THE INFLUENCE OF STRUCTURE AND FUNCTION IN THE SURGERY OF THE BILIARY TRACT

Arris and Gale Lecture on 7th April 1970

by

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AN ACCURATE KNOWLEDGE of anatomy is essential in biliary tract surgery. The studies which form the basis of this lecture were undertaken in order to examine the surgical implications of a number of new concepts in biliary tract anatomy and physiology. Attention was directed to factors which would decrease the risk and improve the effectiveness of biliary operations.

ANATOMY

METHODS OF STUDY

The biliary apparatus was studied in 160 cadaveric specimens and with the cholangiograms of 200 suitable patients by the following methods:

1. *Dissections:* Dissections were made of the biliary tract and of the related blood vessels and viscera.

2. *Casts:* The biliary and the vascular pedicles of cadaveric livers were injected with coloured polyester resins which rapidly solidified, and then the liver was corroded away with concentrated hydrochloric acid, leaving a resin cast of the injected structures. These corrosion casts were used to study the distribution of bile ducts and blood vessels within the liver. Casts were also made of the cadaveric common bile duct, which was injected at a physiological pressure, in order to reproduce physiological conditions[12, 13].

3. *Dye injection:* Dyes, such as methylene blue and eosin, were injected into the various principal and secondary biliary and vascular pedicles of the liver. These dyes then diffused into the liver substance and outlined their areas of distribution.

4. *Cholangiograms:* Bile duct anatomy was studied with the use of operative cholangiograms and T-tube postoperative cholangiograms. The study of intrahepatic bile ducts was aided by oblique and lateral projections, which provided a stereoscopic view of the course of these ducts.

RESULTS AND APPLICATIONS

The results of these studies and their surgical applications are described in three main parts, namely, the proximal bile ducts, the cystic duct and proximal common bile duct, and the distal common bile duct.

Proximal bile ducts

Liver segments

The results support the recent concept which views the liver as a segmental organ[7, 14]. There are four principal liver segments, each segment being supplied exclusively by a branch of the hepatic artery, portal vein and bile duct (Fig. 1). The functional left lobe consists of the left medial and left lateral segments, and the functional right lobe consists of the right anterior and right posterior segments.

Mode of union of bile ducts

In each liver segment the small bile ducts unite, so that finally, that

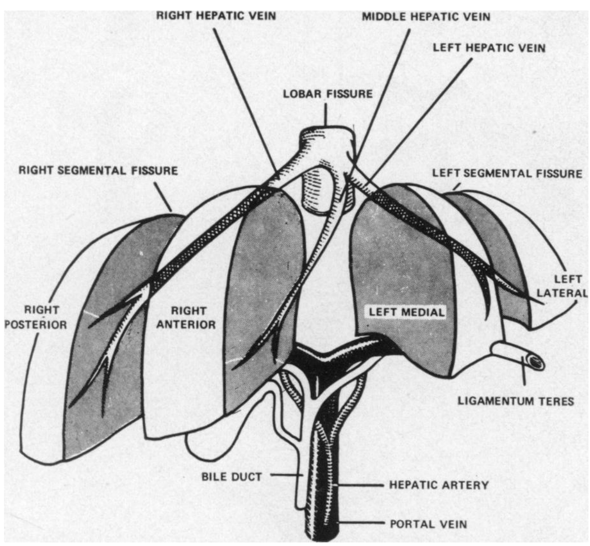


Fig. 1. A diagram of the liver segments.

segment is drained by one principal segmental bile duct. Only occasionally are there two bile ducts in one liver segment which do not unite to form a final common pathway. The modes of union of these ducts is subject to some variation.

Functional left lobe: The various modes of union of the two left lobe segments and their frequency are shown in Figure 2 (*a*). The most significant feature is that in all cases the final common pathway of biliary drainage for the left lobe of the liver is a single trunk, the left hepatic duct.

Functional right lobe: The modes of union of the two right lobe segments are shown in Figure 2 (*b*). In contrast with the left lobe, the right lobe is drained by the right hepatic duct in only three-quarters of the subjects. In the remaining quarter of subjects the right hepatic duct does not exist, and then the right anterior and right posterior bile ducts join the left hepatic duct independently.

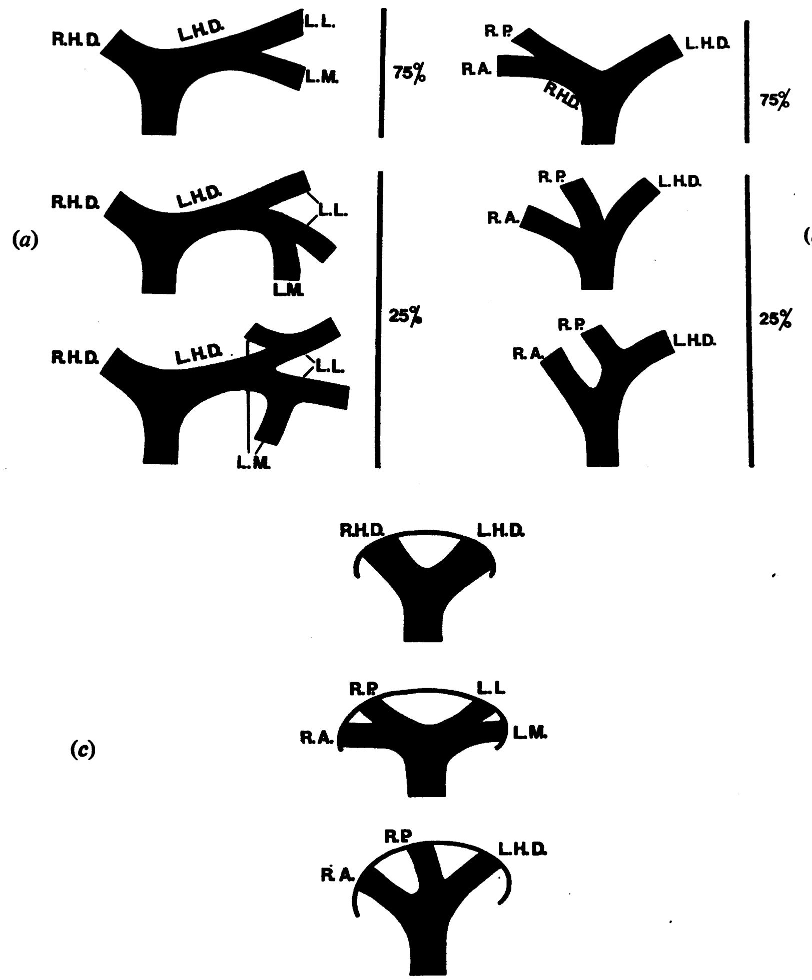


Fig. 2. (*a*) Patterns of union of the left segmental bile ducts. L.H.D.—Left hepatic duct. R.H.D.—Right hepatic duct. L.L.—Left lateral segmental bile duct. L.M.—Left medial segmental bile duct. (*b*) Patterns of union of the right segmental bile ducts. L.H.D.—Left hepatic duct. R.H.D.—Right hepatic duct. R.A.—Right anterior segmental bile duct. R.P.—Right posterior segmental bile duct. (*c*) Bile ducts which may be found outside the liver in different subjects. L.H.D.—Left hepatic duct. R.H.D.—Right hepatic duct. L.L.—Left lateral bile duct. L.M.—Left medial bile duct. R.A.—Right anterior bile duct. R.P.—Right posterior bile duct.

Bile ducts in the porta hepatis

For the purposes of access and exposure, it is important for the surgeon to know how much of the ductal system is outside the liver.

The common hepatic duct is always outside the liver in its entire length. Variable portions of the left and right hepatic ducts, and in a few subjects small portions of the principal segmental ducts, are also extrahepatic. In those subjects in whom the right hepatic duct is not present, parts of the right anterior and right posterior bile ducts are also extrahepatic (Fig. 2*c*).

In most cases the hepatic ducts unite close to their exit from the liver, and in only a few subjects do the bile ducts have a relatively long extrahepatic course, and therefore a low point of union.

Surgical applications

Liver resection: The segmental concept of liver anatomy has led to planned lobar and segmental liver resections, but this is outside the scope of the lecture.

Interpretation of cholangiograms: The identification of the principal segmental bile ducts and of the hepatic ducts in an operative cholangiogram may be of importance during biliary surgery, when dealing with intrahepatic lesions. Thus absence of filling, or the presence of a filling defect, is seen in patients with intrahepatic gall-stones, strictures, and intrahepatic tumours of the bile ducts.

Access, exposure and identification of bile ducts: The bile ducts which are relatively easy to expose surgically are the common hepatic duct, the right hepatic duct and the distal portion of the left hepatic duct. The proximal part of the left hepatic duct is frequently hidden by the pars umbilica portion of the left portal vein, from which it needs to be separated[8, 14]. The branches of the hepatic artery may overlie these ducts, but they can be separated by dissection.

The correct identification of bile ducts in the porta hepatis is of importance in planned segmental or lobar liver resections to ensure that the correct bile duct is ligated. Identification of these ducts is best performed by a combination of dissection and operative cholangiography.

Aberrant and accessory bile ducts: The surgical literature of the past is abundant with reports of so-called ‘ accessory ’ hepatic ducts, usually accessory right hepatic ducts. In the present study and in other recent work which recognizes the segmental concept of hepatic structure, instances of so-called ‘ accessory ’ hepatic ducts were not found[7, 14].

The type of arrangement which in the past was called an ‘ accessory ’ hepatic duct corresponds to the cases in which a right hepatic duct is not found. The surgeon encounters three ducts issuing from the liver, the left hepatic duct, the right anterior bile duct and the right posterior bile duct (Figs. 2*b* and *c*), and he calls one of the ducts an ‘ accessory ’ duct.

These ducts should not be called either ' accessory ' or aberrant. If more than two ducts are found arising from the liver, on no account should one be divided or ligated because serious consequences may follow, such as a biliary fistula, cholangitis and liver abscess.

Hepatic ducts entering the gall bladder or the cystic duct were not found by the author, nor by other workers in recent years who dissected cadaveric specimens[7, 8, 14]. In clinical practice such cases have been documented, but they were always associated with large gall-stones, fibrosis and induration of the porta hepatis[23, 10]. It is likely that these cases are secondary to erosion and obliteration of the bile ducts by gall-stones and by recurrent episodes of cholecystitis.

The last of these unusual ducts to be described is the subvesical duct[7, 8]. This slender bile duct was noted in 20% of cases by the author. It passes in the gall-bladder fossa towards the liver hilum and usually joins the right hepatic duct. It is probably an intrahepatic bile duct which comes

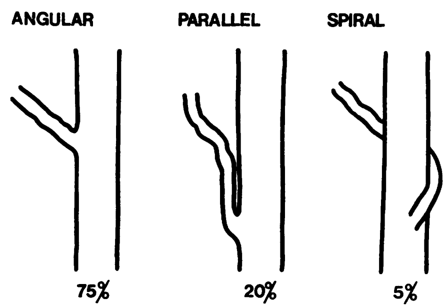


Fig. 3. Modes of union of the cystic duct with the common hepatic duct. Left—Angular union. Middle—Parallel union. Right—Spiral union.

to the surface of the liver due to the relative atrophy of liver tissue in the gall-bladder fossa during development[16]. Inadvertent division of this duct during cholecystectomy may be responsible for temporary post-operative biliary drainage.

Cystic duct and common bile duct

Course of the cystic duct

The demonstration of the course of the cystic duct is an essential and critical part of cholecystectomy. The cystic duct was found to join the common hepatic duct at some point of its course in the gastrohepatic omentum in 80% of cases. In 20% of cases it joined the bile duct in its retroduodenal or retropancreatic portion. Only occasionally does it open into the right hepatic duct.

The mode of union of the cystic duct with the common hepatic duct is accomplished in one of three ways: angular, parallel or spiral (Fig. 3).

Absence of the cystic duct was not seen in any of the present cases. Such cases have been documented at operation, but in all of them there was a large gall-stone in Hartmann's pouch[23, 19, 1]. These cases are regarded as acquired conditions secondary to erosion and obliteration of the ducts by the gall-stone and the associated inflammatory process.

A double cystic duct is excessively rare. If the surgeon encounters what seem to be two cystic ducts, one of the ducts is usually a hepatic bile duct running in close relationship with the cystic duct.

Bile duct injury during cholecystectomy

The majority of operative injuries to the bile ducts occur during cholecystectomy. These injuries have serious consequences, yet most are

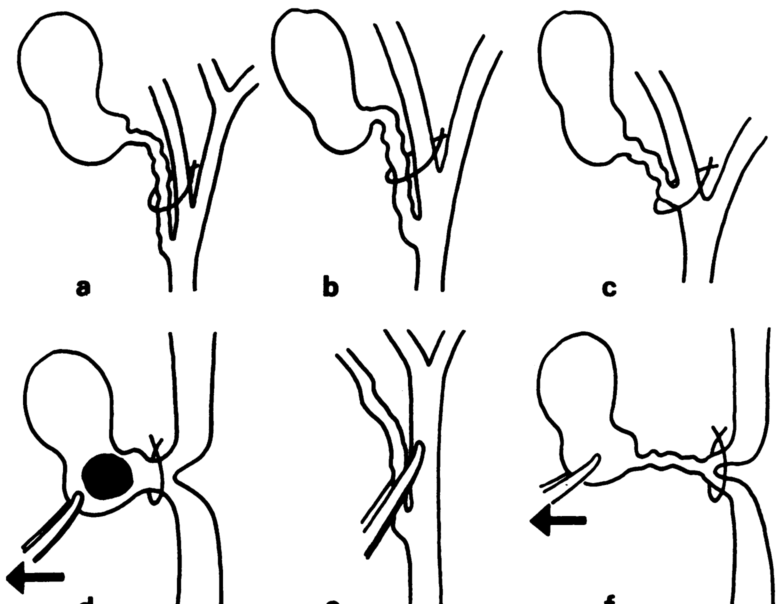


Fig. 4. The anatomical causes of bile duct injury during cholecystectomy. For details see text.

preventable with adequate surgical technique. In the present work only the anatomical causes of such injuries are presented. It is usually the manner of arrangement of the bile ducts which leads to a mistaken identification of the duct system by the unaware surgeon. The various anatomical causes of bile duct injury during cholecystectomy are illustrated in Figure 4.

If the right anterior segmental bile duct (Fig. 4*a*) or the right hepatic duct (Fig. 4*b*) are close to the cystic duct, they are prone to injury. In the uncommon case in which the cystic duct opens into the right hepatic duct (Fig. 4*c*) the latter may be damaged. If the cystic duct is absent and there is a gall-stone at the junction of the gall-bladder and common hepatic duct (Fig. 4*d*) the latter may be injured, particularly if excessive traction is applied to the gall-bladder. In the presence of parallel mode of union of the cystic duct (Fig. 4*e*) the common hepatic duct may be injured when a clamp is applied to the incompletely mobilized cystic duct[21].

Excessive traction on the gall-bladder with ' tenting ' of the common hepatic and common bile ducts leading to their inclusion in a clamp or ligature (Fig. 4*f*) has for a long time been believed to be a common cause of bile duct injury. Most bile duct injuries are more proximally situated,

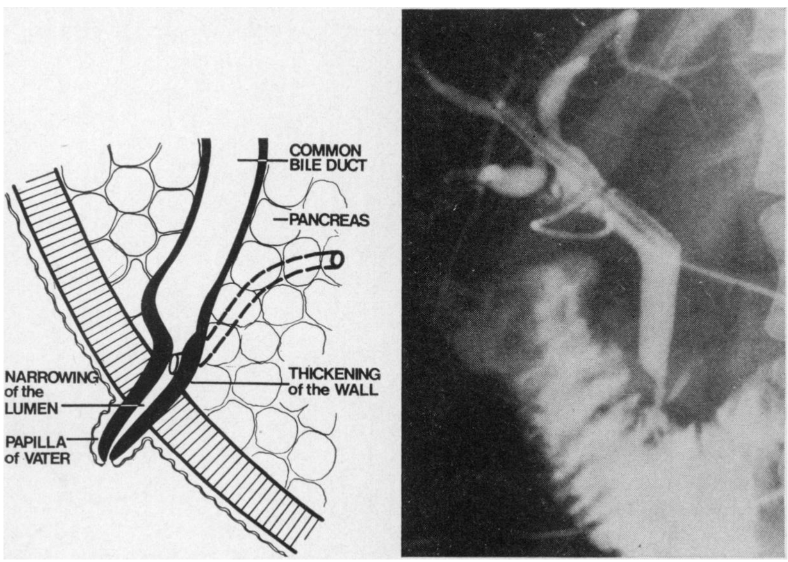


Fig. 5. (*a*) The anatomy of the distal common bile duct. In this case the pancreatic duct joins the common bile duct to form a ' common channel '. Note the thickened narrow distal segment of the bile duct. (*b*) T-tube cholangiogram showing characteristic abrupt narrowing of distal bile duct. In this case pancreatic duct opens independently into the duodenum. Note the presence of duodeno-pancreatic reflux.

and this mode of injury has probably been over-emphasized. It may be a factor in some cholecystectomies performed by the ' fundus-down ' method, or when the cystic duct is unduly short or absent.

Almost all of these injuries are preventable with a careful dissection and identification of the duct system, and with a precise separation of the cystic duct from the main bile ducts. Operative cholangiography may be a helpful aid to dissection.

Distal common bile duct

The external diameter of the common bile duct in any one subject is fairly uniform along its entire length. The lumen of the common bile duct is also uniform, but just proximal to its point of entry through the duodenal wall the lumen narrows abruptly. This narrowing is associated with a corresponding thickening of its wall, and this area is referred to as the sphincter of Oddi (Fig. 5*a*). The width of this narrow segment varies in different individuals, and in the same individual it varies with the phases of action of the sphincter of Oddi, but it is never wider than the common bile duct just proximal to it. The length of this narrow segment was found to vary between 7 mm. and 38 mm. in different subjects.

When there is a ' common channel ' between the bile duct and the pancreatic duct, the pancreatic duct always opens into the common bile duct at the level of this thickened segment (Fig. 5*a*).

The distal bile duct has a characteristic cholangiographic appearance, due to this abrupt narrowing of the lumen (Fig. 5*b*).

During the past 20 years this narrow distal segment has been repeatedly demonstrated in anatomic and cholangiographic studies, yet most current texts still describe a dilated distal segment, or a so-called ' ampulla ' of Vater[6, 9, 12, 18].

Surgical applications

If an operative cholangiogram outlines a narrow distal bile duct, this in itself should not be interpreted as evidence for the condition known as stenosis of the sphincter of Oddi, because this may well be the normal appearance of the bile duct.

When gall-stones are arrested in the lower end of the bile duct, they are usually just proximal to this narrow segment, rather than at the most distal end of the bile duct, as is sometimes supposed. The corollary is that if the surgeon is removing a gall-stone from the distal bile duct by the transduodenal route, he should not be surprised if he needs to divide the sphincter of Oddi before he reaches the gall-stone.

Occasionally the lumen of this narrow segment has an eccentric position in relation to the wide proximal portion. This situation may lead to difficulties in negotiating the distal common bile duct with probes during an exploration of the duct. Under these circumstances mechanical obstruction of the distal duct may be diagnosed in error. In others a false passage may be created into the duodenum if the probe is forcibly pushed through the bile duct above this narrow segment.

Occasionally a localized dilatation is found just proximal to the narrow segment, which resembles a pouch or a diverticulum. These diverticula are of surgical interest, because gall-stones may lodge in them[13]. These gall-stones may be overlooked at operation, particularly if operative cholangiography is not performed, because the instruments used during bile duct exploration slip past the stone.

PHYSIOLOGY

The study of biliary function is much more difficult than that of biliary anatomy. Our methods of investigation are relatively crude and gross. It is difficult to measure the various parameters of biliary physiology without interfering with the normal function.

METHODS OF STUDY

The mode of action of the sphincter of Oddi was studied by flow measurements and by cinecholangiography in patients who have had an exploration of the common bile duct, and who still had a T-tube in place. Altogether 106 studies were made on 32 patients.

1. *Flow studies:* Flow studies were performed with saline infused through the T-tube at a steady rate. Pressure changes were recorded on a manometer with its zero at the approximate level of the common bile duct in the supine patient. In the later studies, simultaneous cholangiography and cinecholangiography was also performed.

2. *Cinecholangiography:* T-tube cholangiography was performed using a ciné camera in some cases, while in others television controlled fluoroscopy was done, using an image intensifier which was coupled to a videotape recording device. In some of the later cases this was combined with pressure measurements of the bile duct.

Special attention was directed to two aspects of biliary tract function, namely, the mechanism of sphincteric action, and biliary-pancreatic reflux.

RESULTS AND APPLICATIONS

Mechanism of sphincteric action

Normal mode of action

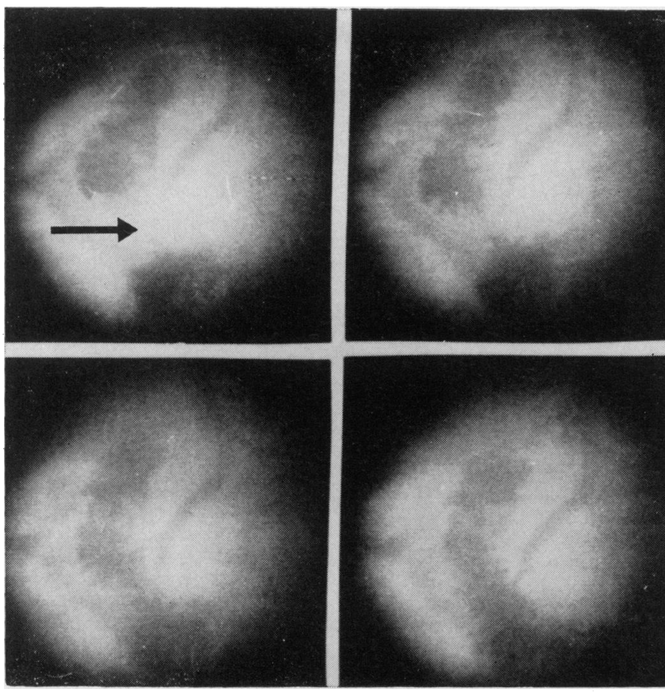
For many years scientific opinion debated the relative importance of the intrinsic bile duct musculature of the sphincter of Oddi and the musculature of the duodenum in the control of sphincteric action. It was found in the present study that the sphincteric and the duodenal musculature work together as a synergic unit, so that argument about their relative importance becomes meaningless. These findings are in accord with other recent workers who have performed cinecholangiography[2, 11].

Relaxation of the sphincteric muscle was found to be associated in time with relaxation of the adjacent segment of duodenal muscle and with the discharge of bile into the duodenum (Fig. 6). Contraction of the sphincteric muscle was associated in time with contraction of the adjacent duodenal musculature. The sphincteric area opens from above down, and closes from below up. There is thus a continuous synergistic cycle of contraction–relaxation–contraction.

Occasionally this orderly synergy breaks down even in patients who have an apparently normal biliary tract and normal duodenum. Thus the sphincteric region may be contracted, yet the adjacent duodenum is relaxed. At present there is no clear evidence to show that these alterations of sphincteric action are ever responsible for symptoms and for so-called functional disorders of the sphincter of Oddi.

Factors modifying sphincteric action

1. *Drugs:* Certain drugs cause a profound alteration of sphincteric



(Reproduced by courtesy of Dr. Robert E. Wise of Boston)

Fig. 6. Sequence of frames from cinecholangiography demonstrating duodeno-sphincteric synergy. Top left—Synchronous contraction of duodenum and sphincter of Oddi. Top right—Slight relaxation of duodenum and sphincteric area. Bottom left—Moderate relaxation of duodenum and sphincter. Bottom right—Complete relaxation of duodenum and sphincter.

and duodenal action. The administration of morphine was found to cause a spasm of the sphincteric region and a contraction of the adjacent duodenum. It is commonly believed that pethidine does not influence the sphincter of Oddi, but in fact it was found to have an effect similar to morphine.

The relaxation of sphincteric spasm produced by morphine and pethidine will resolve spontaneously, but it can be accelerated in most subjects by the inhalation of amyl nitrite.

2. *Sphincterotomy and sphincteroplasty:* Flow studies and cine-cholangiography were performed on 10 patients at intervals varying from 2 to 12 weeks after exploration of the bile duct and transduodenal sphincterotomy had been done. These investigations showed that there was no permanent decrease of sphincteric resistance produced by the operation and the mechanism of sphincteric action was not altered. Drugs such as morphine, pethidine and amyl nitrite had an effect entirely similar to that noted in patients who have an intact sphincter. These findings were in accord with the results of other recent workers[5, 15, 20]. Transduodenal sphincterotomy is of no value in augmenting biliary

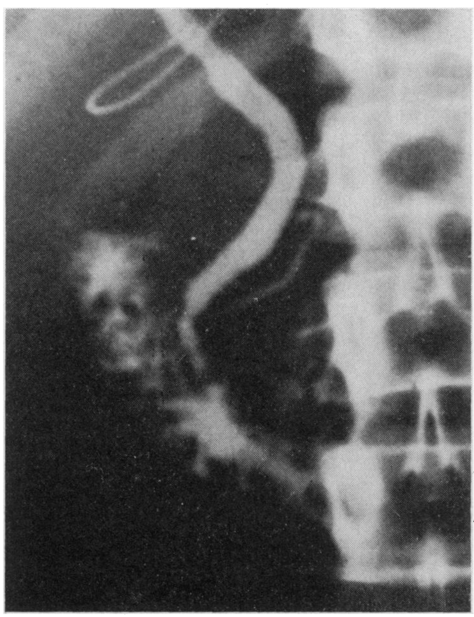


Fig. 7. T-tube cholangiogram demonstrating biliary-pancreatic reflux in the presence of a ' common channel '. Note pancreatic duct opens into the thickened distal portion of the bile duct.

dynamics, as suggested in the past for the treatment of chronic pancreatitis and for the treatment of hypertonic states of the sphincter of Oddi.

Transduodenal sphincteroplasty is a more extensive operation in which the sphincter is divided and the bile duct mucosa is sutured to the duodenal mucosa. The effect of this operation was tested in 4 patients, which included two patients who had a transduodenal sphincteroplasty some time prior to this second operation in which only bile duct exploration and T-tube insertion was performed. The flow studies showed that the resistance of the sphincter was permanently lowered, but the sphincteric area still opened and closed in a way similar to the intact sphincter.

Biliary-pancreatic reflux

The mechanism of reflux

There are few concepts in surgery which have stimulated greater interest than the proposition that bile can reflux into the pancreatic duct under certain circumstances.

Reflux was found to be in part dependent on bile duct pressure, because it was uncommon to find reflux during cinecholangiography when bile duct pressure was less than 20 cm. of water. It is unknown how often pressures of this order are present under physiological conditions, nor is it known what pressure is generated in the bile duct during a contraction of the normal gall-bladder. However, reflux was noted on a few occasions in this study within the range of physiological pressures[17]. Although the frequency of reflux under physiological conditions is uncertain, it is frequently noted during operative and postoperative T-tube cholangiography and was seen in approximately one-third of the present cases.

Reflux of contrast material into the pancreatic duct may be seen in subjects who have an anatomical common channel. Reflux occurs when bile duct pressure is relatively high, and at a phase when the sphincteric area is relaxed (Fig. 7). When the sphincteric region is contracted, reflux does not occur, and any contrast material which had already refluxed into the pancreatic duct remains there until the sphincter of Oddi relaxes again. It was noted earlier that in the presence of a ' common channel ' the pancreatic duct opens into the thickened distal portion of the common bile duct, which is the sphincteric area. Contraction of the sphincter will therefore separate the two channels, while relaxation will produce continuity. It follows that all agents which produce sphincteric spasm, such as morphine and pethidine, and all conditions which produce an obstruction within the sphincteric area will separate the common channel and will therefore oppose reflux. All agents which produce sphincteric relaxation will favour reflux.

These observations are clearly opposite to the original theories which held that pancreatic reflux occurs during spasm or during some other form of sphincteric obstruction[3].

When the common bile duct and the pancreatic duct open independently into the duodenum, another type of reflux is occasionally seen, and this is called duodeno-pancreatic reflux. Contrast material in the duodenum can be seen regurgitating into the duct of Wirsung during a phase of sphincteric and duodenal relaxation (Fig. 5*b*). When the sphincter of Oddi is contracted, further reflux does not occur, probably because the musculature around the pancreatic duct is incorporated as one structure with the sphincter of Oddi. Duodeno-pancreatic reflux is not influenced by bile duct pressure, and it appears to be an entirely physiological phenomenon.

Clinical significance of reflux

The reflux of bile into the duct of Wirsung was in itself regarded as a harmful phenomenon in the past, because this was believed to be an aetiological factor in pancreatitis. It was also thought that reflux was potentiated by sphincteric obstruction, such as gall-stones, stenosis or spasm of the sphincter of Oddi. For the relief of this supposed harmful reflux, sphincterotomy of the sphincter of Oddi was recommended[3].

These views can now be seriously challenged. First, reflux in itself does not appear to be harmful and has been produced on innumerable occasions during cholangiography without ill effects. In the presence of a common channel it probably occurs on occasions under physiological conditions. Duodeno-pancreatic reflux certainly appears to be a purely physiological phenomenon. Secondly, spasm or obstruction of the sphincteric area opposes rather than favours reflux. Thirdly, trans-duodenal sphincterotomy does not alter the dynamics of bile flow. Indeed, the uniformly good results of sphincterotomy for chronic pancreatitis reported by early workers have not been reproduced in more recent series[4, 20, 22].

ACKNOWLEDGEMENTS

This work, which was carried out in three continents during the past five years, could not have been done without the help of many of my colleagues who have generously allowed me to use clinical cases and post-mortem material for study, have conducted the radiological investigations, and offered me the benefit of their wide clinical experience. In particular I wish to thank Mr. R. A. V. Lewys Lloyd, late Senior Surgeon at St. Olave's Hospital, London; Dr. Jane Fullerton, Consultant Pathologist, St. Olave's Hospital, London; Dr. Kenneth W. Warren, Chief of Surgery, Lahey Clinic, Boston; Dr. Robert E. Wise, Chief of Radiology, Lahey Clinic, Boston; Professor W. S. C. Hare, Professor of Radiology, University of Melbourne; Professor E. W. Gault, late Professor of Pathology, Royal Australasian College of Surgeons; and Mr. R. D. Marshall, Surgeon, Prince Henry's Hospital, Melbourne.

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ELECTION TO THE COUNCIL, 1970

ON THURSDAY, 2ND JULY 1970, Mr. Reginald S. Murley and Mr. Walpole S. Lewin were elected Members of the Council of the College.

The result of the Poll was as follows:

Elected	*Votes*
MURLEY, Reginald Sydney (St. Albans City Hospital and Royal Northern Hospital)	458
LEWIN, Walpole Sinclair (Addenbrooke's Hospital, Cambridge)	370
Not Elected	
RODGERS, Harold William, O.B.E. (The Queen's University of Belfast)	322
PARKS, Alan Guyatt (The London Hospital and St. Mark's Hospital)	300
HADFIELD, Geoffrey John (Stoke Mandeville Hospital, Aylesbury)	296
WELBOURN, Richard Burkewood (Royal Postgraduate Medical School)	273
NICHOLSON, William Frank, M.B.E. (Manchester Royal Infirmary)	269
BLACKBURN, Guy, M.B.E. (Guy's Hospital)	269
EASTCOTT, Hubert Harry Grayson (St. Mary's Hospital)	246
RAINS, Anthony John Harding (Charing Cross Hospital)	244
SHIPMAN, John Jeffrey (Lister Hospital and North Herts. and South Beds. Hospital, Hitchin)	242
ABEL, Keith Paterson (The Prince of Wales Hospital, Tottenham)	242
ZACHARY, Robert Bransby (Sheffield Children's Hospital)	241
COX, Robert, M.B.E. (Westminster Hospital)	208
MOORE, Thomas (United Manchester Hospitals)	204
COLLIS, John Leigh (United Birmingham Hospitals)	196
AYLETT, Stanley Osborn, M.B.E. (Westminster Hospital Teaching Group—Gordon Hospital)	195
STIDOLPH, Neville Edsell (Whittington Hospital)	195
HORTON, Robert Elmer, M.B.E. (United Bristol Hospitals)	177
NASH, Denis Frederic Ellison (St. Bartholomew's Hospital)	171
GOUREVITCH, Arnold, M.C., T.D. (United Birmingham Hospitals)	162
SAMES, Christopher Patrick (Royal United Hospital, Bath)	161
JONES, Clifford David Phillips, M.B.E. (Sheffield Royal Infirmary and Hospital)	125
MOTTERSHEAD, Sidney (Tees-side Group Hospitals)	117

In all 2,963 Fellows voted, and in addition 43 votes were found to be invalid.

Fellows are again reminded of the importance of having their voting envelopes signed and witnessed, in order that their votes shall not be wasted by being declared invalid.