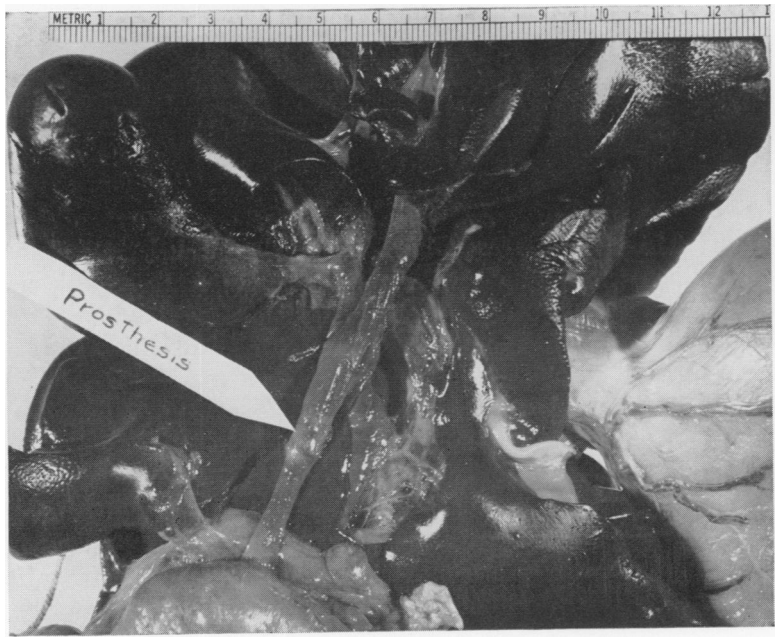

FIG. 5. Minimal proximal dilatation of the common duct, 15 weeks post implant. (Alkaline phosphatase 2.5 B.U.)

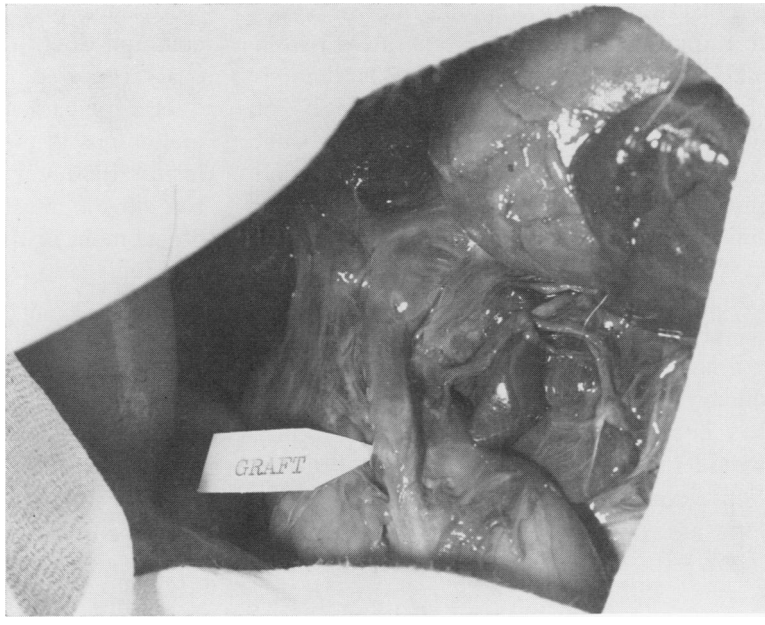

FIG. 6. Marked proximal dilatation of the common duct four months post implant. (Alkaline phosphatase 2.1 B.U.)

tration, and absence of biliary stasis was seen in all other animals. These findings are demonstrated in microscopic sections of a dog sacrificed 21 months after grafting (Fig. 7). Unfortunately, histologic examination of the site of anastomosis was impossible due to the marked swelling of the impervious inner lining of the graft during the preparation of histologic sections which caused total disruption and fragmentation of the surrounding tissues.

These results in animals following common bile duct replacement by the soft type prosthesis, despite its disadvantages, indicate that far better results can be achieved with modifications of this original design. Ten dogs have had common bile duct grafts of the rigid type and four with the combined type of acrylate-amide prosthesis. All of these dogs have been followed less than three months since grafting. Results to date in these animals are most encouraging, but implants have been in place for too short a period for valid conclusions.

Discussion and Conclusions

Survival of 11 of 37 dogs with common bile duct grafts for more than four months, without clinical or laboratory evidence of impaired liver function, stimulates further efforts in development of the *ideal* common bile duct prosthesis. These results are even more encouraging considering that seven dogs died within the first postoperative week (4 from graft failure) while operative technics were being developed, and only one dog died subsequently from complications related to the graft. Long-term survival of four dogs (19–31 months) still living at the time of this report is apparently a unique experience in experimental common bile duct replacement studies.

The fact that the prosthesis utilized in this study (soft design acrylate-amide) failed to permit *biologic fixation* of the graft, required through-and-through sutures for insertion and was of inappropriate diameter in 75 per cent of the animals implanted, makes the results even more significant. Even better results are anticipated in studies of rigid and combined design acrylate-amide common duct prosthesis which permit *biologic fixation,* are of appropriate size, and can be inserted without through-and-through suturing at the site of anastomosis.

Dilatation of the common duct proximal to the graft, and early postoperative rise in alkaline phosphatase, which was demonstrated in all dogs, would seem to be of little importance in experimental bile duct replacement since clinical, laboratory, and histologic findings were within normal limits despite these findings. Similar rise in serum alkaline phosphatase have been demonstrated following mobilization of the distal common duct without grafting.[17] Abnormalities of hepatobiliary function secondary to bile duct replacement in goats has been reported.[4] Results of this study would indicate that hepatobiliary dysfunction does not occur in dogs followed as long as 31 months post bile duct replacement.

Absence of concretions in the proximal common duct, a frequent finding in previously reported experimental common bile duct replacements, may be explained by meticulous attention to preservation of the inside diameter of the common duct at the site of anastomosis, prevention of encroachment of the lumen by the prosthesis, the inert nature of acrylate-amide in tissues and by the absence of stasis in the common bile duct.

Summary

Three types of tubular acrylate-amide prostheses designed to permit successful common bile duct replacement in dogs are described.

The original type (soft) prosthesis was

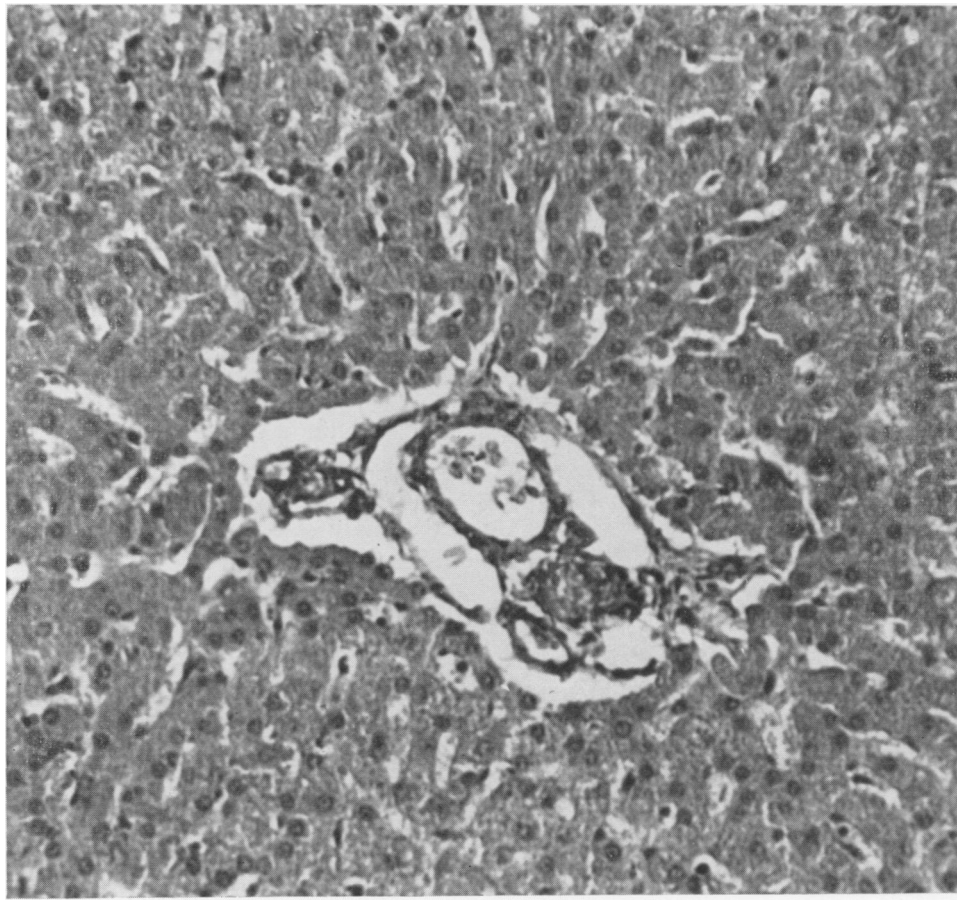

FIG. 7. Photomicrograph (60 ×) of the liver at sacrifice 21 months post common bile duct graft.

used to reconstruct excised segments of the common bile duct in 37 dogs. Technical problems of discrepancies in size between duct and prosthesis are discussed.

The concept of *biologic fixation* of prosthetic materials was applied in design of the bile duct grafts.

Nineteen of 37 dogs with primary bile duct grafts survived more than one month. Four of these are alive 19 to 31 months post grafting. Only five dogs in the entire series died of causes related to the common duct graft.

Significance of dilatation of the common duct proximal to the graft, and elevated serum alkaline phosphatase in the early post graft period are discussed.

Absence of histologic evidence of hepatic dysfunction in all but one dog and absence of concretions in the ducts of all dogs suggest that the methods employed are most encouraging.

The rules concerning the handling of experimental animals as promulgated by the National Society for Medical Research were observed in this study.

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