

THE MORPHOLOGY
OF THE
MAIN BILE DUCTS
WITH SPECIAL REFERENCE TO
THEIR MUSCULATURE.

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T H E S I S

FOR THE DEGREE OF

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Presented by

J. H. LOUW, M.B., Ch.B.,

1946.

ERRATA

- Page 41 Heading to Table 6 should read "Condition of the Gall Bladder in Patients Operated upon for Obstructive Jaundice and in Whom Chronic Pancreatitis was Found".
- Page 124, lines 23 and 24 "At the same time" should read "while the lumen of the bile ducts is being re-established".
- Page 137 Fig.45 and Page 139 Fig. 46 "Gap" should read "Interval".
- Page 157 et seq. "Supraduodenal" should read "Extramural" throughout the section on comparative anatomy.
-

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INTRODUCTION.

— 1 —

INTRODUCTION.

A thorough search of the English, American and Continental literature shows that there is no comprehensive treatise on the form and structure of the main bile ducts.

Numerous contributions on different aspects of the subject are constantly being added to the literature. Reading these articles, which are widely-scattered throughout the literature, indicates the necessity for integration and clarification of the various facts reported. Important anatomical facts are not well-known; opinions on the musculature of the bile ducts differ; and the factors that have influenced and determined the form and structure of the human bile ducts are but poorly understood.

This thesis seeks to correlate, clarify and present in compact form the findings of various investigations on the form and structure of the main bile ducts. Particular attention is devoted to observations on the musculature of the ducts.

While the main ducts form the principal theme of this study, the rest of the extrahepatic biliary system receives such attention as is thought necessary to produce a logical and balanced understanding of the subject.

The data for this work have been gathered from

/personal

personal observations and from the literature, and include the following:-

1. The results of anatomical and histological investigations of human bile ducts. These investigations include:-

- (a) Anatomical dissections;
- (b) Observations on the musculature of the bile ducts;
- (c) Studies of congenital abnormalities.

2. Information obtained from studies of the processes which have determined the form and structure of the human biliary system. These studies include:

- (a) Embryological research;
- (b) Observations on the gross anatomy and musculature of the biliary systems in a large series of vertebrates.

3. Experimental and clinical findings bearing on the controversial subject of the existence of contractile muscle in the bile ducts of man and other species.

ANATOMY.

THE ANATOMY OF THE HUMAN MAIN BILE DUCTS -
THEIR FORM, RELATIONS, BLOOD-SUPPLY, LYMPHATIC
DRAINAGE AND INNERVATION.

The most striking feature of the anatomy of the bile ducts is the frequency of anomalies. A review of the literature shows that the usual text-book descriptions of the ducts and their relations are inadequate. Minor variations from the so-called normal can be expected in 30 - 50% of routine operations and autopsies (10, 118, 119, 134, 278).

These variations are of such importance to the surgeon that their inclusion in a description of the normal is essential. Indeed, their great frequency precludes the use of the term "normal anatomy", which, after all, refers only to the most usual variety found.

In this chapter the usual anatomical features and minor variations are dealt with. Personal observations are frequently referred to. They are based on studies of 25 autopsy specimens, 25 dissected cadavers in the anatomical laboratory and at least 30 operations on the biliary tract.

THE FORM AND RELATIONS OF THE DUCTS.

The extrahepatic biliary system consists of four parts -
See Fig. 6, pg. 12.

1. The hepatic ducts,
2. The gall bladder,

3. The cystic duct,
4. The common bile duct.

The hepatic and common bile ducts comprise the main excretory channel of the liver.

The hepatic ducts.

The intrahepatic bile ducts unite to form two main channels - the left and right hepatic ducts - which drain the left and right lobes of the liver. The left hepatic duct receives a large branch from the caudate lobe (32, 142).

The two ducts issue from the liver at the portal fissure. Each is 1.2 - 2.5 cm. long (77) and 1.5 - 3.5 mm. in diameter (96). They unite at an obtuse angle within, or just beyond, the portal fissure, to form the common hepatic duct.

The common hepatic duct passes downwards and slightly to the right in the lesser omentum until it is joined by the cystic duct to form the common bile duct.

The duct is covered by a plexus of blood vessels and lymphatics, and its relations in the lesser omentum are similar to those of the common bile duct (vide infra).

Near the portal fissure the right hepatic artery crosses behind the duct to reach the right lobe of the liver, while the portal vein moves further away from the duct.

Length and diameter. The average length of the common hepatic^{duct} is 3.0 cm. and the average diameter 4.5 mm., but marked variations are found (See Table 1). It may be
(Pg. 5)
/completely

- 5 -
TABLE 1.

MEASUREMENTS OF COMMON HEPATIC DUCT QUOTED IN LITERATURE.

Author.	Length (in cms).	Diameter (in mm).
Neff, 1919 (274)	2.5 - 5.0	4.0
Piersol, 1920 (283)	2.5	4 - 6
Flint, 1923 (134)	2.5 - 3.3	-
Counsellar, 1928 (96)	-	2.1 - 4.8
Graham, Cole &c. 1929 (142)	3.0	-
Callander, 1934 (72)	4.0	-
Weis, 1935 (360)	2 - 4	4 - 6
Gray, 1938 (144)	3.0	-
Walters & Snell, 1940 (355)	3.5	4.0
Christopher, 1942 (77)	2.5 - 3.0	5 - 6
Cunningham, 1943 (101)	2.5	-
Bockus, 1946 (32)	4.0	4.0
<u>Present Study, 1946</u>	<u>3.5</u>	<u>5.0</u>
<u>Average:</u>	<u>Approximately 3</u>	<u>Approx. 4.5</u>

MEASUREMENTS OF LENGTH AND DIAMETER OF COMMON HEPATIC DUCT
IN 25 DISSECTIONS.

Fig. 1.

Length (in cms.).

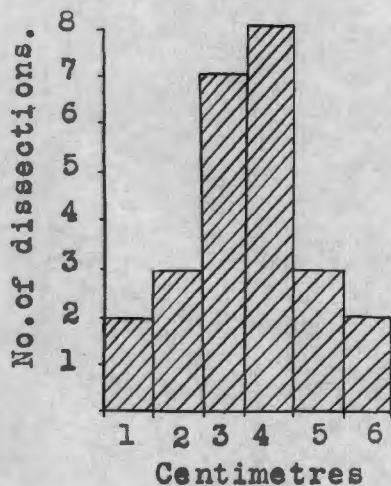
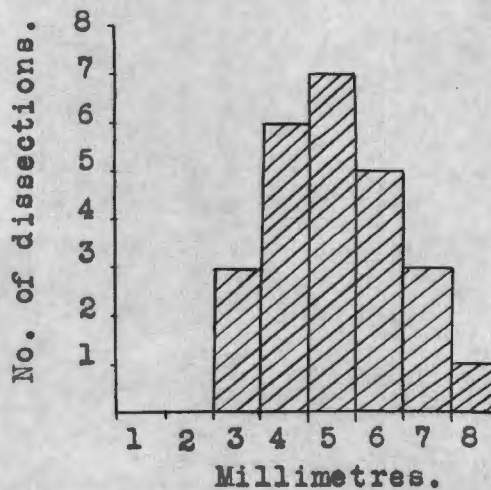


Fig. 2.

Diameter (in mms.).

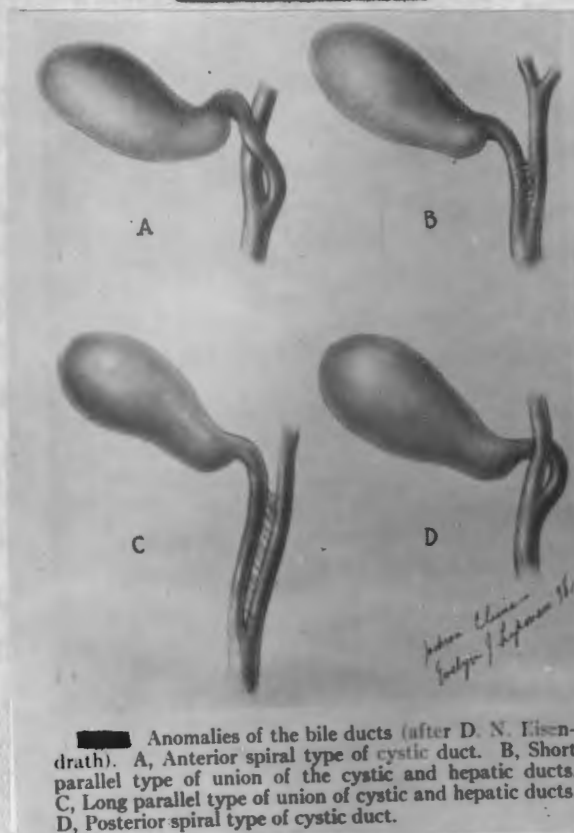


completely absent, in which case there is direct union between the right and left hepatic, cystic and common bile ducts (118, 119, 355, 360). The duct may extend all the way from the portal fissure (the right and left hepatics having no extrahepatic course) to the duodenum, and even enter it separately from the cystic duct (134). In 25 specimens measured for this study the average length was 3.5cm. and the average diameter 5 mm., the variations being indicated in Figs. 1 and 2., pg. 5

Arrangements of cystic and hepatic ducts. The cystic duct usually joins the hepatic at an acute angle to form the triangle of Calot (274), bounded by the cystic duct on the right, the hepatic duct on the left and the cystic artery above (See Fig.6., pg. 12.) The terminal cm. of the cystic duct is bound to the common hepatic duct by connective tissue. This juncture, however, does not occur at any fixed point nor in any definite manner, but varies in different people (256). In addition to the normal angular mode of union, two variations are described, viz: the parallel and the spiral (118, 119). (See Fig.3., pg. 7.)

In the parallel type the cystic and common hepatic ducts run close together and are usually held together by a connective tissue septum for a variable distance before they unite.

**ANOMALOUS JUNCTIONS BETWEEN CYSTIC AND COMMON
HEPATIC DUCTS.**



■ Anomalies of the bile ducts (after D. N. Eisendrath). A, Anterior spiral type of cystic duct. B, Short parallel type of union of the cystic and hepatic ducts. C, Long parallel type of union of cystic and hepatic ducts. D, Posterior spiral type of cystic duct.

TABLE 2.

**ARRANGEMENT OF CYSTIC AND HEPATIC DUCTS QUOTED
IN LITERATURE.**

Author.	No. of Cases	ang-ular	Short Par-allel	Long Par-allel	Anterior Spiral	Posterior Spiral
Ruge 1908 (cited by 118, 146).	43	14		13		16
Descamps 1910 (cited by 118, 146)	50	40		6		4
Kunze 1911 (cited by 118, 146)	39	20		19		-
Eisendrath 1918 (118)	100	75	11	6	5	3
Flint 1923 (134)	200	69	92	28	8	3
Beaver 1929 (10)	57	32	14	4	4	3
<u>Present study 1946</u>	50	30	15	2	2	1
<u>Total:</u>	539	280		210		49
<u>Percentage:</u>	100	52		39		9

In the short parallel type they join above the first part of the duodenum.

In the long parallel type the junction lies between the upper border of the first part of the duodenum and the inner border of the second part.

In the spiral type the cystic^{duct}/winds round either in front of or behind the hepatic^{duct}/before joining it. It may describe either a quarter, half, three-quarters or a complete spiral around the hepatic (118, 119).

Numerous writers have stressed the importance of these anomalous junctions in operations on the biliary system, particularly in relation to injury of the common bile duct (10, 72, 85, 118, 119, 123, 124, 134, 146, 176, 207, 230, 256, 257, 259, 268, 369). An analysis of the more detailed reports is given in Table 2., pg. 7.

In 50 specimens personally examined the angular mode of union was found in 60%, the parallel in 34% and the spiral in 6%. Among several additional autopsy specimens of infants and children the angular mode of union was found in less than half.

The Common Bile Duct (Ductus Choledochus).

The common hepatic and cystic ducts unite in the lesser omentum, usually 2.5 cm. above the first part of the duodenum, to form the common bile duct.

The duct runs first downwards, backwards and to the left, close to the middle-line of the body, in the right free border of the lesser omentum. It passes behind the first part of the duodenum and then usually runs in the head of the pancreas. At about the middle of the second part of the duodenum, on its left side, the duct comes into contact with the main pancreatic duct (of Wirsung). The two ducts pass obliquely through the duodenal wall and open into the duodenum on the summit of the duodenal papilla.

Length and Diameter. The average length of the common bile duct is 7.0 cm. and the average diameter 6 mm., but marked variations are found. (See Table 3, pg. 10) The duct may be represented by no more than its intramural portion (134) or it may measure almost 11 cm. in length. In 25 specimens measured for this study the average length was 6.5 cm. and the average diameter 7 mm., the variations being indicated in Figs. 4 and 5, pg. 10.

These measurements refer to the duct when it has been dissected free and straightened out, and do not apply to the living body.

For descriptive purposes the common bile duct is divided into four parts. These are:-

1. Supraduodenal or pars superior,
2. Retroduodenal,

TABLE 3.

MEASUREMENTS OF COMMON BILE DUCT QUOTED IN LITERATURE.

<u>Author.</u>	<u>Length (in cm).</u>	<u>Diameter (in mm).</u>
Morris and McMurrieh 1907 (267)	7.5	6
Quain's Anatomy 1912 (291)	7	5.6 - 7.5
Harrigan 1916 (150)	6.5 - 8	-
Neff 1919 (274)	7.5	6
Flint 1923 (134)	7.5	-
Counsellar 1928 (96)	-	2.1 - 4.8
Graham, Cole, etc. 1929 (142)	7	3
Deaver and Burden 1931 (107)	6 - 7	-
Callander 1934 (72)	9	-
Weis 1935 (360)	7	6 - 7
Begsley and Johnson 1935 (13)	7.5 - 10	-
Walters 1936 (350)	-	Goose quill
Gray 1938 (6)	-	4 - 10.7
Christopher 1942 (77)	5	-
Cunningham 1943 (101)	8-10	-
Lee MacGregor 1943 (230)	7.5 - 10	-
Bockus 1946 (32)	7.5	6
<u>Present study 1946</u>	6.5	7
<u>Average:</u>	7.0	6

MEASUREMENTS OF LENGTH AND DIAMETER OF COMMON BILE DUCT IN 25 CASES DISSECTED.

Fig. 4.

Length (in cms.).

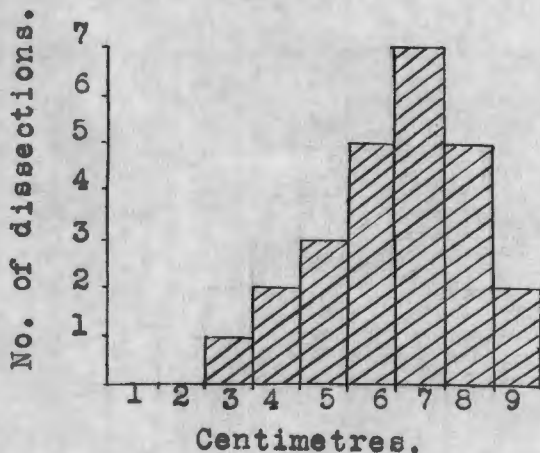
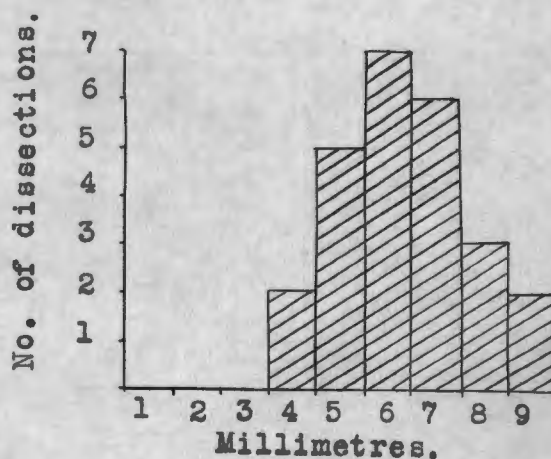


Fig. 5.

Diameter (in mms.).



3. Pancreatic.

4. Intramural or pars intestinalis.

The supraduodenal portion, (Fig. 6., pg. 12) has an average length of 2.5 cm. (72, 134, 150). It lies in the right free border of the lesser omentum between the two layers of peritoneum and anterior to the epiploic foramen. Occasionally the lesser omentum is continued beyond the duct and receives attachment to the inferior surface of the gall bladder. Its free border then passes down to the duodenum (cholecysto-duodenal ligament) or even beyond it to the transverse colon (cholecysto-colic ligament) (13). Often this ligament is not well-developed, but frequently it is represented by a small peritoneal fold connecting the fundus of the gall bladder with the lesser omentum, forming a suspensory ligament which passes over the common bile duct (256). Among the cases examined for this study, a well-developed cholecysto-duodenal ligament was frequently seen in infants and young children, while a suspensory ligament passing over the common bile duct was noted in several adults.

The common bile duct is covered by a plexus of arterioles and venules and is intimately related to the structures in the lesser omentum, viz: the hepatic artery and its branches, the portal vein and lymphatics.

THE BILIARY SYSTEM AND ITS RELATED VESSELS.

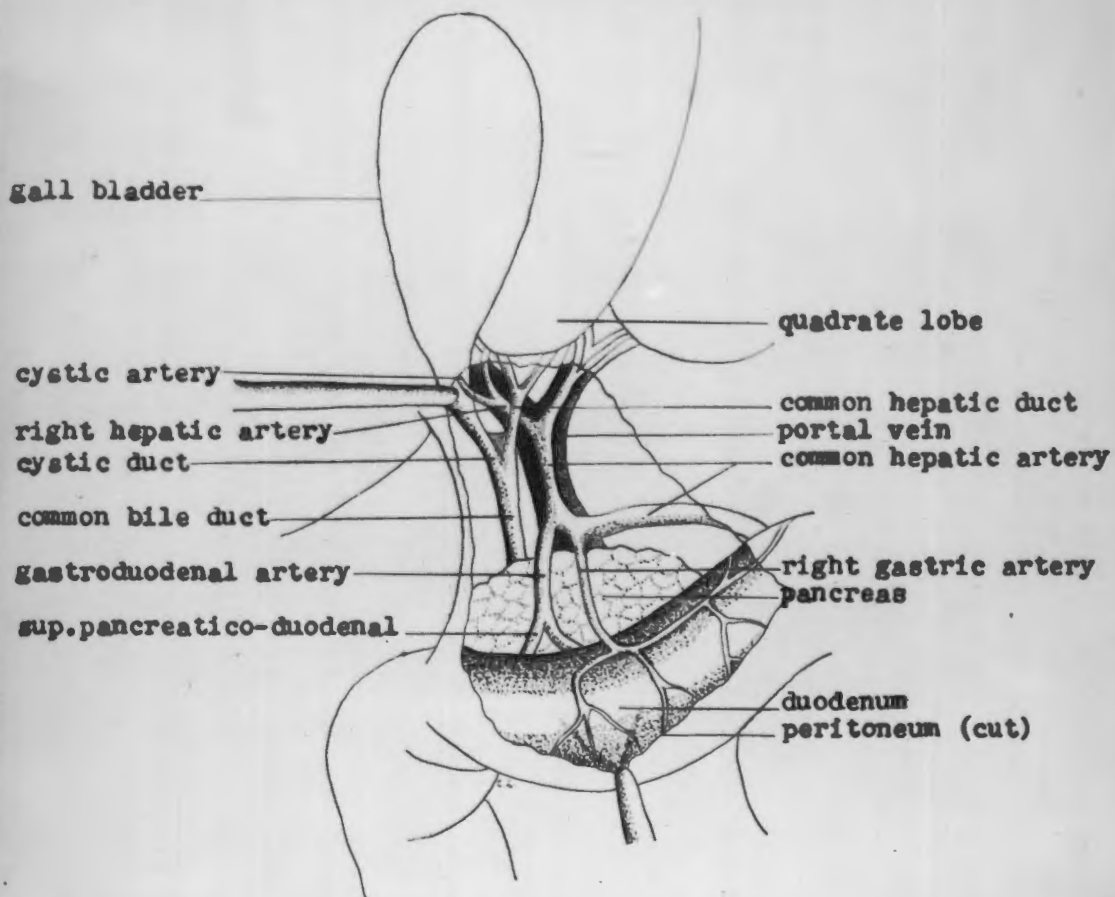


Fig. 6.

The supraduodenal and retroduodenal portions of the bile ducts.

The artery lies on the same plane as the duct and 2 mm. to its left (32, 150). Usually it divides beyond the origin of the common bile duct into the right and left hepatic arteries. According to Flint (134), a fairly large tortuous branch of the hepatic artery often courses along the anterior surface of the duct.

The portal vein lies on a plane posterior to the duct and artery. Its diameter is more than twice that of the duct. As it approaches the portal fissure it becomes further removed from the duct.

Lymphatics accompany the duct and drain into glands situated around it. One node is constantly found at the junction of the cystic and hepatic ducts and lower down one or two regularly separate the duct from the artery (150). When enlarged, these glands may be mistaken for gall stones.

In the living body the normal duct is thin-walled, of a bluish colour and represents on its surface characteristic fine vessels (107, 176). It is visualised by stretching the lesser omentum (81). Because of its thin collapsible walls the duct is not easily felt.

In operations on the biliary system the duct is seldom found as illustrated in the usual diagrams. This first part of the duct is usually overlapped by the duodenum and frequently obscured by pathological changes, (344).

On account of its proximity to Hartmann's pouch the duct and the gall bladder often become adherent, a factor which may have serious consequences in biliary operations.

The retroduodenal portion - Fig.7, pg.15 - is usually 2 cm. long (13, 72, 150). It passes behind the first part of the duodenum just to the right of the peritoneal reflection (144). The upper part of the duct is free but lower down it adheres to the duodenal wall (72).

The gastroduodenal artery lies immediately to the left of the duct and the portal vein lies further to the left and posteriorly.

Posteriorly, the duct is separated from the inferior vena cava and kidney by thin connective tissue. The upper pancreatico-duodenal vein usually passes upwards and to the left behind this portion of the bile duct.

Anteriorly, branches of supply from the gastroduodenal artery ramify on the duct. Quite frequently the superior pancreatico-duodenal artery crosses the front of the duct and the gastro-duodenal artery itself may do so. (See arterial supply).

The pancreatic portion has an average length of 2.5 cms. (13, 72, 150). Anatomical textbooks usually state that the duct runs in a groove on the posterior surface of the head of the pancreas (13, 101, 144, 183).

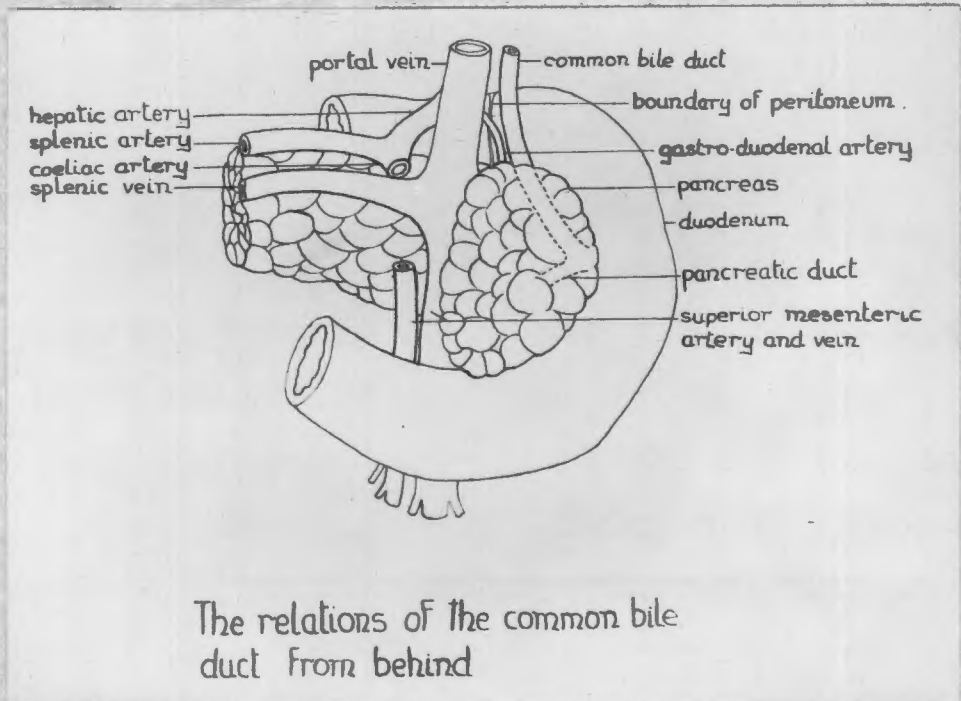


Fig. 7.

The retroduodenal and pancreatic portions of the common bile duct.

A review of the literature shows, however, that in $\frac{2}{3}$ - $\frac{1}{4}$ of cases the duct is embedded in the substance of the gland (7, 150, 274, 307). This was confirmed by personal dissections of 50 specimens among which the duct was completely surrounded by pancreatic tissue in 39, i.e., in 78%. This relation is important in the operation of retroduodenal choledochotomy.

In this part of its course the duct crosses the quadrilateral of Quenu (150) - see Fig. 7., pg. 15.

This quadrilateral is bounded above by the first part of the duodenum, laterally by the second part, below by the third part and medially by the superior mesenteric vein. The course of the duct is indicated by a line starting from the inner third of the inferior border of the first part of the duodenum, and ending at the middle of the medial border of the second part (150).

Anterior to the duct there is pancreatic tissue which diminishes in amount from above down. At the inferior border of the first part of the duodenum it is 14-15 mm. thick; halfway down it is 10 mm. thick; and at the lower end of the duct only 5-6 mm. thick (150).

Posterior to the duct there is usually a thin layer of pancreatic tissue which separates it from the inferior vena cava.

The gastro-duodenal artery courses along the left

/border

border of the duct and, after a variable distance, gives off the superior pancreatico-duodenal artery. This vessel crosses the duct either anteriorly or posteriorly (13, 72).

The duct has no direct relation with the portal vein which approaches it obliquely from below and the left; but a tributary of the vein which issues from the head of the pancreas runs up along the left side of the duct (150).

Just before entering the duodenal wall the duct is closely related to the main pancreatic duct, which lies on its left. The two ducts are bound together by connective tissue and appear to fuse, but they do not usually unite outside the duodenal wall.

The intramural portion has an average length of 1.8 cm. (32, 142, 267, 291). Accompanied by the pancreatic duct it enters the postero-medial aspect of the intestinal wall at about the middle of the second part of the duodenum. The two ducts pass obliquely through the duodenal wall, both tapering abruptly on entering it (6, 322). This reduction in size was very noticeable in 25 specimens dissected for this study.

Practically all textbooks of anatomy (13, 101, 144, 291, 305) state that the bile and pancreatic ducts unite to form a common channel at their duodenal extremities.

A review of the literature on the subject shows that considerable variation exists, and this was confirmed by

/personal

personal dissections of 25 autopsy specimens. An analysis of the available data indicates that:-

1. The two ducts unite into a common channel, the Ampulla of Vater, in 65% of cases. (See Fig. 8A, pg. 19 and Table 4). In about half of these cases, however, the length of the ampulla is 2 mm. or less (6, 7, 73, 246, 297).
2. The two ducts open independently into the duodenum in 32% of cases. (See Table 4, pg. 19). Two varieties are found:-
 - (a) The ducts are separated by a thin septum, both opening on the summit of the duodenal papilla. (See Fig. 8B, pg. 19).
 - (b) The ducts are widely separated, each opening on the summit of a small papilla or in the depth of a slight depression. (See Fig. 8E., pg. 19). This arrangement has been recorded less than 20 times (6, 104).
3. The duct of Wirsung is obliterated, so that the common bile duct alone enters the major duodenal papilla, and the duct of Santerini conveys all the pancreatic secretion. (See Fig. 8B, pg. 19). This arrangement occurs in less than 2% of cases (7, 246, 297).
4. The pancreatic duct unites with the common bile duct outside the duodenal wall. (See Fig. 8E, pg. 19).

The Ampulla of Vater. The ampulla, when present, is subject to wide variations in size. The average
/diameter

Fig. 8. RELATIONS BETWEEN THE PANCREATIC AND BILE DUCTS.

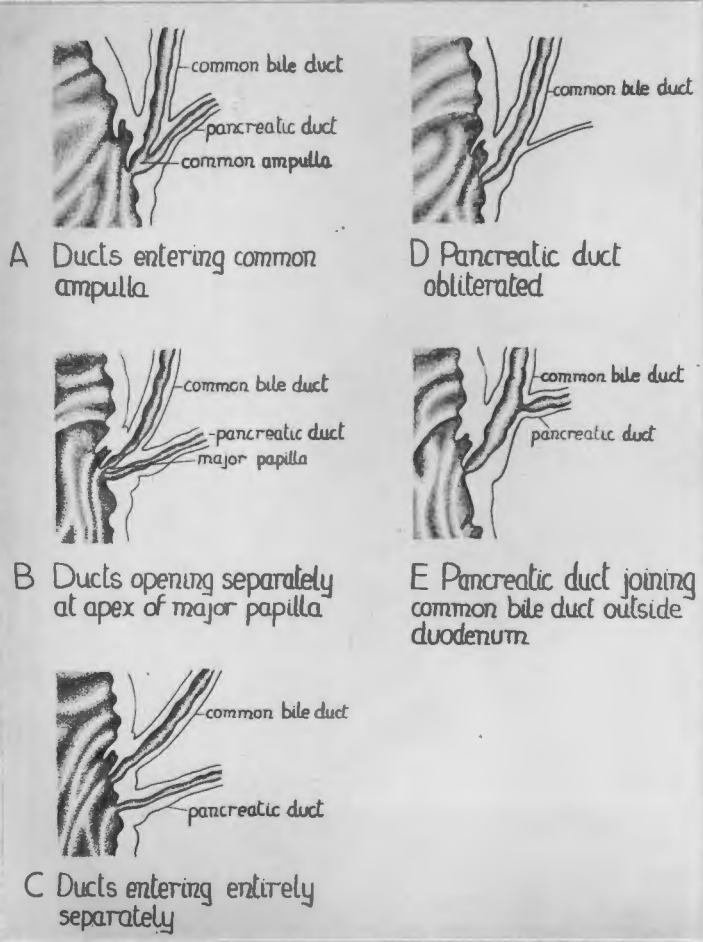


TABLE 4.

INCIDENCE OF SEPARATE AND COMMON ENTRANCES.

Author.	No. of Separate Cases	Entrance	Common Ampulla	Other
Schirmer 1893 (cited by 6, 87, 246, 297)	47	22	25	-
Letulle and Nattan-Larrier 1898 (cited by 73, 89, 297)	21	12	8	1
Opie 1903 (277)	100	11	89	-
Ruge 1908 (cited by 6, 73, 87, 184, 297)	43	11	32	-
Baldwin 1911 (7)	90	20	70	-
Belou 1915 (cited by 246, 297)	50	27	15	8
Mann and Giordano 1923 (246)	200	62	130	8
Cameron and Noble 1924 (73)	100	26	74	-
Nagai and Sawada (cited by 6)	58	5	52	1
Holsapfel (cited by 6)	50	39	11	-
Baggenstoss 1938 (6)	55	21	33	1
Dardinski 1935 (104)	100	5.3	45	2
Reinhoff and Pickrell 1945 (297)	250	73	173	4
Present study 1946:	28	7	18	-
Total:	1189	389	775	25
Percentage	100	32.7	65.2	2.1

diameter is 3 mm. (246, 297). The length varies from less than 1 mm. to 14 mm. (73, 246, 297), the average being 3 - 4 mm. (See Table 5, pg.22).

The practical significance of these variations is, that when the ampulla is long enough, a gallstone lodged in it may direct the flow of bile into the pancreatic duct, or the pancreatic secretion into the bile duct. The general belief is that such reflux is possible only when the length of the ampulla exceeds its diameter.

Pg22.
Table 5/reflects the conclusions of various workers based on calculations from their measurements. In 18 specimens dissected for this study the length was obviously greater than the diameter in 5, i.e., 30%.

The reasoning which has led most of these workers to their conclusions is, however, open to several objections, viz:-

Firstly, errors of only 1 mm. in the measurements affect the calculations considerably. In this study, it was found that errors in the measurement of so small a structure as the ampulla, were so great, that no more than a comparison between the length and width of each case was attempted.

Secondly, most of the authors presume that the obstructing calculus is spherical, whereas, in fact, most biliary calculi are irregularly-shaped.

/Cameron

Cameron and Noble (73) conducted experiments on 74 specimens by obstructing the ampulla with ordinary gall stones. They found that a considerable part of an irregularly-shaped stone may project through the papilla and that fluid injected into the bile duct flowed into the pancreatic duct, even when the length of the calculus exceeded that of the ampulla. In 66 of the specimens examined, i.e., 66% of 100 ducts dissected by them, reflux occurred. This percentage contrasts markedly with those given by other authors. It illustrates the fallacy of basing conclusions entirely on mathematical deductions. Nevertheless, Rienhoff and Pickrell (279), who have recently studied the ampulla very carefully, state that an impacted calculus can convert the ducts into a communicating system only when the length of the ampulla is 4 mm. or more.

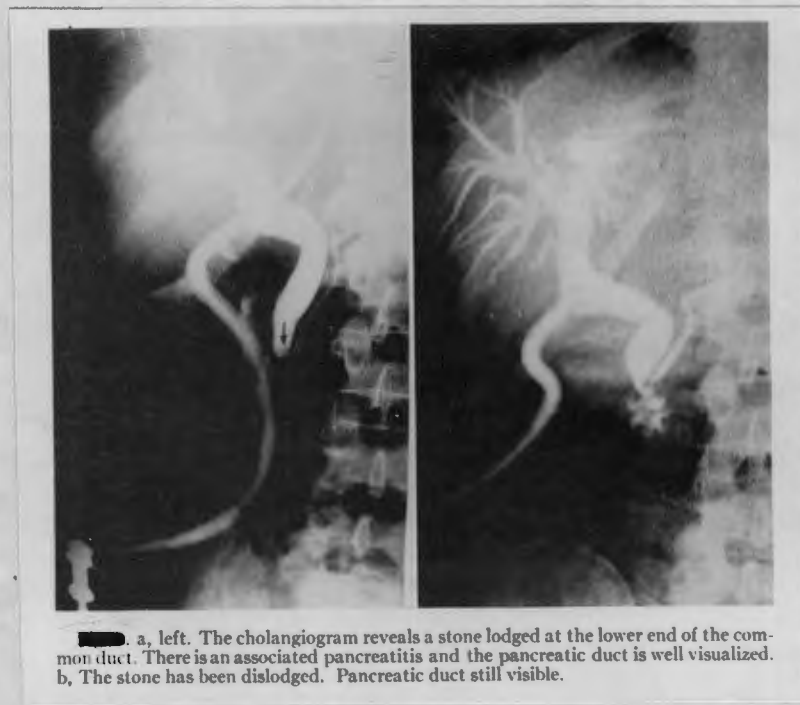
Thirdly Numerous workers have shown that a "common channel" may be produced by inflammatory oedema of the mucosa (80, 90, 184, 234), strictures, (90, 184, 214, 234) parasites, (234) and spasm of the sphincter of Oddi (2, 88, 89, 90, 112, 184, 214, 234, 261, 356).

From a correlation of the work done on this particular subject it is concluded that a common ampulla large enough to permit reflux of the bile into the pancreatic duct is present in about one-third of the population.

/This

LENGTH OF AMPULLA AND ESTIMATED POSSIBILITY OF REFLUX OF BILE INTO THE PANCREATIC DUCT WHEN AMPULLA OBSTRUCTED.

<u>Author.</u>	<u>No. of Cases</u>	<u>Length in mms.</u>	<u>Reflux Possible</u>
Opie 1903 (277)	100	1-11 mm	21
Oster 1910 (cited by 87, 184, 297)	100	-	32
Baldwin 1911 (7)	90	Average	32
V. Schmieden 1920 (cited by 87, 184)	35	-	32
Judd 1921 (186)	170	-	8
Mann and Giordano 1923 (246)	200	1-10	7
Cameron and Noble 1924 (73)	100	1-13	66
Nagai and Sawada 1925 (cited by 322)	34	2-9	25
Job 1926 (178)	151	-	8
Dardinski 1936 (104)	100	1-10	6
Baggenstoss 1938 (6)	55	-	6
Benhoff and Pickrell 1945 (297)	250	1-14	47
<u>Present study 1946:</u>	18		5
	<u>1403</u>		<u>295</u>
Percentage:	100		21



a., left. The cholangiogram reveals a stone lodged at the lower end of the common duct. There is an associated pancreatitis and the pancreatic duct is well visualized.
b. The stone has been dislodged. Pancreatic duct still visible.

Fig. 9.

A cholangiogram showing reflux of dye into the pancreatic duct (After Best-22).

This conclusion is supported by the following findings:-

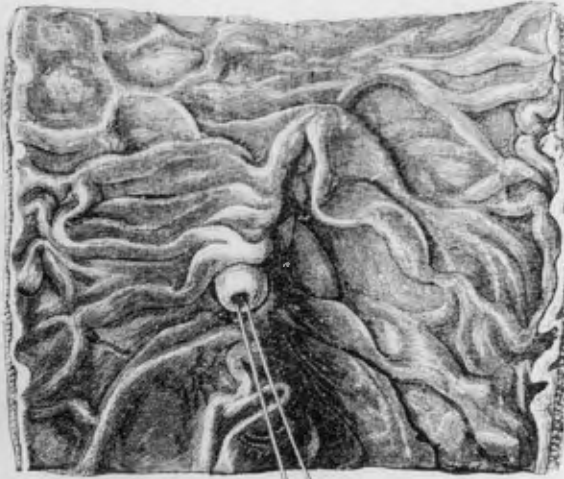
1. Numerous investigators have found pancreatic ferments in the biliary tract (76, 87, 88, 90, 184, 218, 271). A review of the literature shows that these ferments are present in bile obtained from the gall bladder at operation in 15% of cases, and in bile from choledochostomy tubes in 30% of cases.
2. By means of cholangiographic studies, several workers have demonstrated that in the presence of obstruction of the ampulla, the contrast material may pass from the common bile duct into the pancreatic duct (22, 87, 90, 112, 214, 218, 281, 262, 356). (See Fig. 9, pg. 22). During routine cholangiography the pancreatic duct fills in about 20% of cases (87, 90, 184).

The Duodenal Papilla. The ampulla opens into the duodenum through a small tubercle, round or elliptical in shape - Fig. 10, pg. 24. This is the major duodenal papilla or Papilla of Vater.

The papilla is usually situated 7.5 - 10 cm. from the pylorus (104, 72, 77, 322, 144, 101), on a prominent, longitudinal mucosal fold, the plica longitudinalis. This fold runs caudally on the postero-medial aspect of the duodenum from a well-marked transverse fold which overlaps the papilla. (See Fig. 10, pg. 24.). According to Baldwin (7), these folds are very constant. He

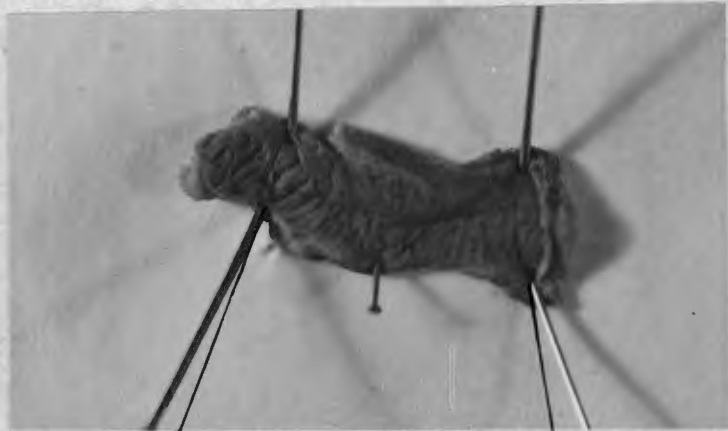
/describes

Fig. 10. The major duodenal papilla.
(After Gray - 144)



Probe in pancreatic duct

Probe in bile-duct



**Intramural
portion.**

**Extraduodenal
portion.**

Fig. 11.

The inner surface of the common bile duct.

describes another large transverse fold situated 1 cm. proximally and containing ^{the} minor papilla. Between these prominent primary folds there are numerous smaller secondary folds.

THE INNER SURFACE OF THE BILE DUCTS.

There is a distinct difference in appearance between the mucosa of the extraduodenal portion of the ducts and that of the intramural portion of the common bile duct and ampulla. The transition is abrupt and corresponds to the diminution in diameter of the common bile duct.

The extraduodenal portion: This is smooth but slightly reticulated by shallow depressions between small folds of mucous membrane. (See Fig. 11., pg. 24). According to Burden (64), some of these depressions are deeper than the rest and represent the orifices of parietal sacculi which open on opposite sides of the duct.

The intramural portion of the common bile duct and the ampulla: The mucosa is thrown into longitudinal folds, giving it a shaggy appearance. (See Fig. 11., pg. 24). According to Dardinski (104), these folds are 2 - 4 mm. long and 2 - 3 mm. wide.

Between adjacent folds there are tiny pockets. Towards the termination of the duct the folds do not fuse but hang free, sometimes even extending through the orifice of the papilla.

THE ARTERIAL SUPPLY OF THE BILIARY SYSTEM.

The arteries of the extrahepatic biliary system are derived from branches of the Common Hepatic Trunk.

The Common Hepatic Artery.

This vessel arises from the coeliac axis and runs transversely to the right. It crosses the right crus of the diaphragm and the coeliac ganglion and passes above the pancreas to reach the front of the inferior vena cava (113). Then it runs forward to the duodenum, passes below the medial end of the epiploic foramen and crosses the portal vein (144).

It then ascends in front of the portal vein and 2 mm. to the left of the common bile duct between the two layers of the lesser omentum. When it reaches the portal fissure it divides into right and left hepatic arteries, which supply the corresponding lobes of the liver.

Branches of the Common Hepatic Artery.

The branches of the common hepatic artery which supply the biliary system are:-

1. The right hepatic artery and its cystic branch,
2. The gastroduodenal artery and its superior pancreatico-duodenal branch,
3. Small twigs which pass directly to the common bile duct.

All the branches are subject to numerous variations.

/These

These have been carefully studied by Descomps, 1910, (cited by 118), Rio Banco, 1912 (cited by 118), Eisendrath, 1920 (119), Flint, 1923 (134) and Osler and Dow, 1945 (278). Their importance in operations on the biliary tract is stressed by many surgeons (176, 207, 230, 257, 268, 344, 357, 359, 369). Nevertheless, they are usually omitted from the descriptions of the vessels given in the standard textbooks, and many operators do not appreciate their frequency (134).

The findings in 25 dissected cadavers examined for this study are illustrated in Fig.12 & 13, pg.28 Figs.15 and 16, pg. 31. In the following descriptions the findings of the various studies are correlated.

The Right Hepatic Artery.

Usual course: The vessel arises from the common hepatic artery and passes behind the common hepatic duct to reach the liver (101, 119, 134, 144). It runs upwards to the portal fissure and often presents a characteristic kink directed towards the cystic duct (268). This normal arrangement was found in 20 of the 25 bodies examined. (Fig.12, pg.28).

The artery gives off the cystic artery and also small branches which supply the upper portion of the common bile duct and common hepatic duct (305).

Variations: 1. In one-fifth of persons it originates from the superior mesenteric (118,119,134,278).

See Fig. 14A, pg. 28.

Fig. 12. THE NORMAL ARRANGEMENT OF THE ARTERIES SUPPLYING THE BILIARY SYSTEM.

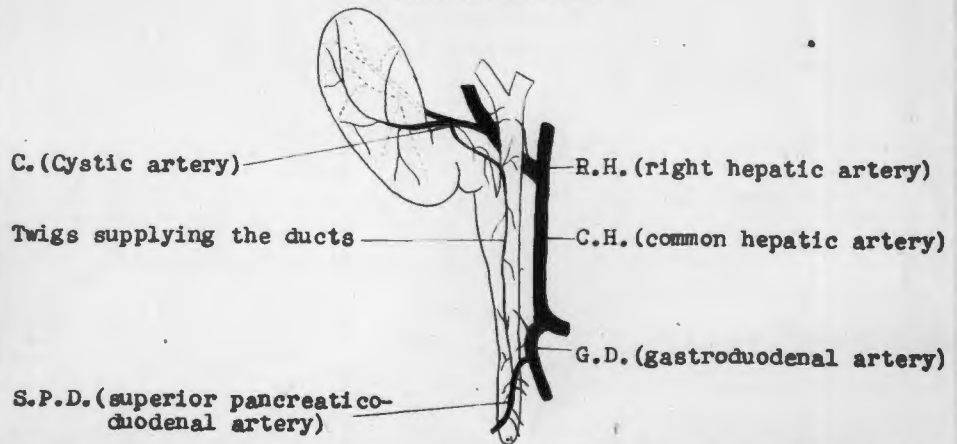


Fig. 13. ANOMALIES OF THE HEPATIC ARTERY ENCOUNTERED AMONG 25 DISSECTIONS.

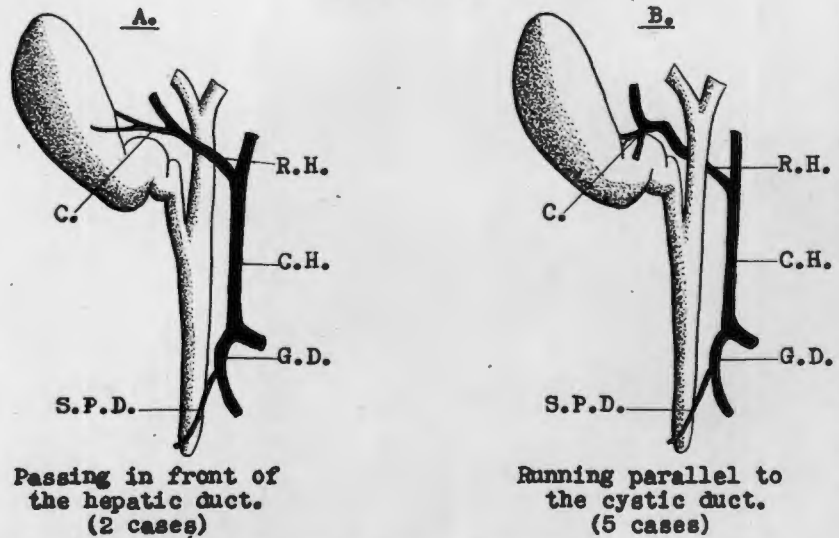
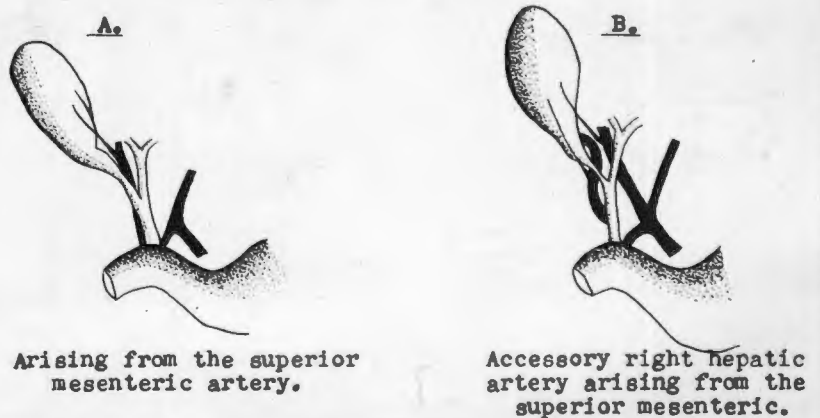


Fig. 14. OTHER ANOMALIES OF THE RIGHT HEPATIC ARTERY REPORTED IN THE LITERATURE. (After Flint)



2. In one-eighth it passes in front of the common hepatic duct. (119, 134, 278) - see Fig.13A, pg. 28. Two such cases were encountered among the 25 dissections.

3. It may run parallel to the cystic duct and close to the neck of the gall bladder, or loop around the edge of the main hepatic duct (118, 119, 134, 278). This anomaly was noted in 5 of the dissections and in at least 3 operations. (See Fig. 13B, pg. 28.)

4. Rarely there are two right hepatic arteries, either both arising from the common hepatic, or one from the common hepatic and the other from the superior mesenteric, (134), - see Fig. 14B, Pg. 28.

The Cystic Artery.

Usual arrangement: The artery arises from the right hepatic artery just to the right of or behind the common hepatic duct (119, 134). It passes behind and parallel to the cystic duct to supply the gall bladder and also to give off branches to the common hepatic and upper part of the common bile ducts. This normal arrangement was found in 22 of the 25 cadavers. (See Fig.12, pg. 28.)

Variations: 1. In one-third of persons the vessel has an anomalous origin. It may arise from the right hepatic artery to the left of the common hepatic duct or from the main hepatic artery, or the left hepatic, or the gastroduodenal, or the superior

pancreatico-duodenal. In one of the dissected cadavers studied for this work, the cystic artery arose from the right hepatic artery to the left of the hepatic duct, (Fig.15A, Pg.31), and in another it arose from the main hepatic (Fig.15B, pg.31). Similar variations were observed at 3 operations.

2. In one-fifth of persons it crosses in front of the common bile duct. (118, 119, 134, 278). In the three cases of anomalous origin of the cystic artery encountered in this study, the vessel crossed in front of the bile duct.

3. Two cystic arteries are found in one-eighteenth of persons. The accessory artery may arise from the right hepatic, main hepatic, gastro-duodenal, or superior pancreatico duodenal vessels. It invariably crosses in front of the bile ducts. An accessory cystic artery arising from the gastroduodenal artery was found in one of the dissections. (See Fig. 15C, pg.31).

The Gastroduodenal Artery.

Usual arrangement: (Fig.12, pg.28) This short trunk is one of the largest branches of the common hepatic artery. It runs downwards and backwards and passes behind the first part of the duodenum. At first it lies to the left of the common bile duct and in front of the portal vein (72, 113, 119, 144) but later

**Fig. 15. ANOMALIES OF THE CYSTIC ARTERY ENCOUNTERED
AMONG 25 DISSECTIONS.**

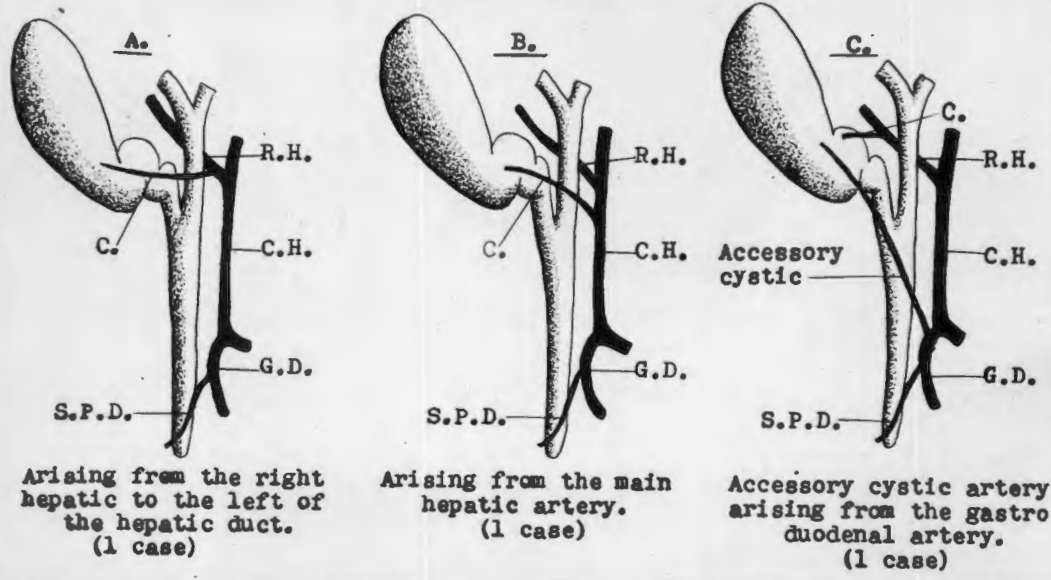
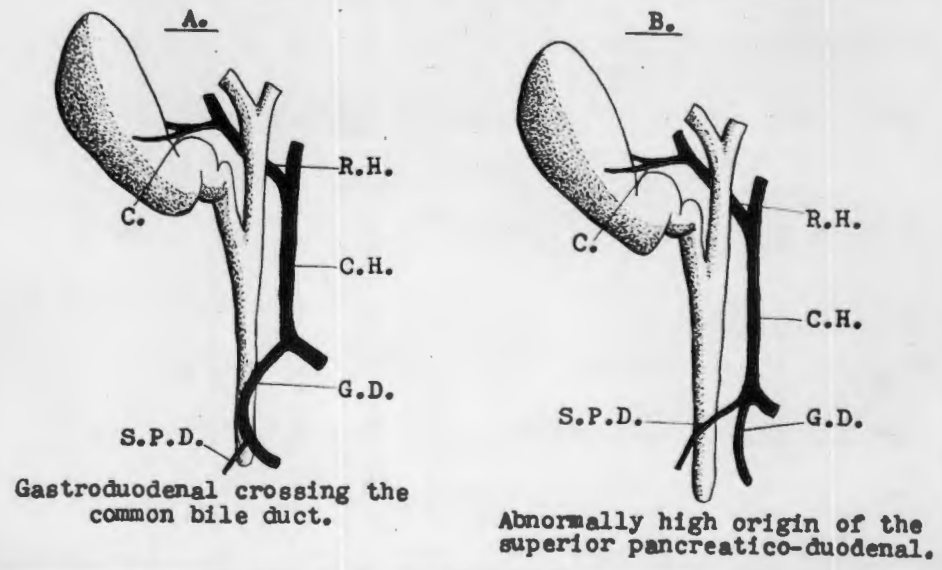


Fig. 16. ANOMALIES OF THE GASTRODUODENAL AND SUPERIOR PANCREATICO-DUODENAL ARTERIES ENCOUNTERED AMONG 25 DISSECTIONS.



it diverges from these structures and grooves the front of the neck of the pancreas.

It gives off several interlacing twigs to the common bile duct, and at the lower border of the duodenum it divides into its two terminal branches, the superior pancreatico-duodenal and right gastro-epiploic arteries.

Variations: The vessel may arch across the left border of the common bile duct or cross the front of the supraduodenal portion of the duct (119, 134). This anomaly was noted in one of the 25 dissections (See Fig. 16A, pg. 31).

The Superior Pancreatico-duodenal Artery.

Usual arrangement: (Fig.12, pg.28). The artery descends in the duodenal loop between the head of the pancreas and the duodenum and crosses either in front of or behind the second and third parts of the common bile duct (13, 72, 119).

It gives off interlacing branches to the common bile duct and is accompanied by the upper and lower pancreatico-duodenal veins.

Variations: Quite frequently the vessel has an abnormally high origin and then crosses the supraduodenal portion of the common bile duct (119, 134). This anomaly was observed in two of the 25 dissections (See Fig. 16B, pg.31).

Rarer anomalies: The right hepatic artery may arise from the aorta, the right renal, the gastric or the inferior mesenteric arteries (134). Lahey (207) quotes a case where he found the portal vein in front of the common bile duct. Flint (134) cites 4 cases where the hepatic artery passed behind the portal vein.

THE ARTERIAL SUPPLY OF THE MAIN DUCTS IN PARTICULAR.

The common hepatic and common bile ducts receive their arterial supply from 5 vessels, viz:-

- | | |
|----------------------------------|----------------------|
| 1. Common hepatic, | } See Fig.12, pg. 28 |
| 2. Right hepatic, | |
| 3. Cystic, | |
| 4. Gastroduodenal, | |
| 5. Superior pancreatico-duodenal | |

The various twigs form a characteristic interlacing network on the surface of the ducts.

According to Flint (134), a large tortuous vessel often courses along the anterior surface of the common bile duct. He states that it arises either from the common hepatic, gastroduodenal or superior pancreatico-duodenal arteries. Although several fairly large vessels arose from the gastroduodenal and superior pancreatico-duodenal in the dissections examined, no vessel large enough to conform to Flint's description was observed.

The blood supply to the papilla, according to Dardinski (104), is arranged in 4 main vessels which run along its sides. They originate from the superior

/pancreatico-

pancreatico-duodenal artery (321) and supply the papilla as well as the surrounding duodenal mucosa.

THE VENOUS DRAINAGE OF THE BILIARY TRACT.

The Veins:

It is generally agreed that the veins draining the extrahepatic biliary system consist of the following vessels (144, 101, 13, 305, 202, 355, 32):-

1. Two groups of veins which drain the gall bladder. The venules of one group originate in the peritoneal surface of the vesicle and usually unite into two main trunks, the cystic veins, which, either separately or after uniting, pass towards the portal fissure. The venules of the other group originate in the hepatic surface of the gall bladder and unite into several small veins, which pass directly into the liver.
2. Veins from the cystic duct which join the cystic veins from the gall bladder.
3. Veins from the common hepatic and common bile ducts which accompany the ducts to the portal fissure. There they either join the cystic veins or pass directly into the liver substance.

The Ultimate Drainage of Venous Blood.

Review of the Literature.

There are conflicting opinions on the ultimate fate of the biliary veins.

The descriptions given in most textbooks of anatomy (144, 101, 13, 305, 72) are based on the studies of Sappey in 1879 (cited by 202). He found that all the veins drained into the portal system. The cystic veins and those from the bile duct drained into the portal vein

at the portal fissure, while the veins which pass directly from the gall bladder into the liver drained into ramifications of the portal vein. He regarded the latter as "representing so many small accessory portal veins."

Kreidler (202) recently confirmed Sappey's observations in general, if not in particular. He studied the venous drainage of human biliary systems by injecting coloured gelatin into the portal vein. He states that the dye did not pass into the hepatic veins which enabled him to distinguish between the portal and hepatic systems. He found that all the veins from the gall bladder and ducts drained either directly into the liver or joined larger vessels which could be traced to the portal vein.

Contradictory evidence is submitted by Petren (cited by 32 and 355). He studied human and animal material and claimed that there were rarely direct venous channels connecting the extrahepatic biliary system with the portal vein, and that all the blood from the gall bladder, cystic duct and common bile duct drained directly into the hepatic circulation. He states specifically that the cystic vein avoids the portal vein in its course directly into the liver.

Personal Observations. In this work the venous
/drainage

drainage of the biliary system was studied by injecting mercury into the vessels of cats and human fetuses. The technique of the procedure, which was suggested by Prof. Goets, was briefly as follows:-

The abdomen and thorax were opened, but before the viscera were removed the vascular system was flushed.

In cats this was done by injecting saline into the aorta and vena cava, the blood escaping through the iliac vessels, which were divided. In human fetuses (4 - 6 months of age) the saline was injected directly into the heart, the blood escaping from the umbilical vessels, which had not been tied. The abdominal viscera and diaphragm were then carefully removed and the hepatic and portal veins divided.

In cats mercury was first injected into the hepatic vein. This filled all the smaller intrahepatic tributaries, but even with considerable pressure, leading to rupture of some of the vessels, no mercury entered the cystic veins, nor did it escape from the portal venous system.

In cats and human fetuses the portal vein was similarly injected. The mercury flowed freely with the intrahepatic rami, and a slightly greater pressure forced the fluid into the cystic veins, which became clearly visible. The pressure was not as great as that exerted when injecting the hepatic vein in cats and never sufficient to rupture the smaller vessels. Mercury did not escape

/from

from the hepatic veins.

These experiments illustrate very clearly that no direct communication exists between the portal and hepatic venous systems in cats and human fetuses. In cats it is impossible to demonstrate continuity between the cystic and hepatic veins. In human fetuses and in cats a communication exists between the cystic veins and portal system.

Conclusions:

It is concluded that the venous blood from the biliary tract drains into the portal venous system. This conclusion agrees with the statements of Sappey and Kreidler and is opposed to the view that the blood drains into the hepatic veins.

THE LYMPHATIC DRAINAGE OF THE BILIARY SYSTEM.

The Lymph Glands.

The lymphatics of the extrahepatic biliary tract ultimately drain into the coeliac group of pre-aortic lymph glands via the hepatic and pancreatico-splenic glands.

The Hepatic Lymph Glands are related to the common hepatic artery and are situated along the bile ducts between the layers of the lesser omentum. There are always three, and often six, of these glands (274). One node, the cystic gland, is constantly placed near the neck of the gall bladder which it drains (32, 72, 144, 274).

Lower down one or two glands regularly separate the common bile duct from the hepatic artery (150).

These glands receive afferents from the common bile duct.

The Pancreatico-Splenic Glands accompany the splenic artery and are related to the posterior surface of the upper border of the pancreas (144). The upper members of this group receive afferents from the common bile duct.

Relation between the Lymphatics of the Biliary System and those of the Liver and of the Pancreas.

A great deal of work has been done on the lymphatic connections between the biliary system on the one hand, and the liver and the pancreas on the other. Most of the observations are based on animal experiments and pathological data and can be applied to the normal human biliary system by analogy only.

Relation to lymphatics of the Liver: Most of our present knowledge of the lymphatics of the liver is based on the works of Sappey (cited by 202) and of Sudler (334). Sappey found that the lymph vessels from the gall bladder and adjacent parts of the liver converged towards, and opened into, the cystic lymph node. Sudler studied human material, as well as pigs and dogs, and claimed that a lymphatic connection between liver and gall bladder existed.

In 1926 Kodama (198) confirmed Studler's observations by injecting trypan blue into the subserous lymph plexus of the gall bladder of dogs. He found that the lymph vessels of the liver became distended with dye.

Winkenwerder (375) in 1927 was unable to demonstrate such a lymphatic connection in cats, and Patey and Whitby (281) in 1933 failed to find it in rabbits.

Subsequently, however, Bartlett, Crile and Graham (9) in 1935, and McCarrel, Thayer and Drinker (223) in 1942 demonstrated very clearly that the lymphatics of the gall bladder anastomosed with those of the liver.

Bartlett, Crile and Graham (9) carried out their experiments in cats by first ligaturing the thoracic duct to promote retrograde flow of lymph and then injecting Prussian Blue into the subserous layer of the gall bladder. They found that the dye invariably passed into the adjacent liver tissue.

McCarrel, Thayer and Drinker (223) experimented on cats, rabbits, monkeys and dogs by injecting Indian ink into the liver tissue adjacent to the gall bladder. In all the animals they found that the ink was carried to the gall bladder.

Clinical and pathological findings support the existence of a lymphatic anastomosis. E. S. Judd (186) studied 1290 cases of biliary disease and found that

/cholecystitis

cholecystitis rarely existed without some degree of hepatitis. This has been corroborated by several authorities (32, 135, 142, 198, 355). In several of the specimens examined for this study there was evidence of hepatitis in that part of the liver immediately adjacent to a chronically-inflamed gall bladder.

The weight of evidence, therefore, supports the view of a lymphatic connection between the liver and the extra-hepatic biliary system.

Relation to Lymphatics of Pancreas. It is generally agreed that lymphatics from the lower end of the common bile duct drain into glands situated in the neighbourhood of the head of the pancreas. An anastomosis between the biliary and pancreatic lymphatics in this region has been demonstrated by various workers (143, 193).

This view has been challenged by Archibald (2), who states that such an anastomosis does not exist. His contention is supported by the work of Kaufman (193) and of Kodama (198). Kaufman (193) failed to produce pancreatic infection in cats by injecting the biliary lymphatics with bacteria. Kodama's (198) investigations in dogs indicated that the lymphatics from the gall bladder passed over the surface of the pancreas and did not enter its substance. He found, however, that when the gall bladder was adherent to the pancreas a direct anastomosis existed between their respective lymphatics.

CONDITION OF THE GALL BLADDER IN
PATIENTS OPERATED UPON FOR CHRONIC
PANCREATITIS (PERSONAL STUDY).

T A B L E 6.

<u>Initials.</u>	<u>Sex.</u>	<u>Age.</u>	<u>Date of Operation</u>	<u>Condition of Gall Bladder.</u>
B.E.	M.	42	4/8/39	Normal.
H.K.	F.	67	6/9/39	Chronically inflamed.
M.R.	F.	55	27/9/39	Chronically inflamed, and stones present.
J.A.B.	F.	53	4/9/40	Chronically inflamed and stones present.
S.P.	F.	44	8/1/41	Chronically inflamed.
I.P.	M.	48	2/10/42	Normal.
S.M.	M.	67	4/11/42	Chronically inflamed.
L.S.	F.	41	3 II/43	Normal.
A.M.B.	F.	43	1/3/44	Chronically inflamed.
My H.	F.	32	3/5/44	Chronically inflamed and stones present.
D.H.G.	F.	28	10/5/44	Chronically inflamed.
W.McK.	F.	40	19/6/44	Chronically inflamed and stones present.
I.R.	M.	28	15/12/44	Chronically inflamed and stones present.

Total number of cases: 13.

Gall bladders normal in 3, i.e., 23%.

Gall bladders inflamed in 5, i.e., 38.5%.

Gall bladders inflamed and stones
present in 5, i.e., 38.5%

} 77%.

Clinical and pathological evidence supports the existence of an anastomotic connection. The co-existence of chronic infection in the biliary system and pancreas was first stressed by Deaver (106, 109). His findings have been confirmed by numerous observers (32, 142, 186, 193, 307, 355). Indeed, Bockus (32) states that, according to many observers, approximately two-thirds of patients with chronic pancreatitis have infections of the biliary tract, and one-quarter of the patients with gall bladder disease have chronic pancreatitis.

In the present study the findings in cases operated on for chronic pancreatitis and chronic cholecystitis were analysed. In 13 cases operated on for chronic pancreatitis the gall bladder showed signs of inflammation in 10, i.e., in 77%, and in half of these calculi were present. (See Table 6, pg. 41). In 44 cases operated on for chronic cholecystitis, signs of pancreatic infection were found in 6, i.e., 15%.

Lymphatic Drainage of Main Ducts in Particular.

From the descriptions given above, it is seen that the main ducts are drained by two groups of lymphatics. These are:-

1. Lymph from the common hepatic and upper part of the common bile duct drains into the hepatic glands situated along the course of the ducts. These send efferents to the coeliac glands. The upper members of this group also drain the

gall bladder and the liver, ^{and} the lymphatics of these organs intercommunicate.

2. Lymph from the lower part of the common bile duct drains into the upper members of the pancreatico-splenic group of glands. These send efferents to the coeliac glands and also drain the pancreas. An anastomosis exists between the pancreatic and choledochal lymphatics around the lower end of the common bile duct.

THE NERVE SUPPLY OF THE BILIARY SYSTEM.

Several accounts of the intrinsic nerves of the human biliary system are available, of which the more recent contributions are those of Harting, 1931 (cited by 355), Reich, 1940, (295), Alexander, 1940 (1), Schulze and Boyden, 1943 (321) and Kirk, 1944 (196).

General Arrangement.

It is agreed that the nerves of the biliary system arise from three sources, viz: the coeliac plexus, the right vagus and the left vagus. Some investigators claim additional fibres from the right phrenic nerve (1, 13, 144).

The coeliac plexus, which connects left and right coeliac ganglia, receives the greater splanchnic, derived from T5 to 9 spinal segments, and the lesser splanchnic derived from T10 and 11 segments. It receives additional filaments from the right vagus (144), which, however, traverse the plexus without relaying there (1).

It gives off several secondary plexuses, of which the hepatic plexus is the largest (144). The right coeliac ganglion is usually larger than the left, and although nerves from both ^{ganglia} anastomose around the hepatic artery, the left contributes less fibres to the biliary system than the right (1).

The hepatic plexus accompanies the hepatic artery and sends ramifications along all its branches. According to most accounts the nerves of this plexus are arranged in two main plexuses - anterior and posterior (1, 321).

The anterior plexus receives branches from the left coeliac ganglion (1) and forms a dense network around the hepatic artery. It receives additional filaments from the left vagus (1, 144). These leave the main nerve near the fundus of the stomach and pass between the layers of the lesser omentum, to join the plexus near the portal fissure (1).

The following branches are distributed from the anterior plexus (1):-

1. Rami which pass along the cystic artery to supply the gall bladder and cystic duct. Secondary branches are given off from these to supply the common hepatic duct.
2. Nerves which course along the anterior surface of and supply the common bile duct. Alexander (1) calls this bundle of nerves the "nervus pancreatico-choledochus".

The posterior plexus receives branches from the right coeliac ganglion (1, 321) and also filaments from

the right vagus which traverse the ganglion (1). The plexus passes upwards posterior to the hepatic artery, in relation to the portal vein. It consists of 3 or 4 large trunks which course along the posterolateral aspect of the vein (1). The extreme right lateral trunk reaches the posterior surface of the common bile duct which it supplies. This nerve anastomoses with the anterior plexus at the junction of the cystic and common bile ducts and gives off a branch of distribution to the gall bladder (1).

The Nerve Supply of the Main Ducts in Particular.

From the description given above, it is seen that the main ducts are supplied by a plexus of nerves which surrounds them. This plexus is made up of:-

1. An anterior network largely continuous with the anterior hepatic plexus, and so with the left coeliac ganglion and vagus - the Nervus Pancreatico-Cheleleochus (1).
2. A posterior network primarily connected with the posterior hepatic plexus and so with the right coeliac ganglion and vagus.

The supply to the terminal portion of the common bile duct and choledocho-duodenal junction has not been studied in detail. Schulze and Beyden (321) who reviewed the literature very thoroughly conclude that the nerves to this area are derived from the plexuses surrounding the common bile duct. Reich (295), however, who studied several human cadavers describes a fairly large nerve which comes

/from

from the hepatic plexus and approaches the second part of the common bile duct. It runs horizontally behind the hepatic artery and directly above or embedded within the superior margin of the head of the pancreas. He believes that this nerve goes to supply the sphincter of the common bile duct.

Kirk (196) has recently demonstrated a large nerve trunk running in close apposition to the extra-duodenal portion of the common bile duct as far as the point where it penetrates the duodenal wall. He calls this nerve the "nervus choledochus" and suggests that it communicates with Auerbach's plexus, which is markedly enlarged in the region of the duodenal papilla.

The subject of the nerve supply to the choledochoduodenal junction obviously requires further study and is at present being investigated by Boyden and his co-workers (52) and by Kirk (196).

GENERAL SUMMARY.

1. The anatomy of the main bile ducts has been studied in detail and described under the following headings:-
 - (a) The form and relations of the ducts,
 - (b) Arterial supply,
 - (c) Venous drainage,
 - (d) Lymphatic drainage,
 - (e) Nerve supply.

2. Personal studies have confirmed the fact stressed in the literature, that variations from the normal are extremely common. These variations concern the following anatomical features:
 - (a) The length and diameter of the bile ducts.
 - (b) The method of union between the cystic and hepatic ducts.
 - (c) The relation of the common bile duct to the pancreas.
 - (d) The relation between the bile and pancreatic ducts.
 - (e) The size of the ampulla.
 - (f) The arterial supply of the biliary system.

3. It has been demonstrated that venous blood from the biliary system drains into the portal vein and its branches.

4. Clinical evidence has been submitted to support the view that the lymphatics of the biliary system communicate with those of the liver and with those of the pancreas.

HISTOLOGY.

THE MUSCULATURE OF THE HUMAN MAIN

BILE DUCTS.

In this chapter the histology of the bile ducts is dealt with under two separate headings, viz:-

1. Review of literature,
2. Personal observations.

In both sections the musculature of the ducts receives particular attention.

REVIEW OF THE LITERATURE.

General Structure:

A review of the literature (13, 64, 101, 142, 144, 230, 255, 291, 304, 317, 355, 360) indicates that the walls of the bile ducts are made up of the following layers:-

1. A mucosa which consists of a single layer of columnar epithelium thrown into numerous folds. Outpocketings of the mucous membrane project into the outer layers of the ducts. These structures are variously referred to as parietal sacculi (96, 98, 335, 336), biliary crypts (142), diverticula (64), mucous glands (64, 142), and pseudo glands (64, 142). Most authors (336, 64, 96, 335, 98) regard them as simple diverticula rather than mucous glands.
2. A submucosa which is a dense connective tissue layer containing numerous elastic fibres.
3. An adventitia which is made up of a large amount of loose fibrous tissue, vessels, nerves, lymphatics and a number of tubular structures which are described as aberrant ducts by some, (96, 98, 142, 336), and as glands by others (64, 144, 355). Most authors describe some muscle fibres in the outer tunic, but there is much difference of opinion on their disposition, amount and nature.

The Musculature:

Studies on the musculature of the ducts have raised two problems; the first concerns the amount of muscle present in the extraduodenal portion of the main bile ducts, and the second the nature and origin of the muscle surrounding the intramural portion of the common bile duct.

The Musculature of the Extraduodenal

Portions: There are conflicting observations on the musculature of the ducts themselves.

Older Literature: Hendrickson (154) in 1898 reviewed the literature from 1761 to 1898. He found seven workers reporting the presence of muscle, and five stating that there was none. At least two reports not included in his review can be added to the latter, viz: those of Beale in 1856 (cited by 64) and Van Braam Houckgeest in 1882 (345).

Modern Literature: Fourteen different textbooks on anatomy and histology published between 1900 and 1946 were consulted on the musculature of the ducts. The majority of accounts stress the paucity of muscle. One author (230) states emphatically that no muscle is found. Four (13, 95, 101, 317) fail to mention the disposition of the muscle fibres. Seven (113, 144, 267, 284, 291, 292, 304) describe circular fibres only. Only two (255, 283) mention longitudinal, oblique and
/circular

circular fibres.

The literature of the last 50 years contains conflicting views on the muscle content of the ducts.

Hendrickson (154) in 1898 studied human and animal ducts. He found that the common and hepatic ducts consisted mainly of fibrous tissue, but described muscle fibres in both. In the hepatic duct they were mainly longitudinal with small numbers of transverse and diagonal fibres. In the common bile duct the transverse fibres equalled the longitudinal, whilst diagonal fibres remained scanty.

Sudler (334) in 1901 noted unstriated muscle in the ducts of man and animals but failed to mention its amount and pattern.

Auster and Crohn (4) in 1922 found muscle fibres in the common bile duct. They were irregularly scattered and mostly transverse.

Matsuno (cited by 64 and 286) in 1923 concluded from his studies that muscle occurred in the ^{bile} ducts but that it was very irregular in distribution. He regarded the ducts as connective-tissue tubes.

Burden (64) in 1925 studied 100 human bile ducts. He found them constantly well supplied with muscle which was situated in the outer layers and made up of "good-sized, isolated, oval bundles". Longitudinal and
/circular

circular fibres are described, the former predominating. He concluded that, from an anatomical standpoint, peristalsis is possible in human bile ducts.

Halpert (147) in 1927, in his studies on the gall bladder, noted that the musculature gradually disappears as the cystic duct approaches the common bile duct.

Nubeer (cited by 355) in 1931 stressed the paucity of muscle in the hepatic and common bile ducts. He failed to find any muscle in 67% of hepatic and 7% of common ducts, but noted a considerable number of longitudinal fibres in 25% of common bile ducts. He concluded that the ducts were mainly fibrous tubes.

Newmann (275) in 1933 stated that the hepatic and common bile ducts were simply fibro-elastic channels with very little muscle. He constantly failed to make out any complete rings of muscle.

MacDonald (227) in 1935 studied 74 autopsy specimens. He found only small isolated muscle fibres in the ducts, and stated that "in many sections a search of several high power fields is necessary to demonstrate even isolated muscle cells."

Aynesworth (5) in 1935 found that the outer coats of the bile ducts consisted entirely of fibrous tissue and that no muscle fibres were present.

Best and Hicken (26) in 1936 and again in 1938

(27) stated that their studies revealed practically no muscle in the hepatic and common bile ducts.

Schwegler and Boyden (322) in 1937 published their findings of most intensive studies on the ducts. They noted only scattered bundles of muscle in the extra-duodenal portion of the common bile duct.

Gordon-Taylor (139) in 1942 stated that examination of several sections of ducts showed but few muscular fibres.

Kirk (196) in 1944 concluded from his studies that "the extraduodenal portion of the common bile duct is devoid of muscle, except in close proximity to the point where it penetrates the gut wall".

Maximow and Bloom (255) in 1944 stated that bundles of smooth muscle first appeared in the common bile duct and they describe longitudinal and oblique fibres forming an incomplete layer around the wall of the duct.

Summary: An analysis of these reports indicates that the majority of workers regard the musculature of the ducts of such paucity as to be negligible. At least three workers failed to find any muscle, while only 5 noted sufficient fibres to describe their disposition. Burden (64) alone observed an amount of muscle large enough to suggest contractibility of the ducts.

The Musculature of the Intramural Portion of the Common Bile Duct.

The structure of the musculature surrounding the intramural portion of the common bile duct in man and animals has been extensively studied by serial sections, maceration methods and three dimensional reconstructions.

The Older Literature: Boyden (48) recently presented literal translations of the original Latin versions by several of the older workers. These translations, which are in agreement with references to the older literature by others, have been freely used for this review.

Francis Glisson (cited by 48, 104, 128, 138, 142, 154, 219, 234, 246, 288, 337) is credited with being the first to describe a sphincter around the termination of the common bile duct. In 1681 he stressed the oblique insertion of the duct into the duodenum, and stated that "the common duct is obstructed by ring-like fibres which occupy not only the opening itself but also the whole oblique tract". He thought the sphincter prevented regurgitation of duodenal contents.

Bidloo in 1685 (cited by 7, 48, 104, 337) illustrated the common channel for bile and pancreatic ducts, which he designated the "orifice provided with fibrous rings".

Bianchus in 1711 (cited by 48, 337) suggested
/that

that contraction of the special muscle at the duodenal end of the common bile duct was responsible for the filling of the gall bladder. He stated that the duct is "furnished with a circle of firm flesh at its opening, a sphincter, so to speak."

Haller, in 1766, (cited by 48) failed to find an independent sphincter for the common bile duct. He considered that compression of the duct by the duodenal muscle prevented regurgitation of intestinal contents. This view prevailed for over 100 years, and even as late as 1869 Luschka confirmed Haller's observations. (48).

Simon Gage, in 1879 (cited by 48, 104, 128, 138, 142, 219, 228, 238, 241, 246, 288, 322, 337, 354) described a sphincter around the bile duct in the cat, while Varriot, in 1882, (cited by 315) and Ranvier in 1886 (cited by 315), are said to have made further observations on animal material. It was, however, not until 1887 that interest in the sphincter was revived.

In this year Ruggiero Oddi (cited by 48, 64, 104, 128, 138, 142, 154, 219, 234, 238, 241, 246, 288, 315, 322, 337) "rediscovered" Glisson's sphincter. He studied the histology of animal and human material and supplemented his findings by a large amount of experimental work. His work on the "sphincter du choledoque", as he called it, was so painstaking and convincing that the sphincter became generally known as the "Sphincter of Oddi", a

term which has persisted to the present day. He described the sphincter as "a more or less pronounced bed of circular fibres encircling the choledochal canal - which one is able to consider as almost completely independent, if one excepts some slender loops which lose themselves between the fibres proper of the intestine". Unfortunately, he presented no illustrations, so that the interpretation of his account of the sphincter has given rise to confusion. As pointed out by Schwegler and Boyden (322), the most reasonable interpretation is that he was referring to the whole of the musculature investing the intramural portion of the common bile duct. They state that Oddi actually knew very little about the anatomy of the human sphincter and that his observations were based mainly on animal material.

Modern Literature: Oddi's work stimulated new interest in the sphincter of the common bile duct, and, since his reports, numerous contributions have been added to the literature. These have been reviewed by Mann (240, 241), Halpert (148), Ivy (170), Boyden and his associates (203, 322), Thiessen (337), Long (219) and others, and most of the original accounts have been available for the present review.

The various investigations which have been mainly concerned with the relation between the choledochal and duodenal musculature, have given rise to two schools of
/thought.

thought: the one maintains that the sphincter represents merely the muscle tunic of the duodenum, while the other claims an independent choledochal sphincter.

The findings of some of the more detailed studies on human material will be discussed.

Znaniecki in 1895 (cited by 148 and 322) was the first to make a special study of the human material. He observed that the numbers of transverse fibres of the common bile duct increased markedly at its lower end to form a sphincter. He followed them to the duodenal papilla and noted that they were best developed in the pre-ampullary region. He failed to find continuity between the muscle of the duct and the muscular coat of the duodenum. Soulie in 1901 (cited by 322) reconstructed a longitudinal section of the pars intestinalis of the common bile duct on the basis of Znaniecki's observations. This clearly shows the pre-ampullary thickening of the sphincter (322).

Letulle and Nattan-Larrier, in 1898, could not find a complete sphincter around the human common bile duct (cited by 148). They noted that the duct

"borrowed" fibres from the duodenal muscle (cited by 322).

Hendrickson, in 1898 (154) studied macerated specimens of human and animal bile ducts. For over 30 years no other description of the muscle of the ducts

/approached

approached his in accuracy and completeness. His findings are well illustrated (See Fig. 17,) and have recently been confirmed by Boyden et alia (203 and 322), Thiessen (337) and others. Briefly they are as follows:-

At the point where the pancreatic and bile ducts penetrate the intestinal muscle there is a distinct hiatus in both longitudinal and circular coats of the duodenum. Several sets of fibres belonging to the ducts are described, viz:-

1. Superficial bundles on either side of the extra-duodenal portion of the duct derived from the longitudinal coat of the duodenum - F fibres, Fig. 17, pg. 58.
2. Deeper longitudinal and oblique fibres covered by the F fibres. They run forward to penetrate the circular muscle of the duodenum, and then bend round the internal aspect of the common bile duct and ampulla, where they decussate - K fibres, Fig. 17. pg. 58.
3. The deepest layer consisting of circular fibres which commence close to the junction of bile and pancreatic ducts and investing the bile duct - I.R. fibres, Fig. 17. He regards these as an independent ring, but, as Schwegler and Boyden (322) point out, they are continuous with
4. a layer of circular fibres embracing the ampulla - S; fibres, Fig. 17, pg. 58.
5. Bundles of fibres encircling the pancreatic duct just before its junction with the bile duct. They commence on the ampulla and further up the duct, and turn abruptly to run in a longitudinal direction - H. fibres, Fig. 17, pg. 58.
6. Fibres lying superficial to the S fibres at the point where the duct penetrates the circular coat of the duodenum. They commence just above the hiatus and do not entirely encircle the duct, but turn forward on the anterior surface of the

/ampulla

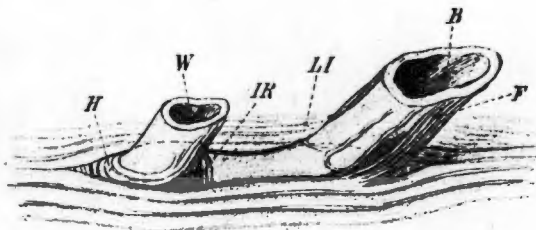


FIG. 28.—Macerated duodenal portion of the common bile-duct of man. The relation of the common bile-duct and the duct of Wirsung to the longitudinal muscular coat of the intestine is shown. $\times 5$.

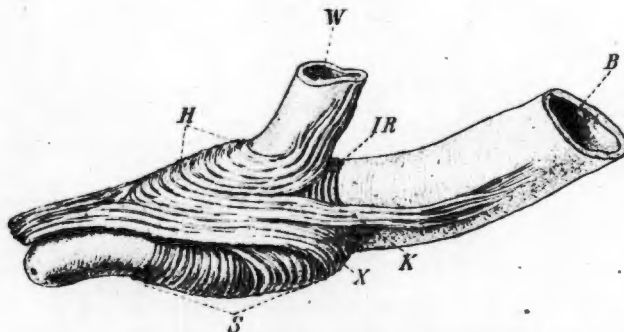


FIG. 30.—Macerated duodenal portion of the common bile-duct of man. All of the intestinal coats have been removed. $\times 5$.

Fig. No. 17.

The Musculature of the Intramural
Portion of the Common Bile Duct.

(After Hendrickson - 154).

ampulla towards the papilla - X fibres,
Fig.17. In many cases these fibres were continuous with the circular coat of the duodenum.

He concluded that the duodenal portion of the human bile duct possesses an independent intrinsic sphincter.

Excellent diagrams of reconstruction of the ducts, as well as diagrams of cross-sections are produced, but no microphotographs of serial sections.

Helly, in 1899 (cited by 322) described longitudinal fibres in the duct, and suggested that their function was to shorten the papilla. He also noted oblique and circular fibres which formed a figure of eight around the bile and pancreatic ducts, suggesting a sphincter for each (cited by 234), but so intermingled as to render it unlikely that one could act without the other (cited by 170).

O. Stracker (cited by 148 and 322), in 1909, examined macerated human and animal bile ducts. He demonstrated in macroscopic sections that the muscle of the duct was independent of the duodenal muscle.

Rost, in 1913, (cited by 148 and 322) during observations incidental to experiments on dogs, described a strong muscle layer arranged circularly around the human papilla.

Auster and Grohn, in 1922, (4) found the muscle fibres of the sphincter scanty and widely separated,

/and

and at no time continuous. They considered that there was fusion of the intestinal and biliary muscles, and regarded the sphincter of Oddi as formed largely by intestinal muscle.

Giordano and Mann, in 1923, (246) demonstrated that the usual position for the sphincter is proximal to the termination of the common bile duct. They found other fibres encircling the pancreatic duct. In 1927 (138) they confirmed these findings, stating that it is usually possible to find a definite bundle of smooth muscle surrounding the common bile duct, but they add that this muscle is intimately intermingled with the duodenal muscle.

Matsuno (cited by 42, 104, 138, 148, 170, 322, 337), in 1923, observed that the muscle of the ^{bile} duct was best developed in the pre-ampullary region. He found that the muscle consisted of a circular band 5 - 10 mm. in length. The fibres were continuous with the duodenal muscle at many points, but were much smaller in size than those of the duodenum. He regarded the muscle sheath as a true sphincter.

Nagai and Sawada (cited by 148, 322), in 1925, studied macerated preparations of the choledoch-duodenal junction in Japanese. They concluded that an anatomical sphincter of the common bile duct existed, and stressed

/the

the variability of the oblique, transverse and longitudinal fibres entering into its formation.

Job (178), in 1926, examined 151 cadavers and found that just inside the duodenal wall the common bile duct had a very definite sphincter. Both the bile and pancreatic ducts had individual longitudinal and circular layers, with a common circular and longitudinal layer almost to the tip of the papilla. As the duct approached the duodenal papilla its musculature gradually decreased in amount. The longitudinal fibres disappeared 1 - 2 mm. from the tip of the papilla; only a few circular ^{fibres} persisted to the tip. He concluded that the duodenal muscle does not form an efficient sphincter.

Porsio (cited by 322), in 1929, found a sphincter but noticed that it was closely intermingled with the intestinal muscle. He inferred that it emanated from the duodenal muscle, arising at the expense of the muscle, as illustrated in his diagram of a longitudinal section.

The Dutch surgeon, Number (cited by 148, 322, 337), in 1931, presented the first series of transverse sections of this region in the adult. Like the work of Hendrickson, his studies outstripped all others in this field (322). Longitudinal, oblique and circular fibres surrounding both the bile and pancreatic ducts are

/described.

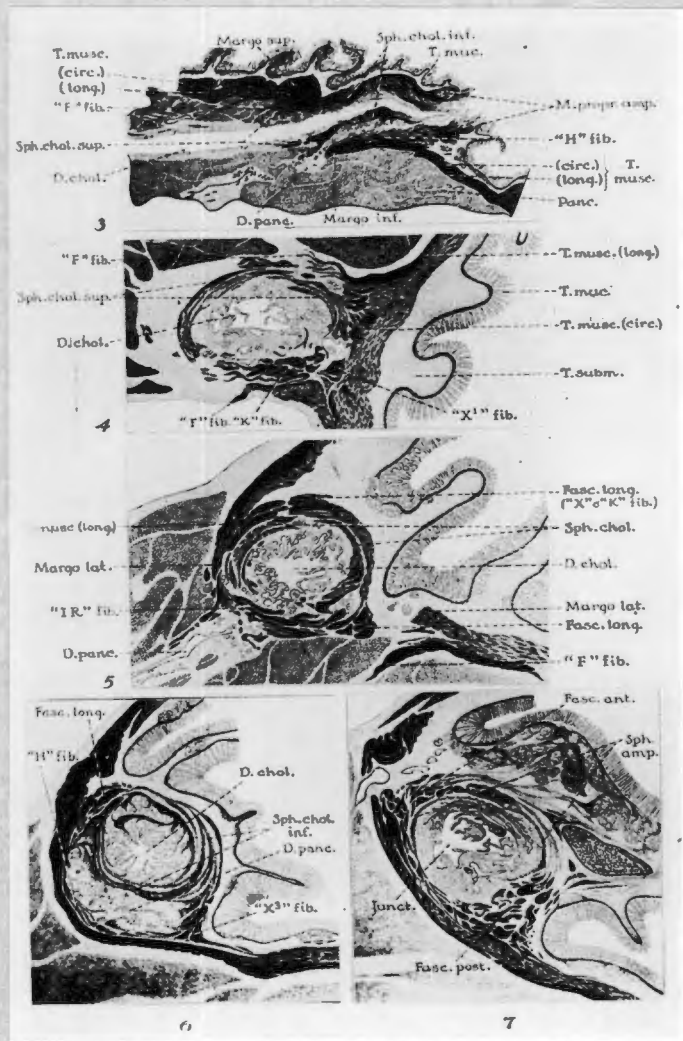


Fig. No. 18.

HuBoer's diagrams of the intramural portion of the common bile duct.

(After Schwegler and Boyden - 322).

Note: The captions were inserted by Schwegler and Boyden (322).

described. Just before the two ducts join, the muscle is arranged in such a way that a figure of eight structure is formed, and in this area the sphincter around the bile duct is best developed. The circular fibres predominate but are mostly incomplete, and are reinforced by oblique and longitudinal fibres, all three together forming a closed mantle around the duct. He considered that the muscle had an ejaculatory as well as a sphincteric function, very much like the ejaculatory muscle around the urethra.

In addition, he found scanty oblique and circular fibres around the papilla, which he thought was capable of peristalsis.

Although he describes the muscle of the ducts as if derived from the longitudinal coat of the duodenum, Schwegler and Boyden (322) point out that he confuses the X, K and F fibres of Hendrickson with the intrinsic muscle of the ducts. They have accordingly appended their own nomenclature to his diagrams. These are illustrated in Figs. 18, pg. 62. It is seen that Schwegler and Boyden (322) interpret most of his diagrams in terms of Hendrickson's findings.

Cestari and Tantini (cited by 322), in 1933, noted that the bile duct possessed an independent muscle which became sparse as it approached the papilla.

Newmann (275) in 1933, observed that there was more muscle in the ampulla than anywhere else in the extrahepatic

/biliary

biliary tract. He concluded that the sphincter of Oddi is separate from the duodenal muscle.

Dardinski, (104) in 1935, reported his observations on 100 macerated specimens. He noted 4 - 5 circular and oblique bands surrounding the base of the papilla. Some of the fibres become continuous with the circular muscle of the intestine. This was the only evidence he could find of an independent sphincter of Oddi. In addition, the duct behind the papilla was constricted by the circular coat of the duodenum, while fibres from the longitudinal coat ran forward on to the papilla.

Deep to the circular and oblique bands on the papilla he found a few longitudinal fibres continuous with those on the bile and pancreatic ducts and extending into the mucous folds of the papilla. He thought their function was to erect these folds.

He concluded that the duodenal muscle is mainly responsible for constriction of the bile duct. The interpretation of his illustrations, however, is difficult.

Boyden and his co-workers have carried out most intensive studies of adult and foetal material by serial sections and macerated preparations. The following is a brief resume of the findings reported by them in 1937 (50, 322), 1940 (203) and 1941 (52, 53). These findings are in close agreement with those of Hendricksen and

Hufoer, whose investigations are constantly referred to by the authors.

A. Fibres derived from the intestinal muscle.

The pancreatic and bile ducts pass through apertures in the longitudinal and circular muscles of the duodenum. The latter is called the choledochal window. In adults the window is reduced to a mere slit by the post-natal growth of camouflaging bands of muscle from its margins. The hiatus in the longitudinal coat is less-markedly reduced. The bands are classified as follows:-

1. Reinforcing or R. Fibres - See Fig. 19 pg. 67-R. These are scattered bundles of muscle that reinforce the angles of the window. They pass from both surfaces of the upper and lower margins of the window to fuse with the intestinal coats on the opposite side. They represent the fibres marked X1, X2 and X3 in Hufoer's diagrams and Schwegler and Boyden's illustrations of foetal sections.
2. Connecting or C. Fibres - See Fig. 19, pg. 67-C. These are closely associated with the R fibres and are likewise fully identifiable only posteriorly. They attach the major papilla and ducts to the tunica muscularis of the gut and represent the fibres which have been described as "borrowed" or "emanating from" the duodenal muscle. They pass from the superior and inferior margins and the angles of the window and hiatus in both directions, to pass longitudinally and diagonally along the common bile duct and ampulla. They correspond to Hendrickson's F, K and X fibres. All are primarily criss-crossing fibres and it is suggested that they not only tie the papilla to the intestinal wall, but also erect the papilla and shorten the duct.

B. Sphincters of the Major Papilla.

Three different sets of fibres are described:-

1. The Musculus proprius choledochus:- (Sph.chol.Fig.19D, pg.67). This is usually a well-developed mass of circular muscle 5-10 mm. long surrounding the lumen of the bile duct like a cohesive band. It consists of two parts:*

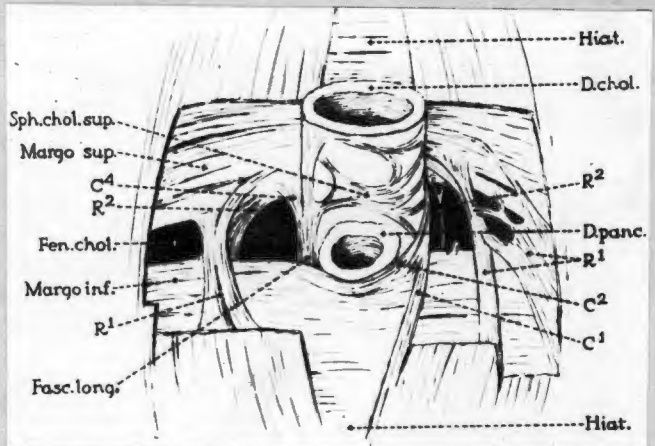
(a) The pars superior. (See Fig. 19A., Pg. 67, Sph.chol. sup.), begins just outside the duodenum as scattered bundles which represent a condensation of the circular muscle found higher up in the duct. In the window they form a complete sphincter. Hendricksen demonstrated them in Fig. 32 of his article but omitted to mention them in the text. This sphincter is shown in Nuboer's diagrams. (Figs.18, page 62).

(b) The pars inferior (See Fig.19C & B., Page 67-Sph. chol. sup.) is represented by a layer of circular muscle continuous with the pars superior and extending from the window to the junction between the bile and pancreatic ducts. Its lower end is best developed. It corresponds to Hendrickson's I.R. and upper fibres, and Nuboer indicated it in his diagrams, although he failed to recognise it as an independent sphincter - Figs.18, page 62).

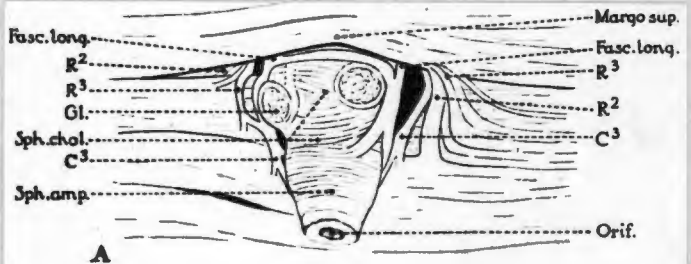
2. The Musculus proprius ductus pancreaticus (See Figs.19, C & D., page 67, Sph.panc.). This is represented by transverse arcs in relation to the pancreatic duct just before it joins the bile duct. Usually they half encircle the duct and then pass in a longitudinal direction up the duct. In two of 12 adult specimens examined they encircled the duct completely. They correspond to Hendrickson's H. fibres (Fig. 17, Pg.58) and are also shown by Nuboer. Their main function is probably to shorten the pancreatic duct rather than to act as a sphincter.

The Choledocho-duodenal Junction (After Boyden - 52 & 203).

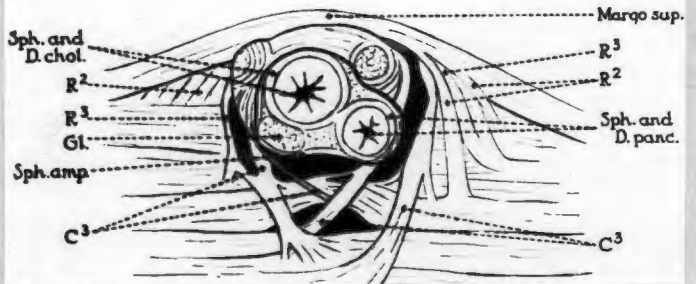
A. External surface of a macerated preparation.



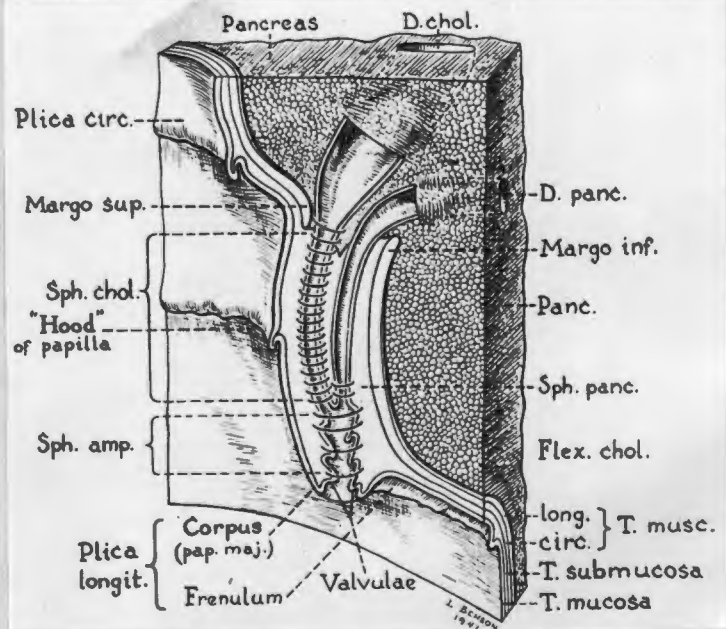
B. Mucosal surface of a macerated preparation - papilla in natural position.



C. Same as B. but papilla elevated and distal half snapped off.



D. Diagrammatic reconstruction showing the various sphincters.



3. The Musculus proprius ampullae (See Figs. 19, B & D, Pg.67 Sph.Amp.) Just before the pancreatic and bile ducts unite to form the ampulla there is a peripheral sheath of muscle encircling both ducts. This is the beginning of the sphincter ampullae, which, in only 2 of 12 specimens, continued as a well-developed muscle nearly to the end of the papilla. Its fibres merge with those of the longitudinal fasciculi.

C. The Longitudinal Fascicles. (See Figs.19 A & B, pg.67, Fasc.long.). These are two bundles running lengthwise on to the papilla in the interval between the two ducts. They consist of C fibres (Hendrickson's K and X fibres) and also intrinsic fibres connecting different transverse levels of the ducts and ampulla. (Lower parts of Hendrickson's H and S fibres). Note:- The authors have produced excellent diagrams of foetal and adult reconstructions (Figs.19 A,B & C, Pg.67) and numerous microphotographs of foetal sections, but, unfortunately, not of adult serial sections.

Gordon-Taylor (139), in 1942, studied specimens prepared by Professor Kirk. In no case could he find a circular arrangement of fibres at or near the papilla. He found that the more basal part of the duct contains oblique and longitudinal fibres which "can be definitely and indubitably traced in continuity with the circular muscle coat of the duodenum." Many of the longitudinal

/fibres

fibres pass into the connective tissue core of the villous processes of the papilla. He concludes that the muscle sheath of the duct is derived from the circular muscle coat of the duodenum. No microphotographs or illustrations are produced.

Kirk (196), in 1944, reported on sections of foetal and adult material. He found longitudinal fibres on the duct commencing just outside the gap in the longitudinal coat of the duodenum. They passed with the duct through the gap.

Thickening of the duodenal coat at the point of penetration of the duct was very noticeable, while the submucosal portions of the ducts were surrounded by circular muscle continuous with the circular coat of the duodenum. As these fibres passed towards the papilla they became oblique and entered the valvular fringes of mucous membrane. He agrees with Dardinski that the function of these fibres is to erect the fringes.

No circular muscle was found at the ostium. He concludes that the duodenal wall is mainly responsible for the sphincteric action around the ducts.

His descriptions are illustrated by microphotographs (See Fig. 27 pg 83)

Summary:

An analysis of the numerous anatomical investigations

on this important region allows one general conclusion, viz: the greater weight of evidence supports the existence of variable amounts of smooth muscle which may possess sphincteric activity at the outlet of the common bile duct. This muscle is so complex and so intimately associated with the duodenal muscle that opinions on its origin differ. Darkinski (104), Gordon-Taylor (139), Kirk (196), Adster and Crohn (4), Giordano and Mamm (246), etc. conclude that the muscle is derived from the duodenum. Hendrickson (154), Boyden et alia (50, 52, 53, 203, 322), Thiessen (337), Job (178), Newmann (275), etc. claim that they have demonstrated independent muscle belonging to the ducts, which is reinforced by fibres from the duodenum.

PERSONAL OBSERVATIONS ON THE MUSCULATURE
OF THE BILE DUCTS.

Material used:

The bile ducts of 20 cases varying in age from 9 days to 69 years were studied. The specimens were obtained from autopsies performed at the Department of Pathology at the University of Cape Town and at the Government Laboratory, Capetown. None of the cases had evidence of disease of the biliary tract and the specimens were procured as soon as possible after death.

Method of study:

The bile ducts were fixed in formalin and embedded in paraffin wax. Serial sections of most of the specimens

/were

were cut and mounted.

The sections were stained by Mallory's method for muscle and connective tissue. With this method muscle stains red and connective tissue stains blue.

Microphotographs of selected sections were taken. In these the muscular tissue appears much darker than the connective tissue.

Description of findings:

The walls of the bile ducts consist of three layers, vis:-

1. An inner mucous membrane which disintegrates within a few hours after death.
2. A submucosa of thick and compact connective tissue.
3. An outer coat (adventitia) composed of loose connective tissue.

The muscle is situated in the outer layer. It will be described under the following headings:-

1. The hepatic duct.
2. The extramural portion of the common bile duct.
3. The intramural portions of the bile and pancreatic ducts and the ampulla.

1. The Hepatic duct.

Muscle fibres are present in the adventitia of all the specimens, but they are always extremely scanty.

Most of the fibres are longitudinal. They are usually scattered but, in some sections, they are arranged into bundles (See Fig. 20B, Pg.72).

No sphincter is present in any part of the duct, but

/occasional

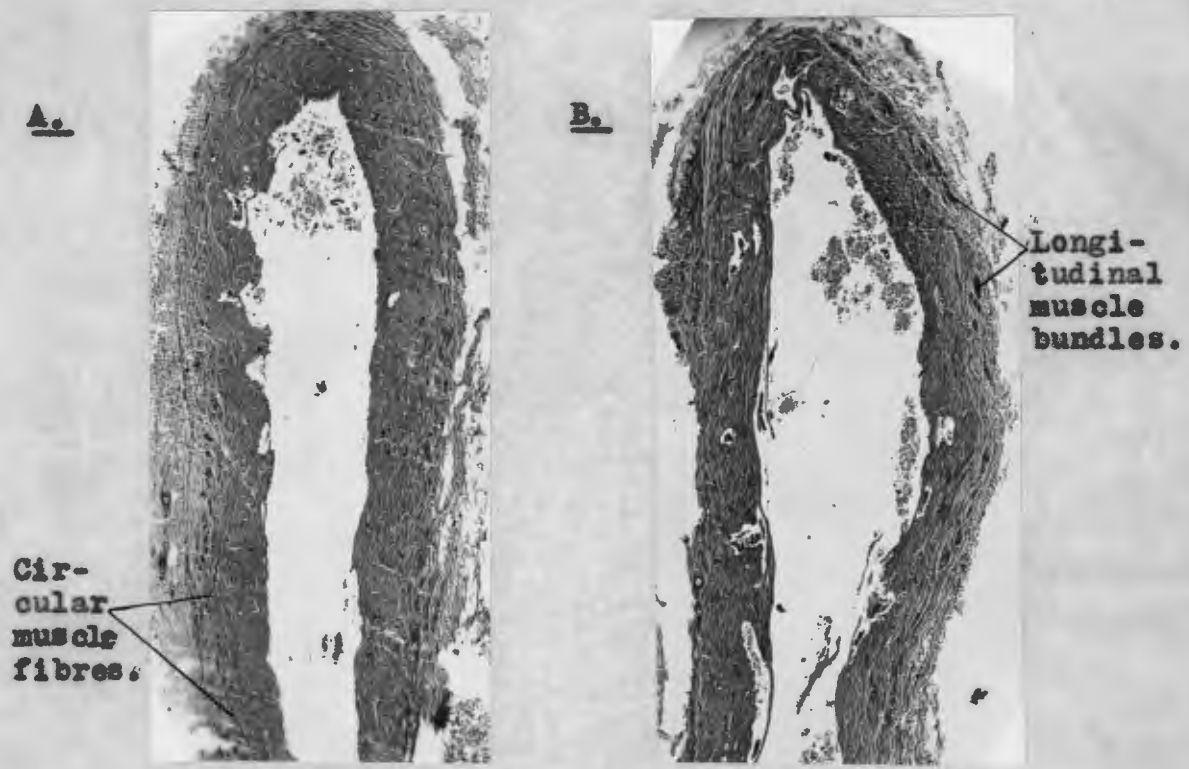


Fig. 20
Sections of the Hepatic Duct. (X 18).

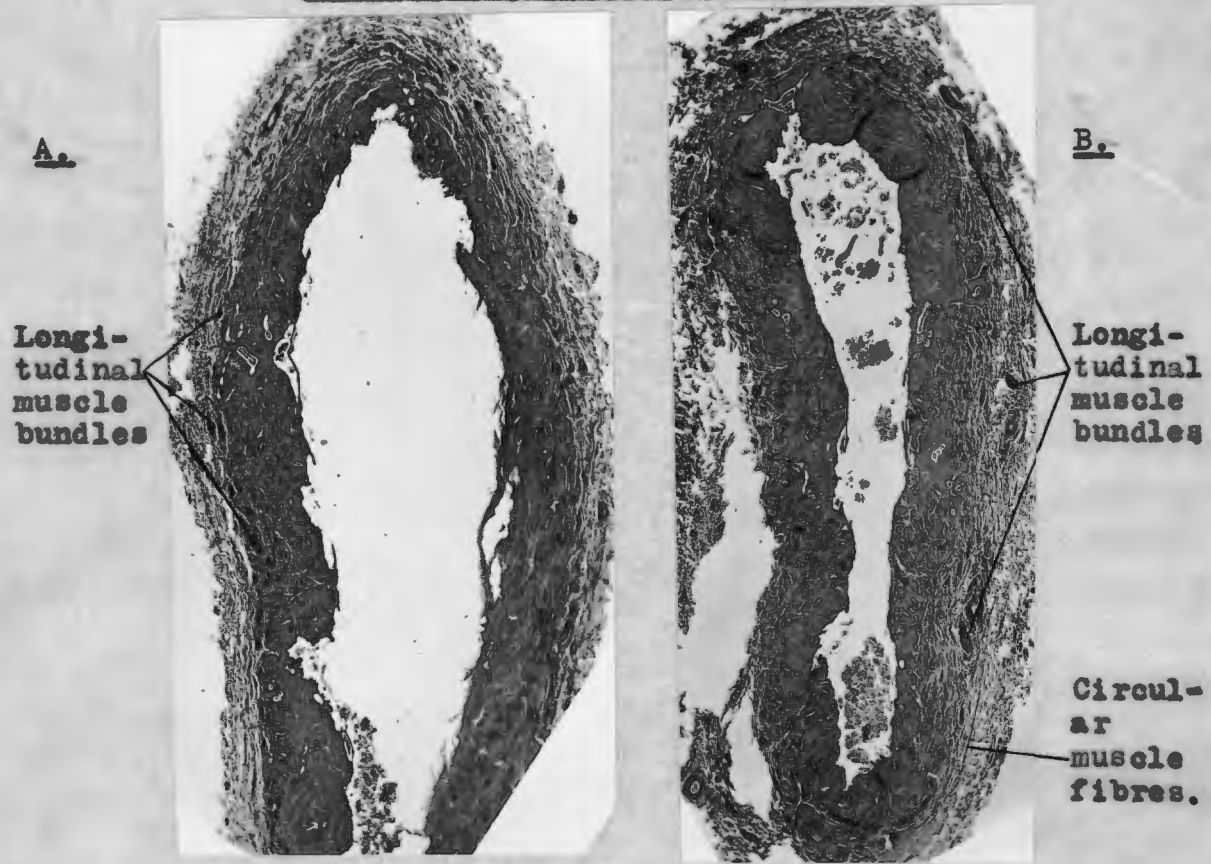


Fig. 21.
Sections of upper 1/3 of the Common Bile Duct. (X 18).

occasional circular and oblique fibres occur at various levels (See Fig. 20A, Pg.72).

The Extramural Portion of the common bile duct.

Muscle tissue is present in every specimen. It is situated in the outer layer of the duct wall and is best developed in the lower third of the duct, gradually diminishing towards the hepatic duct.

Longitudinal fibres lie in the inner zone and circular and oblique fibres in the outer zone.

Upper Third: Longitudinal fibres predominate and are usually arranged in several small bundles (Fig. 21A & B, Pg.72).

Circular and diagonal fibres are scanty and not as well-developed as the longitudinal fibres (Fig.21B, Pg.72).

Middle Third: The longitudinal fibres are more numerous and are gathered into good-sized oval bundles scattered around the duct. In cross-sections there are usually several of these bundles separated by connective tissue containing smaller bundles and isolated fibres (Fig. 22A, Pg.74).

Circular and diagonal fibres are better-developed than in the upper third and, in some cases, they are arranged into small circular bundles (Fig.22B, Pg.74).

Lower Third: The muscle is constantly well-developed - see Figs. 23 A & B, Pg.74.

Longitudinal fibres arranged into large and small bundles are fairly numerous but do not form a continuous sheath around the duct.

Circular and diagonal fibres are much more numerous and better-developed than in the upper regions of the duct. They increase progressively as the

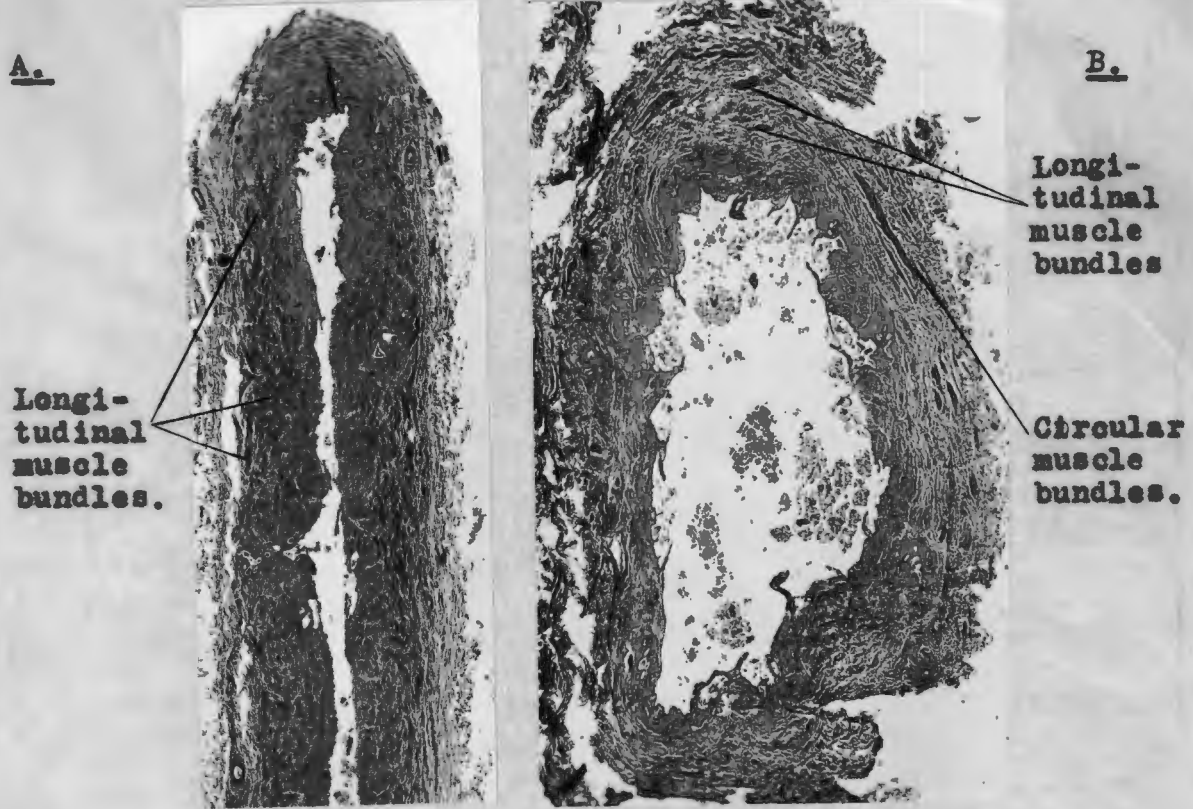


Fig. 22
Sections of the Middle 1/3 of the Common Bile Duct.
 (X 18).

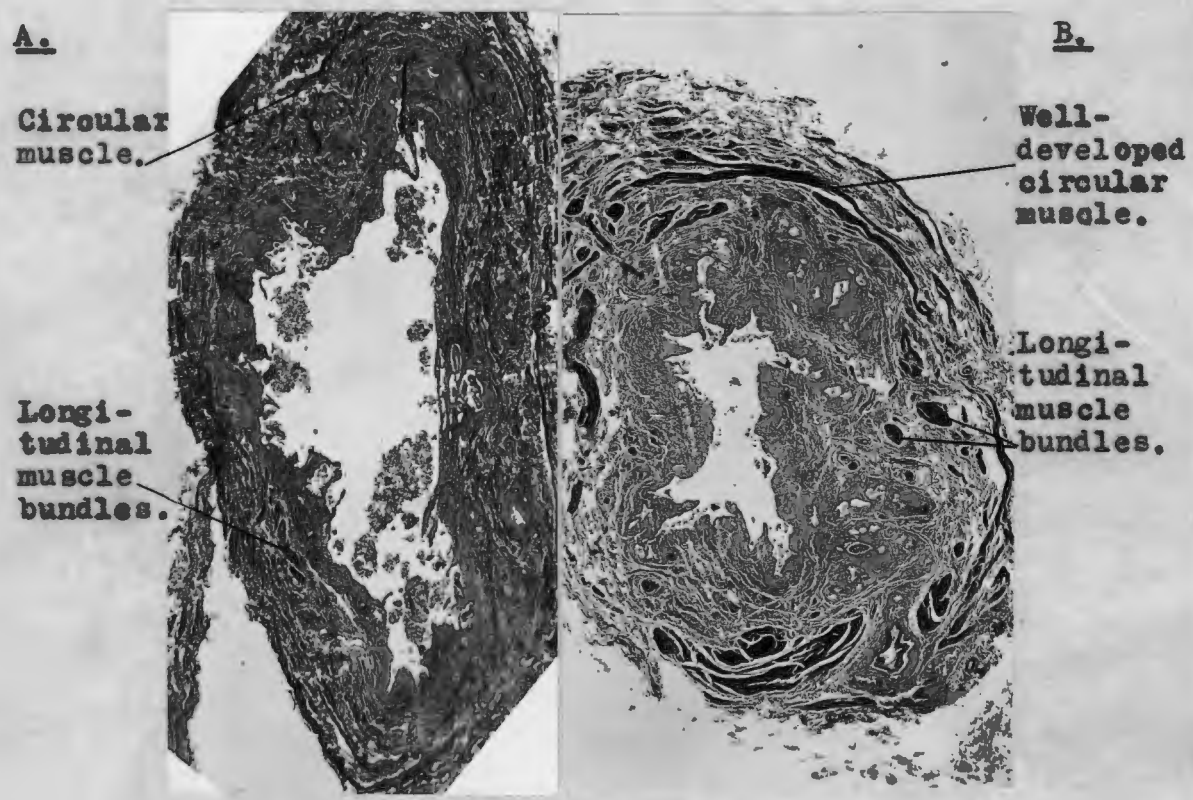


Fig. 23
Sections of the Lower 1/3 of the Common Bile Duct.
 (X 18)

duodenum is approached. In all sections there are circular bundles (Fig. 23A, Pg.74). and in some they form almost a continuous layer around the duct (Fig. 23B, Pg.74).

The intramural portions of bile and pancreatic ducts and the ampulla:

Although there is much intermingling of fibres, two layers of muscle tissue can be identified, viz:-

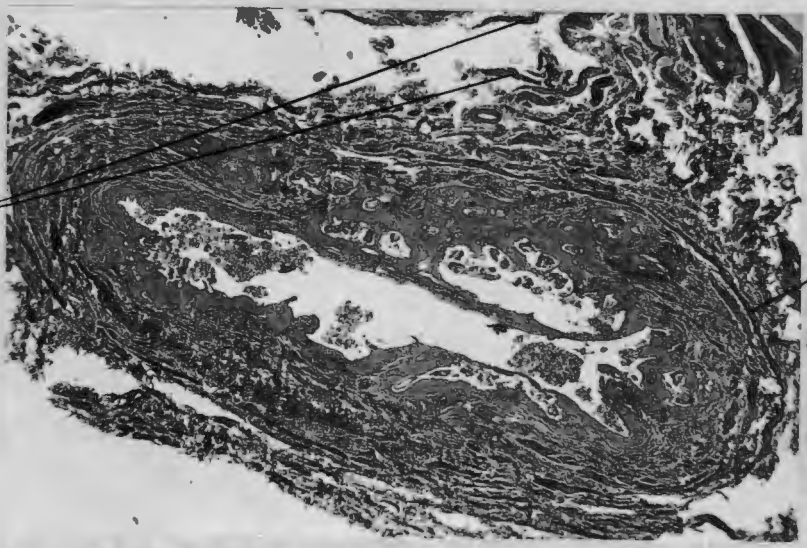
1. An inner layer composed of circular and longitudinal fibres surrounding the ducts and ampulla. The individual fibres are smaller and stain less deeply than the duodenal muscle fibres, and, on tracing them liverwards, they are continuous with the longitudinal and circular bundles of the extramural portion of the bile duct.
2. An outer layer of circular, oblique and longitudinal fibres continuous with and obviously derived from the duodenal muscle.

The inner layer:

(a) Bile duct. At the point where the duct penetrates the intestinal muscle the circular fibres found higher up in the duct increase considerably and form a complete circular layer around the duct (Figs. 24A & B, Pg.76). This corresponds to the "sphincter choledochus superior" of Boyden et alia (See Fig. 19, Pg.67).

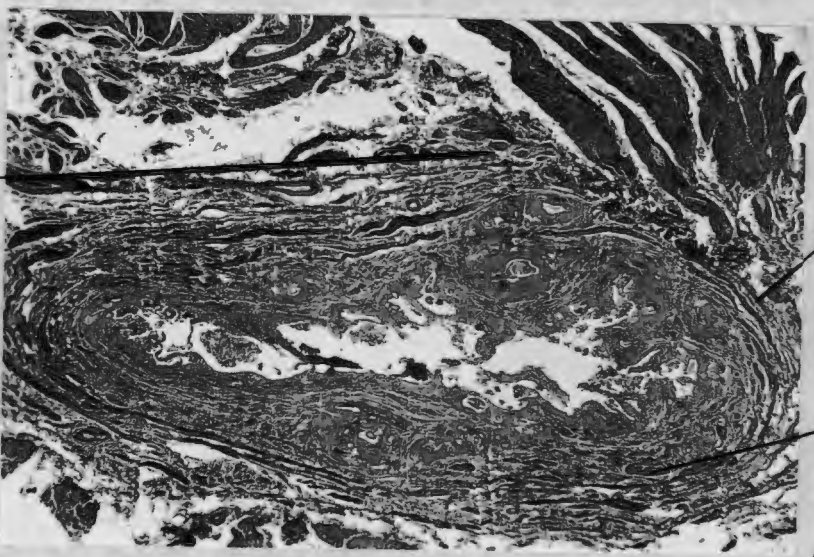
From this point to the junction between the bile and pancreatic ducts the circular sheath of muscle surrounding the bile duct becomes more pronounced, being best-developed just before the ducts join (Figs. 24C, Pg.76 & (25A, Pg.77). This well-developed portion corresponding to the "sphincter choledochus inferior" of Boyden et alia (See Fig.19, Pg.67) and to the "I.R.fibres" of Hendrickson (See Fig.17, Pg.58).

A.
Connect-
ing
fibres
from the
duodenum.
(C or F
fibres).



Intrinsic
circular
muscle
(Sphincter
chole-
dochus
superior).

B.
Rein-
forcing
fibres
from the
duodenum
(R or K
fibres).



Intrinsic
circular
muscle
(Sphincter
chole-
dochus
superior)

Longi-
tudinal
bundles.
(Intrinsic)

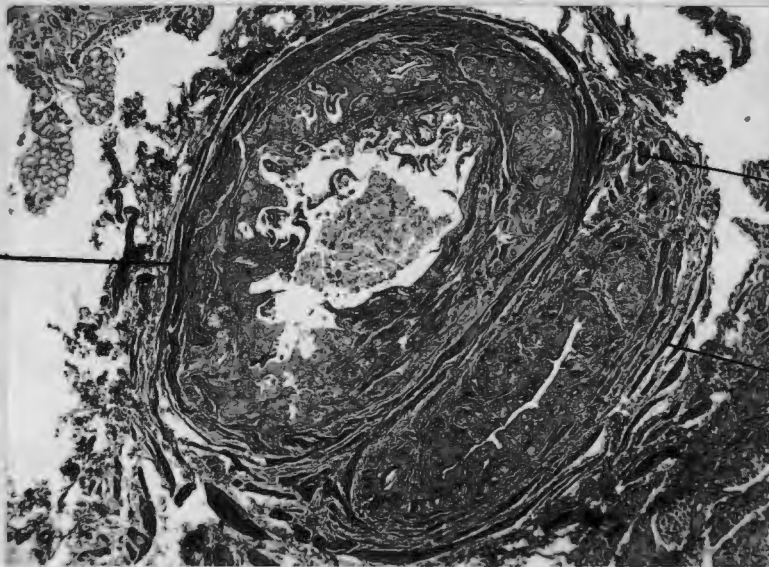
C.
Intrin-
sic
circular
muscle
(Sphincter
chole-
dochus
inferior)



Connect-
ing
fibres
from the
duodenum
(C or X
fibres).

Fig. 24.
Sections of the bile duct soon after
its entry into the duodenal wall. (X 18).

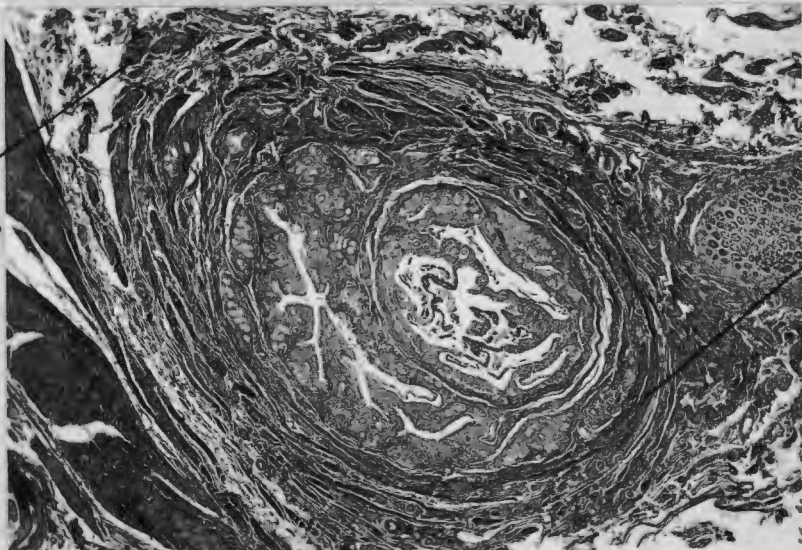
A.
Intrinsic
circular
muscle
(Sphincter
chole-
dochus
inferior).



Longi-
tudinal
fascicles.

Circular
muscle
(Sphincter
pancreati-
cus).

B.
Longi-
tudinal
fascicles.

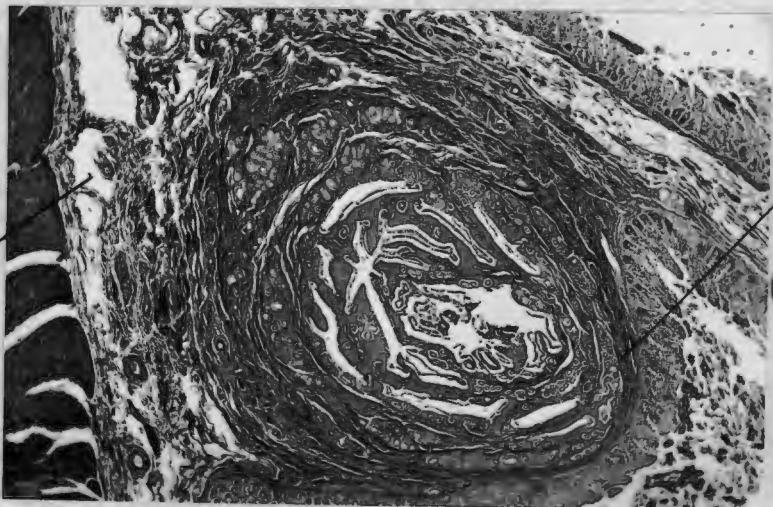


Intrinsic
circular
muscle
(Sphincter
ampullae).

Fig. 25

Sections of the bile and pancreatic
ducts just before they unite. (X 18).

Large gap
between
duodenal
muscle
and
ampullary
muscle



Intrinsic
circular
muscle
(Sphincter
ampullae).

Fig. 26

Section of the Common Ampulla. (X 18).

Deep to the circular layer there are scattered longitudinal fibres and bundles (Fig. 24 B Pg. 76) These correspond to some of Hendrickson's "K fibres", (See Fig. 17 Pg. 58).

(b) Pancreatic duct. Similar fibres surround the pancreatic duct. They are not as well-developed as those of the bile duct and usually do not extend to the part of the duct adjacent to the bile duct (Fig. 25 A Pg 77) They correspond to the "musculus proprius pancreaticus" of Boyden et alia (Fig. 19 Pg 67) and to some of the "H fibres" of Hendrickson (See Fig. 17 Pg. 58)

(c) Ampulla. An incomplete sheath encloses the bile and pancreatic ducts just before they join to form a common ampulla (Fig. 25 B Pg. 77)

This sheath continues on to the ampulla, gradually fading away towards the papilla (Fig. 26. Pg. 77).

A complete circular band surrounding the papilla is seldom present. This ampullary muscle sheath corresponds to the "musculus proprius ampullae" of Boyden et alia (See Fig. 19 Pg. 67).

The outer layer. In all specimens fibres from the intestinal muscle run in both directions on to the ducts. These are the "C and R fibres" and "longitudinal fascicles" of Kreilkamp and Boyden and the "F", "K" and "X fibres" of Hendrickson, e.g.,

1. In sections of the bile duct just as it passes into the duodenal wall, fibres pass

/from

from the intestinal wall on to the extramural portion of the duct. These correspond to the "C fibres" of Kreilkamp and Boyden, and to the "F fibres" of Hendrickson (See Fig. 24 A Pg.76)

2. In sections of the duct where it lies in the duodenal muscle, longitudinal and circular bundles extend from the intestinal muscles onto the intramural portion of the duct. These correspond to the "R" and "C fibres" of Kreilkamp and Boyden and to the "K" and "X" fibres" of Hendrickson (Figs. 24 B&C Pg. 76) and compare with Fig. 18 Pg.62)
3. In sections taken nearer the duodenal mucosa, bundles of longitudinal fibres run outside the circular sheaths of the ducts. These are mainly aggregated into two groups of muscle bundles situated in the interval between the bile and pancreatic ducts (Figs. 25 A & B Pg.77) These fibres correspond to the anterior and posterior fascicles of Kreilkamp and Boyden (See Fig. 18 Pg.62) They merge with the longitudinal bundles of the inner layer, and run into the papillary processes of the ampulla, thus corresponding to the fibres described by Dardinski and Kirk.

Summary of Personal Observations.

A study of the musculature of the bile ducts of 20 autopsy specimens has revealed the following findings:-

1. The extraduodenal portions of the bile ducts:
Inner longitudinal and outer circular and oblique fibres are present in all parts of the ducts. These fibres, particularly the circular and oblique ones, are very scanty in the hepatic duct and upper third of the common bile duct.
In the lower part of the common bile duct the longitudinal fibres are arranged in definite bundles, but a complete longitudinal sheath is not formed. The circular and oblique fibres increase considerably in the last $\frac{1}{4}$ - 1 inch of the duct, where they form almost a complete layer.
2. The intramural portion of the common bile duct.

The musculature is extremely complex and closely related to the duodenal muscle, but outer and inner layers can be distinguished. The outer layer consists of fibres obviously derived from the duodenal muscle. Some of these fibres encircle the ducts, while others pass in a longitudinal direction towards the duodenal papilla. They are regarded as the "C" and "R fibres" and "longitudinal fascicles" of Kreilkamp and Boyden (322) and Thiessen (337), and as the "F" "K" and "X fibres" of Hendrickson (154). The inner layer consists of circular and longitudinal bundles surrounding the bile and pancreatic ducts and the ampulla. The fibres are continuous with the muscle of the extraduodenal portions of the bile ducts, and they are smaller and stain less deeply than the duodenal muscle fibres. In several sections they are completely separated from the duodenal muscle.

DISCUSSION.

1. The extraduodenal portions of the bile ducts.

2. In this study sufficient evidence has been produced to disprove the statement of some authorities that the bile ducts possess no muscle. The present findings suggest that muscular tissue is constantly present in the bile ducts of the human being, and that this muscle is well-developed in the lower third of the common bile duct. The findings agree with those of Burden (64), and support his view that the muscle is sufficiently well-developed to render the bile ducts contractile. The contractibility of the bile ducts, however, has to be determined by other methods of investigation.

2. The intramural portion of the common bile duct.

It is agreed that a sphincter mechanism surrounds the intramural portion of the common bile duct. The origin of this sphincter, however, is the subject of controversy.

(a) Fibres derived from the duodenum.

All workers agree that the duodenal muscle contributes fibres to the sphincter of the common bile duct. These fibres are clearly demonstrated in the sections prepared for this study. Some authorities believe that they do not constitute the true sphincter, e.g., Hendricksen (154) regards them as supporting fibres (F, K and X fibres), while Boyden et alia (52, 53, 203) and Thiessen (337) call them connecting (C) and reinforcing (R) fibres. Other authorities (104, 139, 196) believe that the sphincter is derived entirely from the duodenum, but this view depends on their interpretation of the inner layer of the sphincter.

(b) The inner layer: It is difficult to analyse the origin of the inner layer of the sphincter without methods of visualising all three dimensions.

Most of the investigators who have studied three-dimensional reconstructions, claim that this layer is an independent, intrinsic sphincter. This is illustrated in the diagrams of macerated preparations and reconstructions studied by Hendrickson (154), by Boyden et alia (50, 52, 53, 203, 322) and by Thiessen (337).

The findings of the present study of serial sections, support the view that this inner layer is an independent sphincter, e.g.,

1. It is continuous with the musculature of the extraduodenal portions of the bile ducts.
2. The fibres are smaller and stain less deeply than those of the duodenum.
3. In many sections the layer is clearly separated from the duodenal muscle.

4. The layer corresponds to the "sphincter choledochus" of Boyden (203). This was established by comparing the present sections with Nubeer's diagrams (as annotated by Schwegler and Boyden (322)), and with Boyden's (53, 322) microphotographs of foetal sections.

On the other hand, other workers have failed to demonstrate an intrinsic musculature, and claim that the sphincter is derived entirely from the duodenal muscle. Unfortunately, most of these authors do not illustrate their findings, and it is thus impossible to criticise their conclusions. However, illustrations of the material used by Nubeer (reproduced by 322), Dardinski (104), Kirk (196) and Gordon-Taylor (139) are available for comparison.

Nubeer's diagrams, which have been carefully studied by Schwegler and Boyden (322), have been mentioned before. These workers point out that his drawings demonstrate an independent musculature in addition to the fibres derived from the duodenum.

In his illustrations of macerated specimens, Dardinski (104) demonstrates muscle bands situated on the ampulla, but he does not illustrate the muscle of the ducts themselves, nor the fibres derived from the duodenum. His descriptions are equally confusing. Moreover, more recent maceration studies by Kreilkamp and Boyden (203) and by Thiessen (337) show that his work is incomplete.

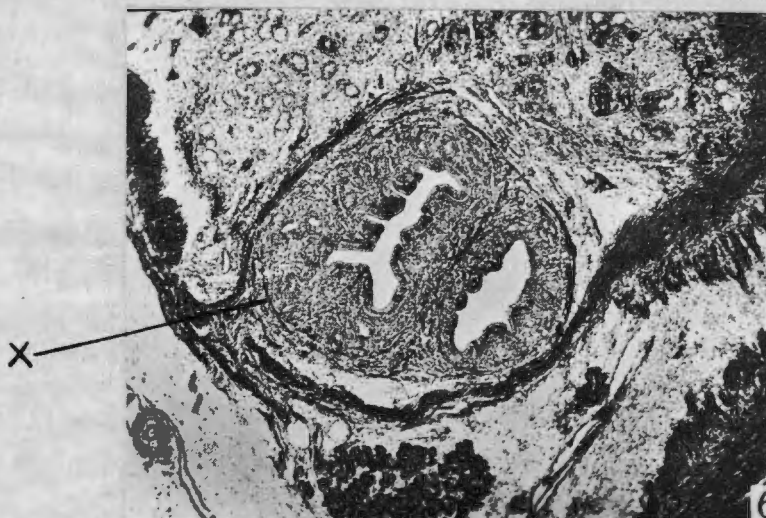


Fig. 27

The intramural portion of the common bile duct. (After Kirk - 196).

Note: The muscle marked X is not continuous with the duodenal muscle.

Kirk (196) presents only two microphotographs of sections of the adult papilla, and in neither are the various muscle fibres labelled. Fig. 27 pg. 83, which he uses to illustrate his conclusions, is a photograph of a section of a foetal duct. This shows the outer layer of muscle obviously continuous with the duodenal muscle, but, in addition, an inner layer, composed of smaller fibres, is clearly seen. (Fig. 27 pg. 83) He fails to describe this layer, which corresponds to the inner layer described in this study, and to the musculus proprius ampullae of Kreilkamp and Boyden (203).

Gorden-Taylor's (139) views are similarly criticised because his descriptions are based on the sections prepared by Kirk (196).

CONCLUSIONS:

1. All parts of the main bile ducts possess an intrinsic musculature. This muscle is very scanty in the hepatic duct, but increases as the duodenum is approached. It is well-developed in the lower third of the common bile duct.
2. Sufficient muscle is present in the extraduodenal portion of the common bile duct to support the view that the duct is capable of contracting independently.
3. Although the intramural portion of the common bile duct is reinforced by muscle fibres from the duodenum, it possesses its own intrinsic sphincter. This is the sphincter described by Oddi.

CONGENITAL ABNORMALITIES.

CONGENITAL ABNORMALITIES OF THE
BILE DUCTS.

Minor variations of the extrahepatic ducts and their blood supply have already been discussed and their frequency has been stressed.

Grosser departures from the normal are much rarer but they are of great clinical significance. They are often the cause of ill-health and a small number are incompatible with life. (32, 316).

It is not always clear exactly how the abnormalities have originated, but authorities agree that they are due to errors of development. Several workers (259, 336, 316) point out that anomalous biliary structures in man represent normal arrangements in lower animals.

In this chapter the data on the most important abnormalities affecting the main ducts directly or indirectly are reviewed. Information obtained from the literature is supplemented by data personally collected on the following anomalies:-

1. Congenital absence of the gall bladder - 3 cases.
2. Congenital cystic dilatation of the common bile duct - 1 case.

3. Congenital obliteration of the bile ducts - 7 cases.
4. Accessory hepatic ducts - 4 cases.

Total: 15 cases.

CONGENITAL ABSENCE OF THE GALL BLADDER.

This is a very rare and interesting anomaly which merits special consideration in a study of the bile ducts.

In about half of the recorded cases the abnormality is associated with atresia of the bile ducts (145). Most of these cases are incompatible with life.

In the rest the absence of the gall bladder is the only abnormality noted. Only this variety, which represents true congenital absence of the gall bladder, is dealt with in this section.

The literature contains several contributions on the subject (111, 131, 133, 145, 254, 259, 311, 314, 316), the most recent available article being that of Dixon and Lichtman (111) in 1945.

These authors collected 30 cases from the older literature and 50 reports since 1900, to which they added 10 cases of their own, i.e., a total of 90 cases.

Three additional cases are reported in this thesis.

Report of Cases:

/Case 1.

Case 1 - an autopsy specimen. See Figs. 28A

and B, page 88.

This specimen was discovered during routine dissection of a cadaver in the anatomical laboratory and is now kept in the surgical pathology museum. It was removed from an adult and carefully dissected by Mr. J. Jordaan.

As illustrated in Figs. 28A and 28B, page 88, there is no vestige of a gall bladder and the liver presents no distinct gall bladder fossa.

A single duct passes from the portal fissure to the duodenum. It is 8 cm. long, and the average width of the flattened structure is 7 mm. About 1 cm. from the duodenum it is joined by the pancreatic duct and the two ducts enter the duodenum at the usual site.

The walls of the duct are perfectly smooth with no localised dilatations or knobs to suggest a rudimentary cystic duct.

Its relations to the structures in the lesser omentum are within normal limits. The right hepatic artery passes behind its upper end.

No calculi could be felt in any part of the duct.

The single duct passes into the hepatic tissue for a distance of 1.8 cm. and then divides into right and left branches. There is no sign of an intrahepatic gall bladder.

The musculature of a longitudinal strip removed from the lower third of the bile duct was studied. The muscle is more scanty than that of normal ducts, but definite longitudinal bundles are present, (See Figs. 29A, page 89,) and occasional circular fibres can be seen.

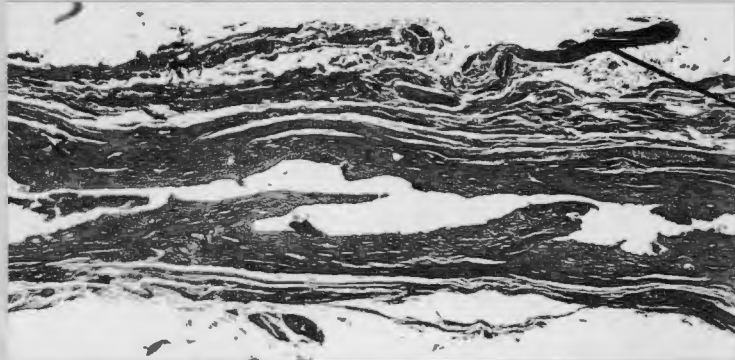
Case 2 - D.C.M. an European male aged 39 years.

This patient was operated on by Major Lennox Gordon at the Wynberg Military Hospital on 6th September, 1945. He had symptoms suggestive of biliary disease and a cholecystogram failed to reveal a gall bladder shadow.

A.No gall
bladder
fossaBile
ductB.No intra-
hepatic
gall
bladderIntra-
hepatic
division
of the
bile duct.Fig.28Congenital absence of the
gall bladder.Case 1.

A.

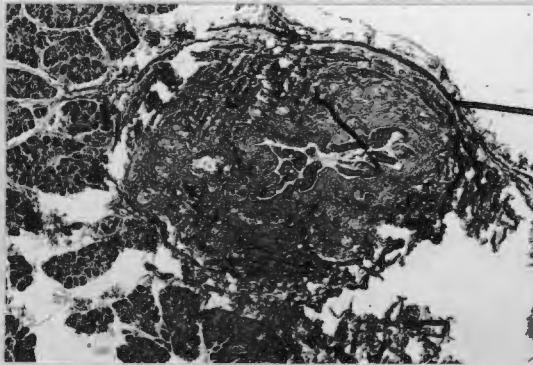
Strip of the
duct of an
adult.
(X18).



Longi-
tudinal
muscle
bundle.

B.

Lower third of
the duct of an
infant.
(X30).



Circular
muscle
bundles.

C.

Ampulla of an
infant.
(X30).



Scanty
muscle
fibres.

FIG. 29

The muscle of the bile ducts
in congenital absence of the
gall bladder.



Fig. 30

Congenital absence of
the gall bladder - Case 3.

At the operation the liver was seen to consist of several lobes, and there was no evidence of hepatitis or cirrhosis. At the usual site of the gall bladder fossa there was a deep fissure between adjacent lobes.

There was no sign of a gall bladder. The common bile duct, which was somewhat dilated, was traced to the portal fissure, where it passed into the liver without branching. The walls were perfectly smooth with no evidence of a cystic duct. The relations to the structures in the lesser omentum were normal. No stones could be palpated.

Although the presence of an intrahepatic gall bladder in this case cannot be disproved without a dissection of the liver, the completely negative cholecystogram in conjunction with the operative findings which are identical to the findings described in Case 1, suggest that it is a genuine case of congenital absence of the gall bladder.

Case 3 - P.M.179/46. - An autopsy specimen.

This specimen was obtained from a coloured female aged 18 hours. The child had multiple congenital abnormalities and had died from inhalation pneumonia. The body was not jaundiced and bile-stained meconium was present in the intestines.

As illustrated in Fig. 30 page 90 the liver is normal in size (a portion of the left lobe was removed for section) with no evidence of biliary cirrhosis.

There is no sign of a gall bladder and the liver presents no gall bladder fossa (which is usually well-marked in newborn infants).

A single duct passes from the liver to the duodenum, where it opens into the lumen of the gut through a prominent papilla. (Indicated by the probe in Fig. 30 page 90). The bile duct is about one and a half times as wide as the ducts of normal infants. Its walls are perfectly smooth with no localised dilatations.

The liver was carefully dissected to follow the intrahepatic course of the duct. It divides at some distance from the portal fissure into right and left

/branches.

branches. There was no sign of an intrahepatic gall bladder.

The musculature of the bile duct was studied and the findings are illustrated in Figs. 29 B & C, page 89. Briefly they are as follows:-

Extraduodenal portion: Scanty muscle bundles consisting mainly of longitudinal fibres are present in all parts of the common bile duct, but do not appear in the hepatic duct. They are well-developed in the lower part of the duct only. The musculature is definitely less well-developed than that of other infants of the same age.

Intramural portion: Circular fibres surround this portion of the duct almost to the tip of the duodenal papilla. They are scanty and do not form a homogeneous layer as in other infants of the same age.

DISCUSSION:

These three cases illustrate several points mentioned in the literature.

Anatomy. Among the 60 cases reported since 1900 the cystic duct was absent in 42, present in 4 and not mentioned in 14. The gall bladder fossa was absent in 25, present in 7 and not mentioned in 28. In the three cases described the cystic duct is absent from all, while the gall bladder fossa is absent from two and present in one.

The size of the common duct varies. It was noted in 39 of the 60 cases reported on by Dixon and Lichtman (111). Among these it was dilated in 19 and normal in 20, but 9 of the dilated ducts contained stones.

In the three cases described, the duct was dilated in two and normal in one and no stones were found.

Musculature of the duct: The histology of the bile ducts in congenital absence of the gall bladder has not been studied in detail. Mauro (254) mentions that hypertrophy of the sphincter of Oddi may be found, while Everett and MacCumber (131) state that the histology resembles that of normal ducts.

The present findings suggest that the muscle is not as well-developed as that of normal bile ducts. This finding is supported by comparative studies on the musculature of the bile ducts (See section on Comparative Anatomy).

Pathogenesis: Two theories have been advanced to explain congenital absence of the gall bladder (145, 254). The first postulates that the anomaly is due to failure of the gall bladder to develop from the hepatic diverticulum (see section on Embryology). This would also result in absence of the cystic duct, and possibly in absence of the gall bladder fossa, a condition of affairs found in the majority of cases.

The second theory maintains that the anomaly is due to failure of the gall bladder bud to resolve from the solid stage (see section on Embryology).

/The

The presence of a solid cord residue or a cystic duct and associated obliteration of the ducts would favour this theory - see Fig. 31A, page 102.

It is obvious, however, that studies of human anatomy and embryology alone cannot afford an adequate explanation for the condition. It is well-known, however, that many species of animals normally lack^a gall bladders, and a study of the phylogeny of the biliary tract may help to explain the origin of the condition.

REDUPLICATION OF THE COMMON BILE DUCT.

At least 17 cases of double choledochus have been reported (45, 131). The condition is extremely rare and there is no record of a case at this University.

The most detailed study of this anomaly was carried out by Boyden (45) in 1932. He found that there are two main varieties of reduplication, viz:-

1. Two separate but parallel channels.

Anatomy: Two sub-varieties occur, viz:-

- (a) Two separate ducts - at least three cases reported.
- (b) A separate common bile duct - one authentic case reported.

Etiology: Boyden suggests that these varieties are due to double vacuolisation during the solid stage in the development of an otherwise normal duct. He bases his views on the high incidence of single ducts

/with

with a double lumen in embryos (See Embryology).

The occurrence of double ducts in lower animals is well-known. The arrangement is normal in reptiles, birds and some fishes, but it is very rare in mammals (See Comparative Anatomy) and Mentzer (259) and Sweet (336) suggest that the anomaly resembles a "throw-back" to the more primitive type.

2. A bifurcating duct.

Anatomy: In this variety the lower end of the bile duct splits into two, giving it the appearance of an inverted Y. One limb always opens with the pancreatic duct at the ampulla. The entrance of the other limb is never distal to the ampulla and tends to fall into two general areas, viz:-

- (a) Bordering on the pylorus or extending further into the stomach. - Boyden (45) collected three such cases from the older literature. In an additional case described by him the duct opened just on the duodenal side of the pylorus. Everett and Macumber (131) subsequently described a case where it entered the postero-superior aspect of the stomach.
- (b) Situated on the duodenum within 3 cm. of the usual site of the ampulla - 11 cases reported.

Etiology: The explanation of the bifurcating ducts is more difficult.

Some authorities (259, 336) suggest that the condition is as a reversion to a more primitive type,

/but

but it does not resemble the pattern of double ducts found in lower animals. (See section on Comparative Anatomy). Moreover, the anomaly does not occur in other mammals (36).

Another view, viz: that the second duct represents a supernumerary outgrowth similar to an accessory pancreas, is criticised by Boyden (45) on the grounds that no independent masses of hepatic tissue emptying into the gut have been reported.

Boyden (45) postulates that the proximal limb represents a segregated portion of the primary hepatic groove of the embryo. (See section on Embryology). Should the groove subdivide very early and in such a way that the proximal portion is left above the zone of growth separating stomach from duodenum, then it will develop into a limb emptying into the stomach. Should the division occur below this zone of growth, then it will empty into the duodenum.

He bases his hypothesis on a study of at least two authentic embryological specimens where the hepatic groove was elongated and subdivided into a proximal pars hepatica and a distal pars cystica at a very early stage. (See section on Embryology).

MALPOSITION OF THE COMMON BILE DUCT.

Anatomy.

The usual point of entry of the common bile duct is at the ampulla of Vater, which is situated 60 - 140 mm. from the pylorus (322).

There are at least five cases of malposition of the bile duct on record (45). In two of these it opened into the stomach; in one it passed through the pylorus, and in two it entered the first part of the duodenum.

Etiology: Mentzer (259) suggests that this anomaly represents a reversion to a more primitive type, but the only vertebrate in which the duct opens into the stomach is the fresh-water Bream (279).

Fillipini (cited by 45) suggests that it is due to the hepatic groove originating at a more proximal level than normal, but he offers no proof for this.

Boyden's (45) hypothesis that these ducts represent examples of a bifurcating choledochus where the lower duct has atrophied, seems the most reasonable. He presents evidence that in some of the reported cases a vestige of the lower duct was recognisable (45).

CONGENITAL CYSTIC DILATATION OF THE COMMON BILE DUCT.

This anomaly, which was first described by Vater in 1723 (cited by 189) is very rare. Shallow et alia (326) collected 182 cases reported in the literature until January, 1946. Since then an additional case in an American negro has been described (380), And yet another described by Morison and Saint (266) may be added to the list.

The anomaly is of such great rarity that Judd and Greene (189) found a report of only one true cyst among 17,381 operations on the biliary tract, while Walton (358) found only two among 23,048 autopsies at the London Hospital. Among the cases reported, 80% were females (142, 167, 326, 358).

An additional case obtained from the records of the Department of Pathology of the University of Capetown is reported in this thesis. It is the only instance of congenital cystic dilatation recorded among 2,084 autopsies performed over a period of 8 years (1938 - 1946).

Report of a Case:

Case. 4 (P.M. 161/1941). M.v.S., a coloured female died at the age of 2 months. She had suffered from intermittent attacks of jaundice since birth.

At autopsy the body was found to be jaundiced.

The liver was slightly enlarged and bile-stained, but there was no obvious cirrhosis.

The gall bladder was not dilated and appeared to be normal.

The bile ducts: The left, right and lower part of the common hepatic ducts were normal. There was a bile-containing sac about 2 ins. in diameter involving the middle and upper parts of the common bile duct, and part of the cystic and common hepatic ducts.

The common duct below the cyst was narrowed but patent, and bile could be squeezed through it into the duodenum.

DISCUSSION:

Anatomy. This case illustrates several of the features of the condition mentioned in the literature.

The condition is characterised by unusual enlargement of the common bile duct into a cyst varying in capacity from 30 to 8,000 cc. (167, 358). In practically all the cases reported the dilatation involved the middle and upper parts of the common bile duct (142), usually lying above and behind the duodenum (358). This was so in the case described above.

Although the cyst is usually demarcated at the junction of cystic and hepatic ducts (142), these ducts may be involved (358) as they were in the case described.

The common bile duct leaves the duodenum at its usual place, continues for a variable distance usually with normal diameter, and then suddenly enlarges into a cyst (167). The cyst is more or less spherical but always eccentric, being more like a saccular than like a fusiform aneurysm (358).

The wall of the cyst consists of thick, dense fibrous tissue (142, 167, 326, 358) which often contains some muscle fibres (358). There is no epithelial lining (358).

The cyst usually contains thin, bile-stained fluid (142, 358) and small calculi have been found in it (142). In the case described, bile-stained fluid was present.

Although the duct system above the cyst often shows some evidence of back pressure, the liver is not usually

/much

much affected (358) as is illustrated in the case described.

Etiology: The cause of the condition is not well-understood. The view that it is of congenital origin is supported by a report of a case in a stillborn foetus (189). In the case described, the history of jaundice since birth gives further support to this theory. There is no proof that it is due to obstruction of the duct by calculi, atresia, compression, kinking or foetal cholangitis (36, 142, 167, 326, 358), but these may be secondary factors (358). The common bile duct of the case described was not examined histologically ~~and~~ to determine whether it was primarily or secondarily narrowed.

Various theories have been advanced to explain the development of the anomaly during embryonic life, viz:

1. That it is due to an achalasia comparable to that found in other systems (167). This theory fails to explain why the cyst is limited to only part of the common bile duct. Moreover, no neuromuscular imbalance has been demonstrated.
2. That it is due to congenital weakness of the duct wall at the site of an accessory duct (358). This theory also fails to explain the localisation of the cyst. Besides, no accessory ducts have been demonstrated in the cysts reported.
3. Budde (cited by 36) and Yotuyanagi (cited by 355) suggest that the condition is due to inequalities of growth of the embryonic bile duct during the solid stage. Subsequent vacuolisation would then leave a hollow, spindle-shaped enlargement astride the common bile duct. Once cystic enlargement of the duct has been established, pressure changes would increase its size.

Boyden (36) supports this theory. He suggests that an anatomical basis for such an initial dilatation

of the duct exists in the embryonic structure which he calls the hepatic antrum (see section on Embryology). This sets the stage for subsequent inequalities of growth.

CONGENITAL OBLITERATION OF THE BILE DUCTS.

This anomaly was first carefully analysed by John Thomson in 1892 (205). More than 200 cases have been reported (158) and in some instances more than one member of a family was affected (142).

Among 2,084 routine autopsies performed at the Department of Pathology of the University of Cape Town in 8 years, 6 cases of congenital obliteration of the bile ducts were encountered. These cases are analysed in the table on page 103 and one of them is described. An additional case recently personally operated on is briefly described and included in the analysis.

Reports of two cases.

1. Case 5 P.M. 148/48 - an autopsy.

Specimen.

The specimen was obtained from the body of a coloured female (C.B.) aged five months. There was a history of progressive jaundice and abdominal swelling since birth.

The appearance of the liver and biliary system is illustrated in Fig 31A page 102

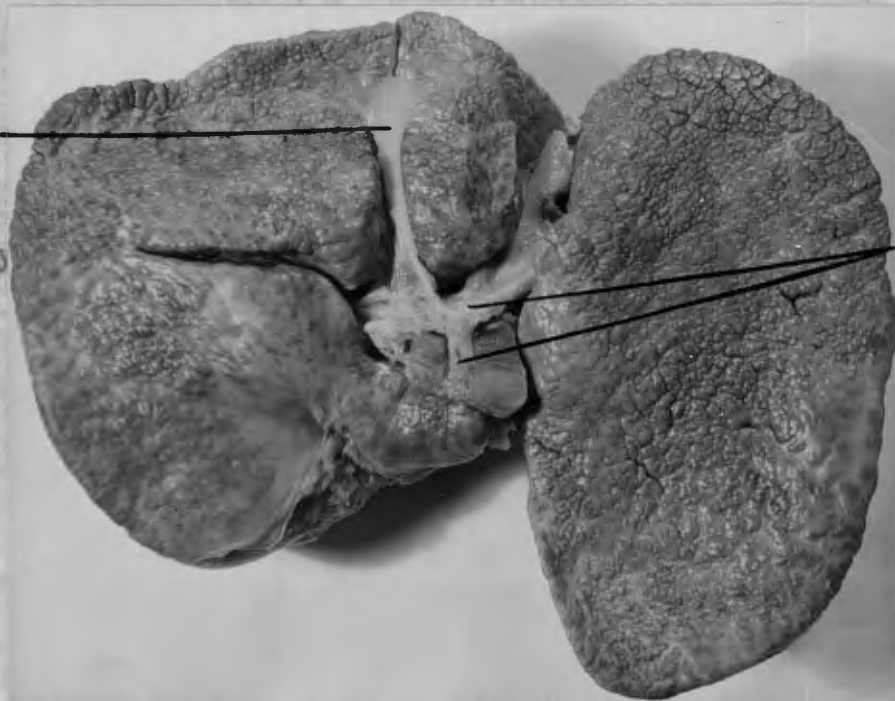
The liver is enlarged and dark green in colour. It shows a diffuse, fairly fine cirrhosis. There are several enlarged glands in the portal fissure.

The gall bladder is rudimentary, pale and empty.

/The

A.
Case 5

Gall
blad-
der
rudi-
mentary



Fibrous
rudiments
of bile
ducts.

B.
Case. 6



Enlargement
of the
Liver.

Fig. 31

Congenital Obliteration of
the Bile Ducts.

The bile ducts. The cystic, hepatic and common bile ducts are all represented by solid fibrous cords.

2. Case 6. J.C. a coloured female aged 7 months.

This child had a history of progressive jaundice and abdominal swelling since birth. On examination the patient was wasted and deeply jaundiced but fairly vigorous and healthy. The liver and spleen were both enlarged and hard - see Fig. 31B page 102. Free fluid was present in the peritoneal cavity.

Examination of the blood revealed a slight anaemia but no other abnormality.

Operation findings 13/9/46. The liver was enlarged and resembled very closely the liver of the case described above. The spleen was enlarged.

A gall bladder was present but it was pale and contained no bile.

The cystic duct was tenuous and on injecting saline into the gall bladder only the distal third of the duct became distended.

No hepatic or common bile ducts could be found even after the hepatic artery and portal vein had been clearly exposed, and the gall bladder injected with saline.

Several large lymphatic glands were present in the portal fissure.

Brief analysis of findings in seven cases. (Personal study)

The following table indicates the portion of the biliary system affected in each of the seven cases collected for this study.

TABLE 7.

<u>Case.</u>	<u>Age.</u>	<u>Whole system.</u>	<u>Several Parts.</u>	<u>Single Part.</u>
P.M.160/41	7 weeks	all ducts and gall bladder	-	-
P.M.161/41	2 mths	-	-	Part of common duct
P.M. 54/42	11 days	-	(all the ducts	-
				/P.M.

<u>Case.</u>	<u>Age.</u>	<u>Whole system.</u>	<u>Several Parts.</u>	<u>Single Part.</u>
P.M. 46/43	11 days	-	-	Hepatic ducts
P.M. 148/43	5 months	-	all the ducts. (Gall bladder present & empty)	-
P.M. 20/46	12 days	-	all the ducts. (Gall bladder present & empty)	-
J.C.	7 mths	-	all the ducts. (Gall bladder present & empty).	-

DISCUSSION:

Anatomy. These cases illustrate several of the features of the anomaly mentioned in the literature.

In extreme cases all the ducts are represented by fibrous cords which occupy the usual position of the affected parts. This is the condition in one of the cases analysed (P.M. 160/41). All gradations exist between this and the normal, and in 20 - 30% of cases, most of the ducts are patent and the condition amenable to surgical treatment (158, 167, 204, 205, 316).

In one-sixth of the cases reported on by Ladd (204), there was associated absence of the gall bladder. This is so in one of the seven cases analysed above. (P.M. 160/41).

The atresia may be complete or partial and often several ducts are involved. The following varieties have been described. (142, 158, 167, 204, 205, 316, 355):-

1. Obliteration of the whole of the extra-hepatic biliary system.
2. Obliteration of several parts of the system, e.g.,

- (a) Cystic and hepatic ducts,
 - (b) All the ducts but not the gall bladder (which may be connected directly to the duodenum),
 - (c) Gall bladder and cystic duct,
 - (d) Gall bladder, cystic duct and part or whole of the common bile duct,
 - (e) Hepatic and common bile ducts.
3. Obliteration of a single duct or of the gall bladder alone.

The varieties found in the cases collected for this study are indicated in the table above. The commonest variety in this series is obliteration of all the ducts but not of the gall bladder.

In all cases there is back-pressure on the liver and, with time, a biliary cirrhosis develops (158, 204, 205). This is well-illustrated in the two cases described - see Figs. 31 A & B page 102.

Etiology: It is generally believed that the anomaly is due to arrested development during the solid stage of the embryonic ducts (142, 158, 204, 205, 355), i.e., there is failure of re-canalisation (see section on Embryology). There are, however, accessory factors to be considered, viz:-

Hicken and Crellin (158) point out that in many cases the superadded irritation of bile stasis causes a mild degree of cholangitis and renders an incomplete

/stenosis

stenosis complete.

Shelton and Torey (329) have recently submitted evidence to support a theory that many cases are sequelae of erythroblastosis foetalis.

In this connection, one of the cases (J.C.) collected for this study, had a mild anaemia only. Another (P.M.148/43) had an anaemia and a leucocytosis of 35,000, but the blood-smear was normal. A third case (P.M.20/46) showed definite evidence of erythroblastosis foetalis. Reports on the blood of the remaining four cases were not available, but the findings in the three cases quoted are sufficiently significant to urge that any family with a history of congenital obliteration of the bile ducts should be examined for Rhesus incompatibility.

ACCESSORY HEPATIC DUCTS.

Incidence: Flint (134) found accessory ducts in 14.5% of 200 dissections. Beaver (10) found them in 8.8%, Mentzer (259) in 11% and Osler and Dow (278) in 20% of their cases. Among 50 dissections studied for this work, accessory ducts were found in 6%, but many of the specimens were spoilt and accessory ducts may have been missed.

Anatomy: Flint (134) states that all accessory ducts come from the right lobe of the liver, but Beaver



Cystic duct.

Cyst-hepatic duct.

Fig. 32

Accessory hepatic duct.

(10) reports ducts from the left lobe of the liver as well.

The ducts may join any part of the common hepatic duct (10, 118, 134, 278), the right hepatic duct (278), the left hepatic duct (10), the cystic duct (10, 118, 134, 278) or the gall bladder (32, 268, 278, 316, 359). Occasionally they are multiple (118, 316). Fig. 32 pg. 107. illustrates an accessory duct joining the gall bladder. The specimen was removed at operation and is kept in the surgical pathology museum of the University of Capetown.

Accessory ducts vary in size from threadlike structures to that of the right hepatic duct, the commonest size being about midway between the two extremes (134).

Their importance in operations on the biliary system is obvious. Sometimes their division is inevitable, and, if unrecognised, this will be followed by bile leakage, which may have fatal consequences (134, 268).

Etiology. The origin of accessory hepatic ducts, and particularly of cyst-hepatic ducts, is not easily explained on embryological grounds alone. It is well-known, however, that multiple hepatic ducts, including cyst-hepatic ducts, are common findings in birds, reptiles and many fishes (259, 316). A study of the phylogenetic
/history

history of the biliary system may afford an explanation for their occurrence in man.

SUMMARY:

1. The findings of personal studies of examples of the following congenital abnormalities of the biliary system have been described.

- (a) Congenital absence of the gall bladder (3 examples)
- (b) Cystic dilatation of the common bile duct (1 example)
- (c) Obliteration of the bile ducts (7 examples)
- (d) Accessary hepatic ducts (4 examples)

2. The literature on these anomalies and also on reduplication and malposition of the common bile duct has been reviewed.

3. The etiology of the various conditions has been discussed and it has been pointed out that a proper understanding of their origin depends on a knowledge of the embryology and phylogeny of the biliary tract.

EMBRYOLOGY.

THE DEVELOPMENT OF THE HUMAN BILIARY SYSTEM.

A study of the development of the bile ducts is essential for a clear conception of their form and structure. Embryology affords a better understanding of the intricate structure of the normal ducts and also helps to explain the origin of congenital abnormalities.

Various workers have contributed to the literature on the subject and among them Lewis (216) and Boyden and his associates (35, 36, 45, 47, 52, 322) deserve special mention. The contributions, however, are widely scattered and have not been put together in the form of a correlated description of the embryology of the biliary system.

In this chapter the development of the biliary system is described in chronological sequence as far as possible. Particular attention is devoted to the embryological processes which have a bearing on anomalies of the biliary system and to the origin and development of the musculature of the bile ducts.

The description is based on a correlation of facts obtained from the literature supplemented by personal studies of the following human embryos and fetuses:-

/Crown

<u>Crown-Rump Length (mm).</u>	<u>Approximate age in weeks.</u>	<u>Specimens, Number of</u>
7	6	1
40	10	2
96	14	1
118)	16	2
124)		
148	18	1
210	24	1
294	32	1
320	36	1
330 to 350	40	<u>4</u>
	Total:	<u>14</u>

The 7 mm. embryo was prepared by Dr. Keen of the Department of Anatomy.

All the others were personally dissected. The biliary system of each was carefully removed and prepared for microscopic examination by the method used for the adult material. Serial sections were cut of most of the specimens.

THE ORIGIN AND DEVELOPMENT OF THE COMPONENT
PARTS OF THE BILIARY SYSTEM.

It is generally agreed that the human liver and biliary apparatus arise in the first lunar month from a single longitudinal fold or thickening in the ventral wall of the primitive foregut (3, 45, 62, 109, 144, 149, 194, 216, 336). This fold is variously described as the hepatic diverticulum, groove or furrow.

The 4th week:

The hepatic rudiment becomes recognisable towards the end of the 4th week of intrauterine life. Sweet (336) and Weber (cited by 62) point out that in the earliest stages it assumes the form of a folding of the intestinal wall extending longitudinally through one or two adenomeres.

The rudiment has been observed in embryos of 14 somites as a thickened area of the duodenal entoderm in the region of the junction between fore- and midgut (149). This area, which lies on the curve of the anterior intestinal portal close to the opening of the gut into the yolk-stalk, is a highly dynamic embryonic field at this period (45). It lies between the heart, yolksac and foregut, and is almost surrounded by veins, being flanked on either side by vitelline and umbilical veins, and separated from the lung bud above by the sinus

/venosus

venosus (45). In addition, the hepatic rudiment is itself developing rapidly. There is thus an ideal setting for minor variations from the normal development which would later result in gross congenital abnormalities.

From the hepatic rudiment a small bud arises which appears in embryos of 17 somites (3) and 23 somites, i.e., 2.5 mm. (216), as a median ventral outgrowth of the entodermal tube. - See Div. hep. Figs. 53A and B, pg. 115. It possesses thick walls which enclose a single cavity in wide communication with the primitive gut.

There is usually no evidence of subdivision of the liver bud at this early stage, but in at least two authentic cases of 20 and 24 somites it has been elongated and subdivided into a pars hepatica and pars cystica (45). Subdivision of the bud at this period when growth changes are extremely rapid, offers an explanation for the occasional occurrence of double common bile ducts in man (45).

The 5th week:

At the beginning of the 5th week the development of the hepatic bud is complicated by the appearance of the pancreatic rudiments. The earliest embryos in which they have been found are those of 3 mm. (149, 166, 216).

The ventral pancreas appears as an outgrowth of the
/duodenum

duodenum adjacent and caudal to the hepatic diverticulum (7, 62, 109, 144, 149, 166, 216, 277, 297, 322). Some authorities hold that the bud first consists of two lateral halves which represent the two lateral rudiments of lower vertebrates (7, 109, 149, 277).

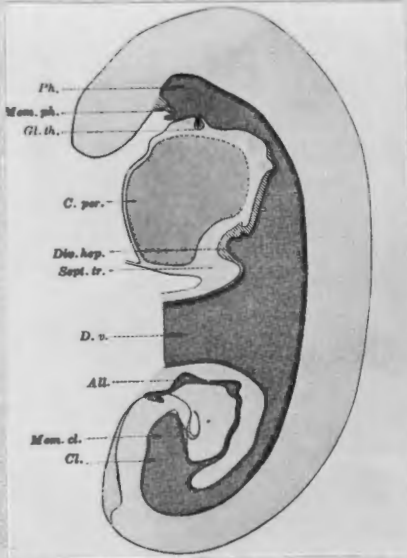
The exact point of origin of the ventral pancreatic bud is variously given as from the hepatic diverticulum (62, 109, 166), from the angle made by the latter and the gut (144, 149, 322) and from the gut itself (7, 277).

From a review of the literature (3, 11, 33, 35, 36, 194, 216, 322), it appears that the ventral pancreas usually arises in the angle between the hepatic bud and the duodenum - See Panc. v. Figs. 34A & B, Pg. 115. Slight variations occur which determine the final relation of the main pancreatic duct to the bile duct. If the pancreas arises from the angle the final duct may or may not open into the duodenum in common with the bile duct. If it arises from the hepatic duct the final duct will open into the common duct. If it arises from the duodenum the final duct and bile duct will open entirely separately.

While the pancreatic buds are developing the hepatic diverticulum enlarges, and, at the 4 mm. stage, the cells in its anterior and ventral walls have increased considerably. They form irregular masses and anastomosing

/cords.

A



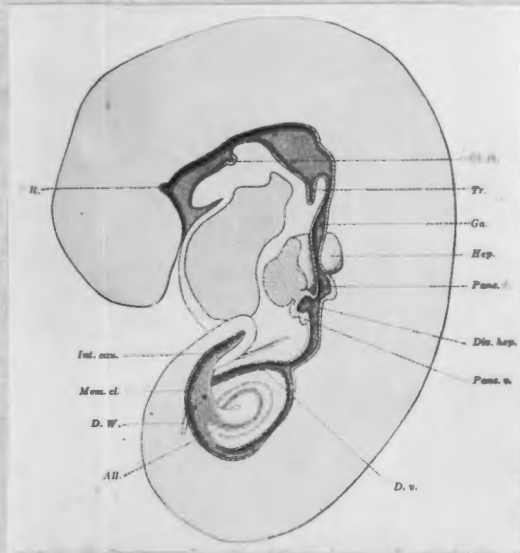
B



Fig. 33

The hepatic diverticulum of an embryo of 2.5 mm. (After Ingalls).

A



B

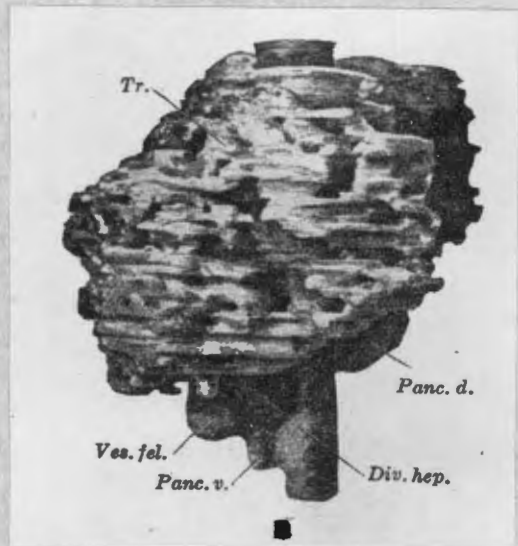


Fig. 34

The subdivisions of the hepatic diverticulum and the ventral pancreatic bud of an embryo of 4.9 mm. (After Ingalls).

cords (216).

Soon afterwards the bud divides into a larger cranial pars hepatica and a smaller caudal pars cystica (149). These subdivisions are clearly seen in 4.3 mm. (45) and 4.9 mm. (216) embryos. See Ves. fel. and Tr. Fig.34B., page 115. The pars hepatica forms a large crescentic mass of cells which invades the septum transversum. It is connected with an outpocketing of the intestine which corresponds to the original hepatic diverticulum. This part is destined to become the liver. Distally the pars cystica forms a rounded outgrowth of the diverticulum, and in the angle between the diverticulum and the duodenum the ventral pancreatic bud grows downwards.

The 6th week:

With the development of the duodenal loop, the hepatic bud extends from its apex into the septum transversum (149). At the same time, there is rapid differentiation of the various ducts which can be clearly recognised in 7.5 mm. (216) and 8 mm. (36) embryos. See Figs. 35 & 36, Pg.118. In these embryos the liver, which has become very large, is connected to the hepatic diverticulum by a short, thick stem which represents the hepatic duct. The pars cystica is differentiated into a terminal knob-like structure (the gall bladder) connected to the diverticulum by the cystic duct.

The proximal portion of the bud has become drawn out to form the common bile duct. All the structures are buried in the mesoderm of the ventral mesentery, the common bile duct lying in its free edge (149). The gall bladder and cystic duct are embedded in the under-surface of the liver and cause only a slight swelling of its peritoneal surface (216). This position of the gall bladder explains the occasional occurrence of intrahepatic gall bladders in man (194).

At this stage, the zone where the bile and ventral pancreatic buds meet has elongated into a segment that is common to both channels, and the bile and pancreatic ducts unite into a common channel before joining the duodenum. This is the hepato-pancreatic duct or primitive ampulla (322). The bile duct still pierces the duodenal wall more or less at right angles, but with further development its course becomes more and more oblique (322).

Subsequent growth of the liver downwards and to the right exercises pressure on the intestinal loop and initiates its rotation (230). This is accompanied by differences in the rate of growth of different parts of the walls of the duodenum (144). These factors produce considerable changes in the course of the bile ducts which, at the same time, are becoming longer and more
/slender.

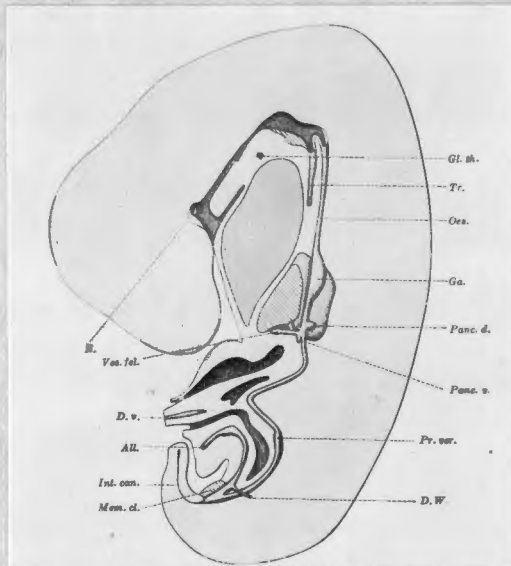


Fig. 35

The digestive system of an embryo of 7.5 mm. (After Lewis - 216).

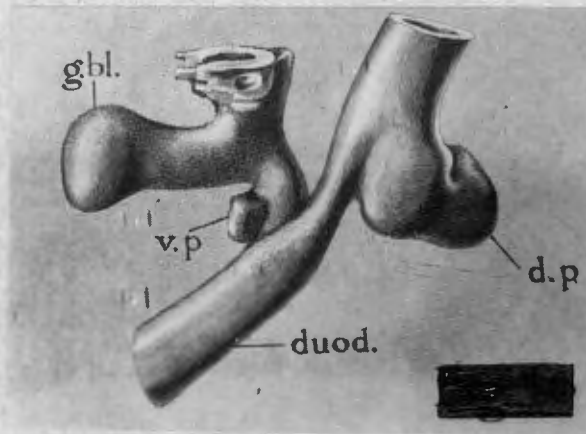


Fig. 36

The biliary system of an embryo of 8.0 mm. (After Boyden - 36).

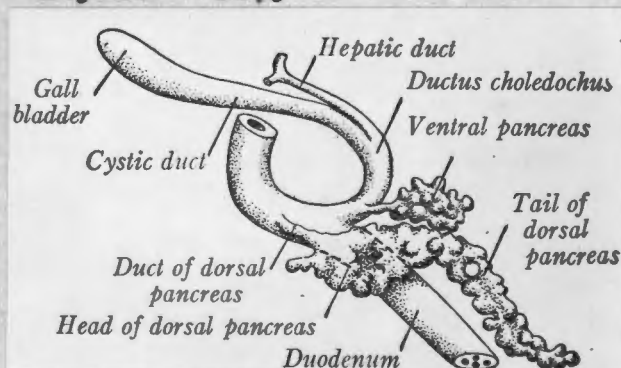


Fig. 37

The biliary system of an embryo of 10 mm. (After Arey - 3).

slender. These changes can be seen in embryos of 9-10 mm. - See Fig. 37, Pg. 118. The gall bladder and bile ducts are now long, thin tubes. The common bile duct is bent dorsally on the right side of the duodenum, and it is now attached to the dorsal aspect of the intestine (216). This has brought the ventral pancreas into the mesoduodenum, where it lies to the right of and below the dorsal pancreas (149).

The close relationship of the head of the pancreas to the bile duct in the adult is thus explained. Depending on eccentricities of growth, the relationship will vary somewhat: the common duct may groove the pancreas or it may be entirely surrounded by pancreatic tissue, or it may even contain pancreatic tissue in its walls (297).

(At the end of the 6th week - 12 mm. stage - the two pancreases fuse and their ducts unite to form the ducts of Wirsung and Santorini (62)).

The 7th week:

During the 7th week the rapid elongation of the main bile ducts continues. Growth takes place in three zones, viz: in that portion of the hepatic outgrowth which adjoins the duodenum (the future common bile duct);

In the narrow stalk which separates the gall bladder from the rest of the diverticulum (the cystic duct) and in the infratrabecular region (future hepatic duct). In the meantime the body of the main outgrowth temporarily persists at its original calibre, and it appears relatively larger than the other ducts (36). In embryos of 15 mm. it is a conspicuous dilatation which Boyden (36) has named the hepatic antrum. (See hep. ant. Fig. 38, Pg.121.) He points out that the apparent increase in size of this part of the hepatic outgrowth is merely relative; and that it is eventually used up in contributing to the formation of the surrounding ducts. He suggests that the persistence of the hepatic antrum accounts for the rare anomaly of cystic dilatation of the common bile duct (36).

The gall bladder at this stage is an elongated tube lying in the mesenchyme of the fossa vesicae felleae (47) - see Fig. 38, Pg.121 - and the hepatic duct is still wholly outside the liver, but has six main branches which run up and become continuous with the liver cell cords (31).

The ampulla. Further elongation of the segment where the hepato-pancreatic duct joins the duodenum has pushed the bile and pancreatic ducts out to the level where the intestinal muscle is forming, and

/at

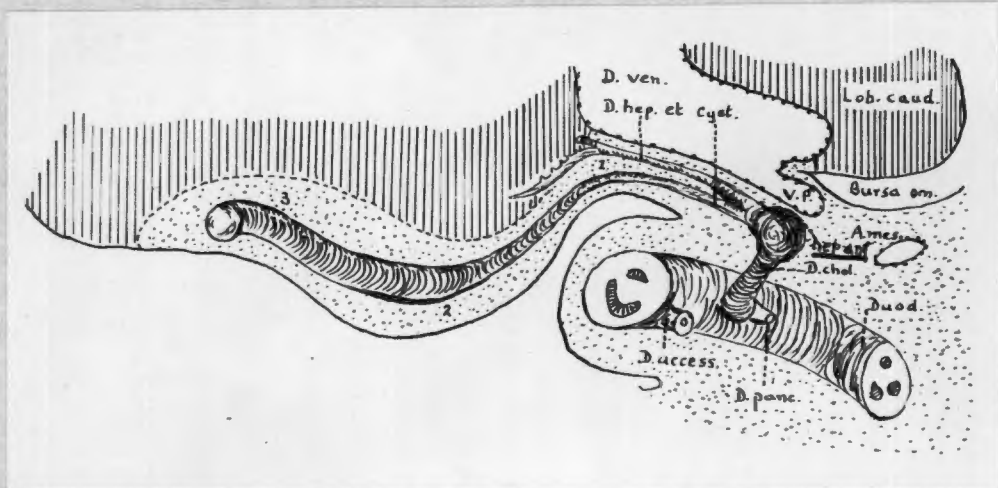


Fig. 38

The biliary system of an embryo of 15 mm. (After Boyden - 47).

- Note:**
1. The hepatic antrum, (hep. ant.).
 2. The curvatures of the gall bladder (1, 2 and 3).

at this stage (15 mm). the pars intestinalis of the common bile duct consists wholly of the primitive ampulla (322).

Subsequent Development:

At the end of the second lunar month the external appearance of the biliary system closely resembles the pattern found at birth.

Subsequent changes are brought about mainly by differences in the rate of growth of the biliary system and surrounding organs. The parts most affected are the gall bladder and ampulla.

The gall bladder is affected by growth changes in the fossa vesicae which produce a number of bends in the organ and its duct. Some of these persist as the normal convolutions of the cystic duct. Others usually disappear, but may persist as a "phrygian cap" deformity of the gall bladder (47). In early embryonic life the gall bladder is almost embedded in the liver, but later it assumes a more superficial position.

A striking feature noted in all the foetal material personally examined was a well-developed cholecystoduodenal ligament. It was also noted that the "long parallel" mode of union between cystic and hepatic ducts was much more common than in adults.

The ampulla is affected by the more rapid growth of the duodenal wall. This causes the junction of bile

/and

and pancreatic ducts to be drawn back through the gap in the intestinal wall. By the 4th month this junction is a fourth of the way through the duodenal wall, and by the 6th month it has receded halfway to the mucosa. At the same time the course of the common bile duct through the duodenal wall becomes more oblique (322). (This retrogression of the ampulla is of importance in the study of the development of the sphincter of Oddi). According to Schwegler and Boyden (322), this process is continued in post-natal life until finally, in many cases, the bile and pancreatic ducts open separately on the duodenal papilla. This explains the frequency of such an arrangement in adults.

THE DIFFERENTIATION OF THE ENTODERMAL AND MESODERMAL
ELEMENTS OF THE BILE DUCTS.

Since the hepatic diverticulum arises from the foregut, it is comprised of entodermal epithelium which will differentiate into the epithelial lining of the gall bladder and bile ducts, and into the hepatic parenchyma.

The mesenchyme of the ventral mesentery and septum transversum, which surrounds the diverticulum, is associated with the entodermal derivatives in their development, and gives rise to the connective tissue and muscular elements of the extrahepatic biliary tract.

/Entodermal

Entodermal Derivatives:

Although the original hepatic diverticulum is hollow and remains so until the 5 mm. stage (216, 322, 355), its component parts regularly become obliterated by epithelial proliferation (3, 205, 216, 322, 355 and Ylppo cited by 204, 205.)

The solid stage of the gall bladder and common bile duct is presumably acquired in the beginning of the 6th week when the ducts elongate (216). The youngest embryo in which both the gall bladder and the common bile duct have been found to be solid, is one of 6.75 mm. (216). At this stage the duodenum is patent (216). This is illustrated in Figs. 39A & B, Pg. 125 which represent sections of a 7 mm. human embryo. The hepatic diverticulum is partially solid, while the foregut is obviously patent. (That the appearance of the hepatic bud is not due to a tangential section was proved by studying a series of twenty sections. In all of these it had a similar appearance).

Recanalisation of the lumen by a process of vacuolisation soon follows the solid stage. The cystic and common bile ducts are the first to re-acquire a lumen, then the hepatic duct and, finally, the gall bladder. At the same time the duodenum passes through a similar solid stage.

In 7.5 and 9.4 mm. embryos there is a lumen in

/the

A.
Low Power
View.

(X 215)

Liver
cords.

Bile duct
(partially
obliterated).



Foregut
(patent)

B.
High Power
View (X 780).
showing
partial
obliteration
of the bile
duct.

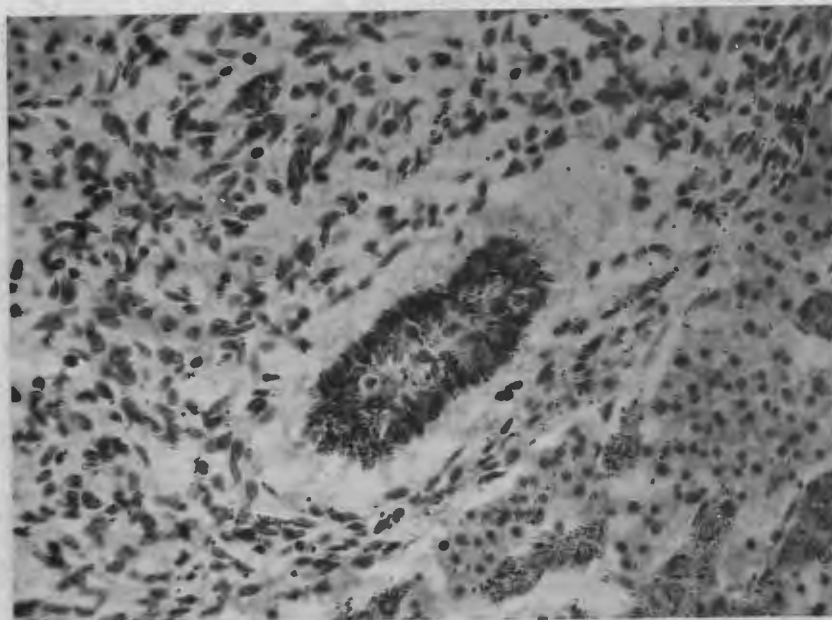


Fig. 39

Section of the hepatic diverticulum of an embryo of 7 mm.

the common bile duct, but the gall bladder and the hepatic duct are still impervious (216). The latter is a short, solid stem connecting the hepatic trabeculae with the common bile duct (216). At this stage the epithelium of the duodenum has begun to proliferate and divides its cavity into discontinuous vacuoles (216, 322).

At 10 mm. the hepatic duct acquires a lumen and the lumen of common bile duct is usually single and well-defined (31, 216, 322). The lumen of the duodenum is entirely bridged and subdivided by epithelial folds (216).

At 15 mm. the gall bladder is still solid (3, 216), but at 16 mm. irregular vacuoles are found in the part adjacent to the cystic duct (216). All the ducts are patent. The duodenum is still partially solid, but the vacuoles have coalesced to form two main channels (322), and the bile and pancreatic ducts open into closed cavities (216).

At 18.5 mm. vacuolisation commences in the fundus of the gall bladder and the lumen of the cystic duct starts encroaching on the neck of the organ (47).

At 21 mm. the whole of the lumen of the gall bladder has been re-established, and the extrahepatic biliary tract now consists of a system of hollow structures lined by a single layer of epithelial cells (47, 147). The duodenal lumen has also been completely /re-established.

re-established.

Later, the mucosa of the gall bladder and bile ducts develops into small folds, and by the end of the 4th lunar month it has assumed the characteristic adult pattern (147). At this stage the valves of the ampulla are recognisable as wrinkles in the lining epithelium, and by the 6th month they have developed into low rounded folds (322).

Note: 1. There are at least four cases on record where in embryos ranging from 9 - 22.8 mm. in length a single common bile duct had a double lumen in the midst of its course, the two cavities being united proximally and distally (45). Boyden suggests that the septum usually disappears, but if it should persist a septate common bile duct will be formed.

2. The solid stage of the extrahepatic biliary system is an important embryological event from the point of view of congenital obliteration of the bile ducts. The various types of obliterated ducts can be explained on a basis of partial or complete failure of recanalisation of the ducts.

Mesodermal Derivatives:

Early Development. The outer coats of the biliary tract develop from the splanchno-pleuric

/mesoderm

mesoderm of the ventral mesogastrium.

The hepatic diverticulum grows into the ventral mesentery and septum transversum soon after it has formed, and at the 7.5 mm. stage the epithelium of the diverticulum is surrounded by a layer of mesoderm (216) - see Figs. 33A & 34A, Pg.115 and Fig.35, Pg.118. This mesoderm remains wholly undifferentiated until the end of the 7th week (15 - 17 mm. stage) (47, 216). The duodenal muscle, on the other hand, originates at about the 6th week (10 - 14 mm. stage) (322), and at the end of the 7th week circular fibres are recognisable (216).

The first step in the formation of a muscle coat around the biliary system is a re-arrangement of the mesodermal cells into concentric layers around the gall bladder and bile ducts. This is recognisable first in the gall bladder, where it has been observed in 22.8 mm. (216) and 25 mm. (213) embryos. In the intramural portion of the common bile duct this re-arrangement is not noticeable until the 26 mm. stage (322), while in the rest of the ducts the mesenchyme remains undifferentiated until still later stages.

Differentiation into true muscle fibres takes place when the mesenchymal cells are sufficiently well-developed to take on an acid stain. This has been

/noted

noted in the gall bladders of 29 mm. (216) and 40 mm. (213) embryos, and Schwegler and Boyden (322) found that the muscle of the pars intestinalis differentiated between the 9th and 11th weeks (40 - 50 mm). No author has described muscle cells in the extramural portion of the bile ducts at this early stage, but in an embryo of 14 weeks examined during this study, scattered muscle fibres are recognisable in the lower half of the bile duct - See Fig. 47A, Pg.141.

In Figs.40AB&C, Pg.130, which are sections of a 40 mm. embryo (10 weeks) prepared for this study, the concentric arrangement of mesodermal cells around the gall bladder and bile ducts is clearly recognisable. Some of the outer cells of the gall bladder and of the intramural portion of the bile duct have commenced to differentiate and appear slightly darker than the rest. They are not as well-stained as the duodenal muscle, which is a thick, well-developed band. The mesoderm of the extramural portion of the ducts has not differentiated beyond connective tissue.

Later Development:

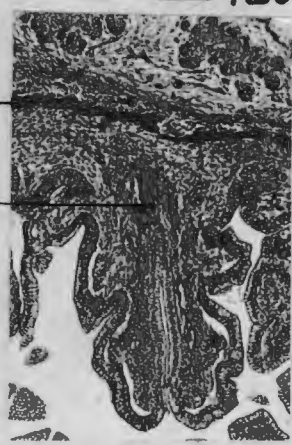
The subsequent development of the muscle of the various parts of the biliary system will be dealt with under separate headings:-

The Gall Bladder: Soon after ^{their} ~~its~~ first

/appearance

Duodenal muscle.

Muscle commencing to differentiate.



A.

Duodenal Papilla. (X 180)

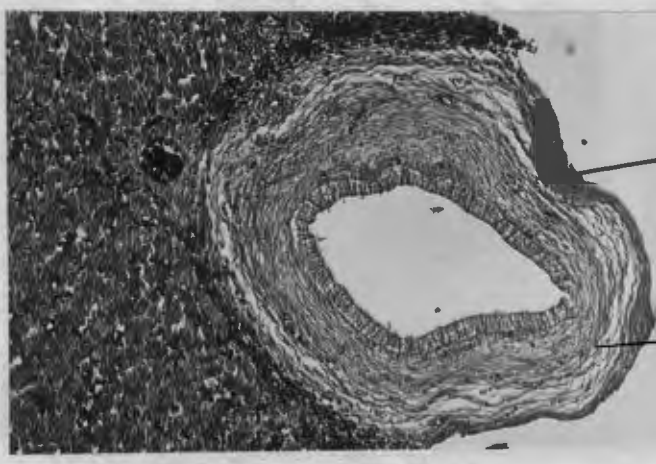


Mesoderm undifferentiated.

B.

Bile Ducts. (X 700)

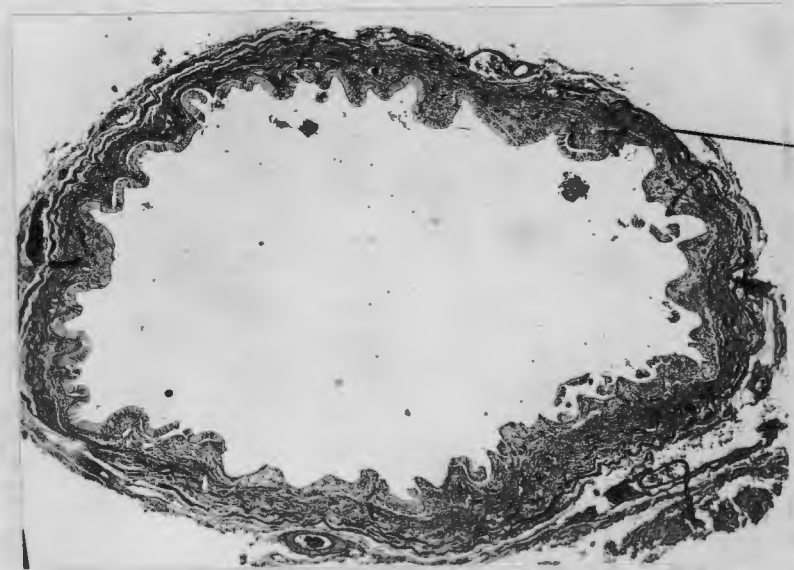
Fig. 40
sections of a 40 m.m. embryo. (10 weeks)



Muscle commencing to differentiate.

Concentric layers of mesoderm.

C. Gall Bladder. (X 700)



Muscle.

Fig. 41

Section of the gall bladder of an embryo aged 24 weeks. (X 30).

appearance in the 5th - 10th weeks, the muscle cells of the gall bladder wall arrange themselves into a zona muscularis, which may be tentatively separated from a zona sub-epithialis and a zona perimuscularis (213, 216).

In 80 - 95 mm. embryos a well-defined tunica muscularis composed of smooth muscle cells embedded in a connective tissue stroma has developed (213). By the end of the 6th month the muscular tunic is arranged into incomplete inner longitudinal and outer oblique layers, thus resembling that of the newborn (213). This is illustrated in Figs. 41, page 130, which is a section of a 24-weeks old foetus studied for this work.

THE INTRAMURAL PORTION OF THE COMMON BILE DUCT.

The development of this part of the biliary system has been very thoroughly studied by Schwegler and Boyden (322). They state that the muscle surrounding the bile duct is derived from two sources, viz:-

- (a) From an independent differentiation of the mesenchyme surrounding the bile duct;
- (b) From the duodenal wall.

These findings differ from those of Porsio (cited by 322), Reitz (cited by 322), Gordon-Taylor (139) and Kirk (196), who concluded that the bile duct muscle originates entirely from the duodenal muscle.

Nevertheless, a study of the sections prepared for this work confirms the findings of

/Schwegler

Schwegler and Boyden (322) in general, if not in particular. The following account of the development of this region is, therefore, based on the descriptions given by these authors. The various points which have been confirmed by this study are illustrated by microphotographs of sections personally prepared.

1. The appearance of the "choledechal window".

The gap where the intestinal muscle is penetrated by the bile duct is much more pronounced in young embryos than in adults. It consists of a longitudinal hiatus in the longitudinal muscle (H2 Fig. 42, Pg 133) and a transverse slit in the circular muscle (fen. chol. Fig. 42, Pg. 133)

The gap is clearly illustrated in Fig. 43, Pg 133. which shows the duct entering the duodenum of a 40 mm. embryo dissected.

2. The differentiation of the intrinsic muscle of the bile and pancreatic ducts. As mentioned above, Schwegler and Boyden (322) have found that the muscle of the intramural portion of the duct begins to differentiate between the 9th and 11th weeks, when the duodenal muscle is already well-formed. They point out that this is just the time when the muscle around the bladder end of the ureters is beginning to differentiate and they regard the formation of choledechal and ureteric musculature as analagous processes.

The first cells to differentiate are those situated just within the gap in the intestinal muscle (322). This is illustrated in the 40 mm. fetus sectioned for this study - see Fig. 43yPg.133.

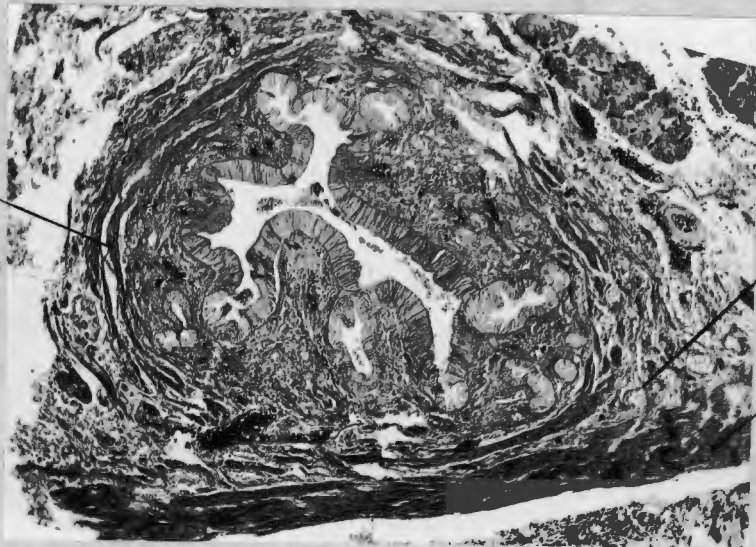
As the muscle sheath forms it encircles the duct partially or completely and corresponds to the "sphincter choledochus superior" of the adult. Schwegler and Boyden (322) point out that, although this muscle is in contact with the intestinal muscle, it constitutes an independent ring. This point is illustrated in Figs. 44A and 44B, on page 135, which are sections taken through the superior margin (margo superior, Fig. 42, page 133) of the choledochal window of fetuses aged 24 and 32 weeks.

Schwegler and Boyden (322) point out further that the muscle of the duct is disposed within the slit in the duodenal muscle "like an iris within the slit of the eyelids"; an arrangement which is not to be expected if the intrinsic muscle of the duct is derived from the duodenal muscle. This disposition of the muscle is illustrated in Fig. 44C, page 135,

/which

A.
32 weeks.
(X 80)

Circular muscle (Sphincter choledochus superior) separate from the duodenal muscle.



Connecting fibres from duodenum.

duodenal muscle.

B.
24 weeks.
(X 30)
(Superficial section).

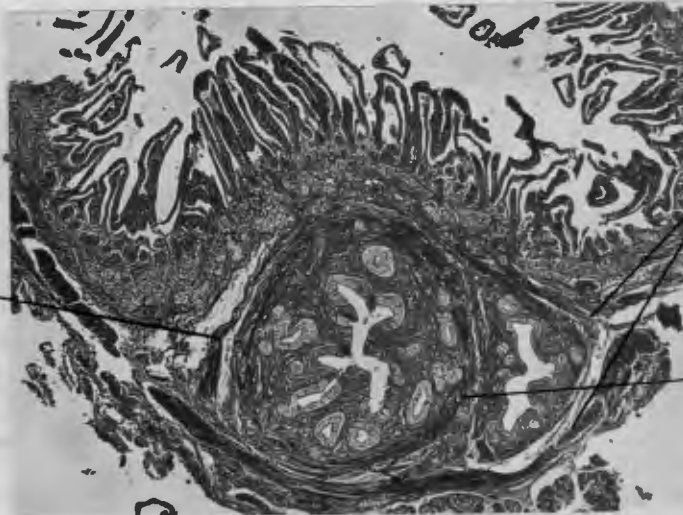
Connecting fibres from the duodenum.



Sphincter separate from the duodenal muscle.

C.
24 weeks.
(X 30)
(Deep section).

Connecting fibres from the duodenum.



Eye-shaped slit in the duodenal muscle.

Intrinsic sphincter.

Fig. 44.

Sections taken through the superior margin of the "choledochal window" of fetuses aged 24 & 32 weeks.

which is ^a deeper section of the pars intestinalis in a 24-weeks-old embryo.

When the "sphincter choledochus superior" first appears, the rest of the mesenchyme of the duct and ampulla is still undifferentiated, but, by the fifth month, it has differentiated nearly as far as the distal end of the ampulla (322), (Figs. 45A & B, Pg. 137, which represent sections close to the duodenal papilla, and show that the mesenchyme surrounding this part of the ampulla has differentiated into muscle fibres.

At the same time, and principally on account of the more rapid growth of the duodenal wall, the junction of the bile and pancreatic ducts is gradually pulled away from the choledochal window towards the mucosa (322). The effect of this is to carry the lower part of the intrinsic muscles of the ducts away from the intestine and to set them up as independent agents (322). This is illustrated in Figs. 46A, 46B, and 46C, Pg. 139. which represent sections of the ducts and ampulla in 16-weeks, 24-weeks and full-term foetuses. In Fig. 46A, page 139 (16-weeks foetus), the muscles surrounding the bile and pancreatic ducts are separate from the intestinal muscle. They represent the "sphincter choledochus inferior" and "musculus /proprius

A.
16 weeks.
(X 30)



Intrinsic
sphincter.

Distinct gap.

Duodenal
muscle.

B.
32 weeks.
(X 24)



Intrinsic
sphincter.

Distinct gap.

Duodenal
muscle.

Fig. 45

Sections taken through the
ampulla of fetuses aged
16 weeks and 32 weeks.

proprius ductus pancreaticus" of the adult. In Figs. 46B and 46C, Pg 139, the muscle of the ampulla (musculus proprius ampullae of the adult) is distinctly separated from the duodenal muscle.

3. Muscle fibres derived from the Duodenal Wall.

While the intrinsic muscle of the ducts is developing, it comes into contact with the muscle coats of the duodenum. At the same time the intestinal muscle throws off circular and longitudinal fibres which lie outside the muscle of the ducts, occupying the corner of the slit in the duodenal coats and passing along the ducts in both directions (322). These fibres, which are illustrated in Figs. 44A, B & C, Pg. 135, undergo further development in postnatal life to form the connecting and reinforcing fibres and longitudinal fascicles of the adult (203).

The extraduodenal portion of the bile ducts.

The development of the muscle of the extramural portion of the bile ducts has not been carefully studied.

Walters and Snell (355) state that connective tissue and muscle fibres differentiate from the mesoderm during embryonic life, but Bloom (31) found only connective tissue in the hepatic duct, and Lee and Halpert (213) failed to find muscle tissue in the bile ducts of fetuses aged 24 weeks and less.

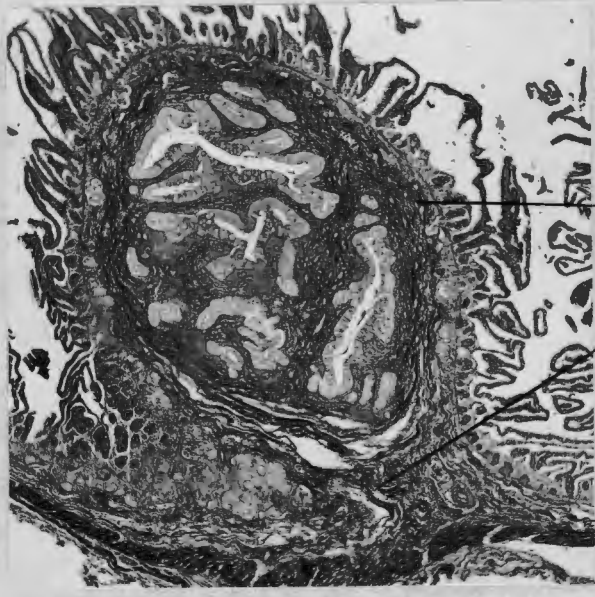
A. 16 weeks.
(X 30)

Sphincter of
pancreatic
duct.



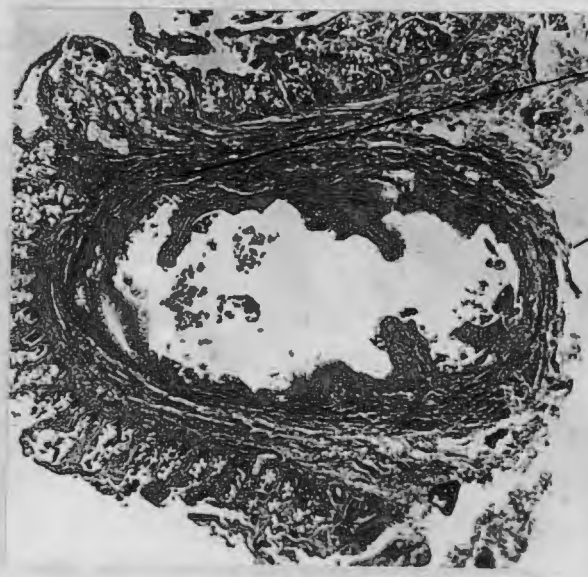
Intrinsic
sphincter
of bile
duct.
("sphincter
choledochus
inferior").
Duodenal
muscle.
Distinct gap

B. 24 weeks.
(X 30)



Intrinsic
sphincter
surrounding
both ducts.
("Musculus
proprius
ampullae").
large gap.
Duodenal
muscle.

C. 40 weeks.
(X 24)



Intrinsic
sphincter
of ampulla.
Distinct
gap
(duodenal
muscle not
shown).

Fig. 46

Sections taken close to the junction
of bile and pancreatic ducts of
foetuses aged 16, 24 and 40 weeks.

The findings in this study, which are opposed to the observations of Bloom (31) and of Lee & Halpert (213) are as follows:-

1. No muscle tissue was found at the 40 mm. stage - see Fig. 40B, page 130.

2. Lower third: At 14 weeks scanty muscle fibres can be identified in the lower half of the duct - see Fig. 47A, Pg. 141.

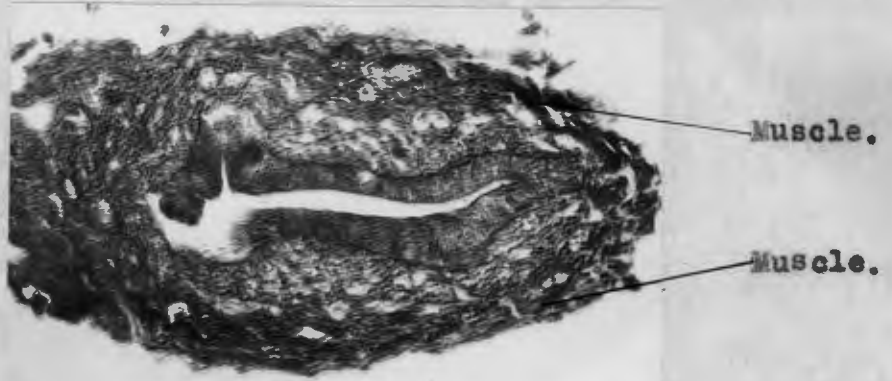
At later stages the muscle in the lower third of the duct becomes better-developed. This is shown in Figs. 47B & C, Pg. 141, which represent sections from 24- and 36-weeks foetuses.

3. Middle third: The muscle in the middle third of the common bile duct becomes defined still later and remains poorly-developed, usually being recognisable only with high magnifications, but in all the sections of foetuses of 24 weeks and older some muscle fibres are seen - see Figs. 48 A & B, Pg. 142.

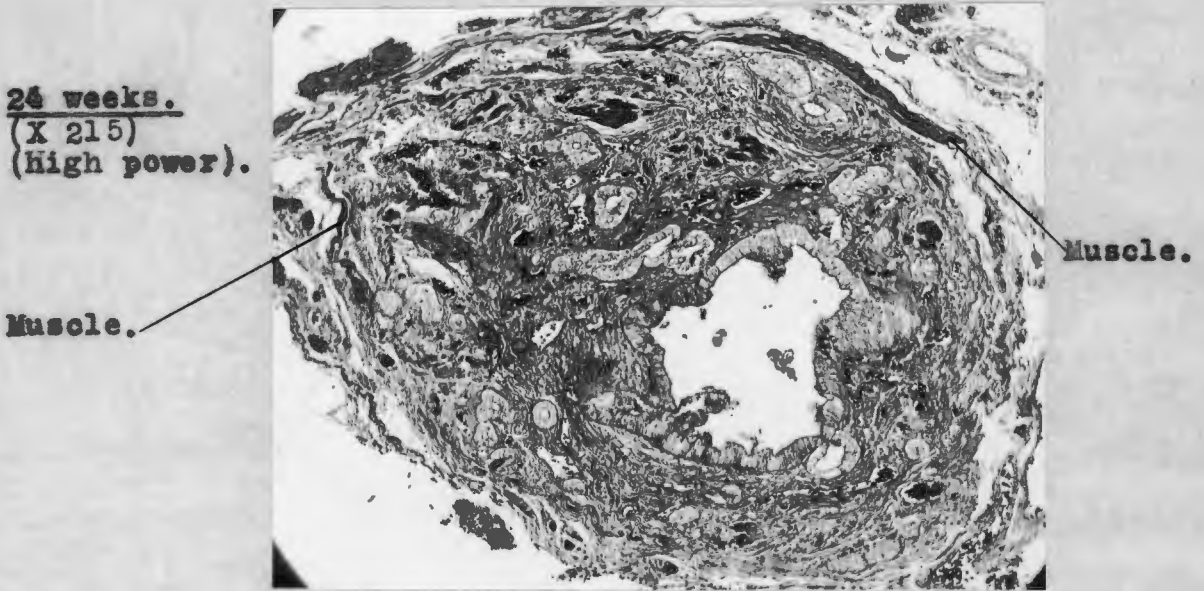
4. Upper third: No muscle tissue could be found in the upper third of the common bile duct nor in the hepatic duct of foetuses of 36 weeks and younger. In Fig. 49, Pg. 142, however, which is a section of the duct of a 40-weeks foetus (still birth), muscle fibres are recognisable in the ducts close to their point of union with the cystic duct.

/These

A. 14 weeks.
(X 700)
(High power).



B. 24 weeks.
(X 215)
(High power).



C. 36 weeks.
(Low power).
(X 30)

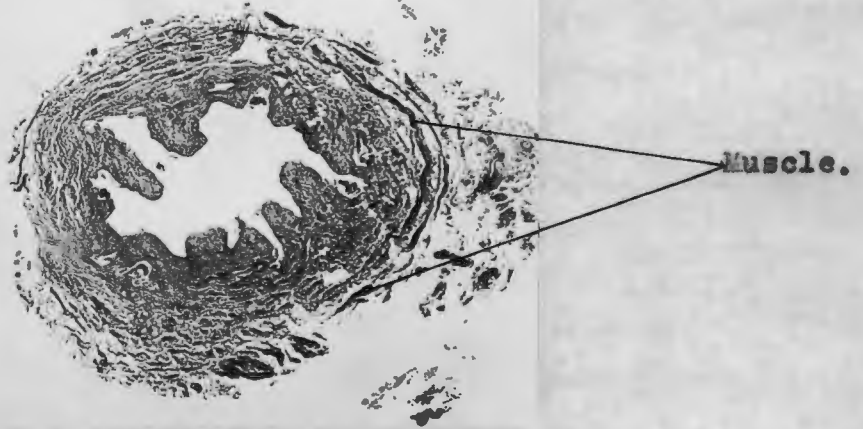


Fig. 47.

Sections of the lower third of
the common bile duct of fetuses
aged 14, 24 and 36 weeks.

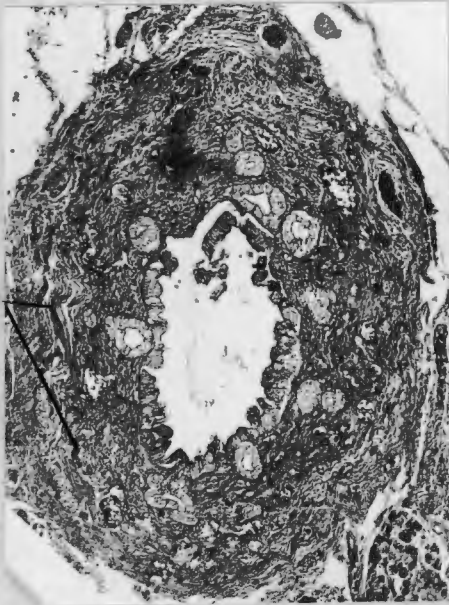
24 weeks.

32 weeks.

A.

B.

Muscle



Muscle

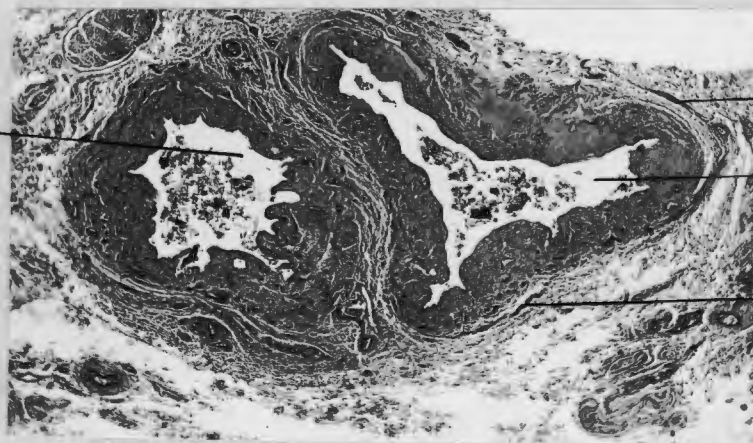


Muscle

Fig. 48

Sections of the middle third of the common bile duct of fetuses aged 24 weeks and 32 weeks. (X 140)

Cystic duct.



Muscle.

Hepatic duct.

Muscle.

Fig. 49

A section taken near the junction of hepatic and cystic ducts of a still-born infant. (X 30)

These sections indicate that there is a gradient in the development of the musculature of the extramural portion of the ducts, i.e., differentiation commences at the lower end and then gradually extends up the duct as the foetus grows older. Similar growth gradients are seen in the muscle of the intramural portion of the common bile duct, viz: from the choledochal window to the ampulla (vide supra), and in the ureteric muscle, viz: from the bladder to the kidney (322). (The ureteric muscle first appears at the bladder end of the ureter at about the 53 mm. stage and then gradually extends upwards towards the kidney, until, at 150 mm., it is present along the entire length of the ureter). The only difference is that the muscle in the extramural part of the bile duct is much slower in developing.

Summary of the Development of the Bile Duct Musculature

A study of the development of the muscle of the bile ducts has shown:-

1. The earliest differentiation of the mesenchyme occurs in the 8th week. This is indicated by a concentric arrangement of the cells around the gall bladder and bile ducts. At this stage the duodenal muscle has already differentiated.

2. Differentiation into muscle tissue commences

/in

in the 9th and 10th weeks. Muscle is first seen in the gall bladder, then in the intramural portion of the bile duct and, lastly, in the rest of the duct system, e.g.,

- (a) The gall bladder muscle appears in the 9th week and is well-developed at the end of the 6th month;
- (b) The intrinsic muscle of the intramural portion of the bile duct appears in the 10th week, and is well-developed at the end of the 5th month.
- (c) Muscle fibres appear later in the extra-mural portion of the ducts and are reasonably well-developed in the lower third of the common bile duct only. They are recognisable in the lower third of the common bile duct at 14 weeks; in the middle third of the common bile duct at 24 weeks, and in the upper third of the common bile duct and the hepatic duct only at the end of pregnancy. This gradient of development is similar to that found in the ureter, but it takes place more slowly.

3. Although the intramural portion of the bile duct receives offshoots from the duodenal muscle, an independent musculus proprius develops in situ. This conclusion is based on the following findings, which corroborate the observations of Schwegler and Boyden (322):-

- (a) In sections of a 40 mm. embryo muscle fibres have commenced to differentiate from the mesoderm surrounding the bile duct. In the same sections the duodenal muscle is well-differentiated and there is a distinct gap at the point where it is penetrated by the bile duct. At this period the muscle around the lower end of another hollow

/muscular

muscular tube, viz: the ureter, commences to differentiate.

- (b) In sections through the "choledochal window" of 24- and 32-weeks fetuses the muscle tissue completely encircles the ducts. Although it is in contact with the duodenal muscle it constitutes an independent ring.
- (c) In sections of the same and other fetuses the sphincters ampullae, choledochus inferior, and pancreaticus are completely separated from the intestinal muscle.

GENERAL SUMMARY:-

1. The normal development of the biliary system has been followed from the time of its first appearance to its mature condition at birth.
2. The developmental origin of the following variations and abnormalities of the adult biliary system have been discussed.
 - (a) Variations in the relation of the bile duct to the head of the pancreas.
 - (b) Variations in the relation between the bile and pancreatic ducts.
 - (c) Intrahepatic gall bladder.
 - (d) Duplication of the common bile duct.
 - (e) Septate common bile duct.
 - (f) Cystic dilatation of the common bile duct.
 - (g) Obliteration of the gall bladder and bile ducts.
3. Personal studies of the development of the musculature of the bile ducts have shown that:-

/(a).

- (a) The intrinsic muscle surrounding the intramural portion of the common bile duct has an independent origin from the mesoderm surrounding the duct. It differentiates later than the duodenal muscle from which it is clearly separated in the early stages of development. At a later period it is reinforced by muscle fibres derived from the duodenum.
- (b) Muscle fibres are present in the extra-duodenal portions of the bile ducts of fetuses aged 14 weeks and older. They differentiate from the mesoderm surrounding the bile ducts. Their differentiation commences at the lower end of the common bile duct and extends towards the hepatic duct, which is reached at the end of pregnancy only.

COMPARATIVE ANATOMY.

THE COMPARATIVE ANATOMY OF THE
EXTRAHEPATIC BILIARY SYSTEM.

Anatomists all agree that comparative anatomy is of great value in a study of the factors which have influenced and determined the form, structure and functions of the constituent parts of the human body.

It is well-known that various forms of the same organ exist in different animals, and that the extremes may be so far different from one another as not to be recognised. By means of comparative studies these extremes may be united together by numerous intermediate steps. The gradual development of an organ can then be traced from its primitive form, through several intermediate stages, to the highly-specialised structures found in man and the higher mammals. In this way, the phenomena which influence the everchanging form and structure of an organ are studied, and their relation to the variations of the organ determined.

REVIEW OF THE LITERATURE.

The literature contains numerous contributions on different aspects of the comparative anatomy of the biliary system. The articles, however, are widely scattered, and there are many contradictory statements

/concerning

concerning some of the species that have been dissected. Many descriptions are based on dissections of a single animal or a limited number of species, and attempts at correlating the various findings have not met with much success.

The findings of the more extensive investigations will be briefly reviewed:

In 1866 Owen (279) recorded observations on the gross anatomy of the biliary systems of a large group of animals. He mentions several species that normally lack a gall bladder and suggests that absence of the organ is related to caecal as opposed to gastric digestion.

In 1867 MacAlister (cited by 241, 328, 340, 376) reviewed the findings in a large number of species. He concluded that animals that feed continuously have no gall bladder, whereas those that feed intermittently have one.

In 1887 Oddi (cited by 65, 128, 138, 154, 199, 219, 238, 241, 322) reported his observations on the musculature of the intramural portion of the common bile duct in dogs, cats, sheep, cattle, pigs, horses, pigeons, fowls and guinea fowls. He concluded that an independent sphincter existed in each species.

/In

In 1895 Rachford (cited by 241, 340, 376) compiled data on the bile and pancreatic ducts in a series of mammals. He concluded that the fat content of an animal's food has a bearing on the presence or absence of the gall bladder.

In 1898 Hendrickson (154) studied the musculature of the bile ducts in rabbits, dogs and man. He found muscle tissue in all parts of the ducts of each species and considered that an independent sphincter of Oddi existed in each.

In 1907 Schache (315) studied the histology of the bile ducts in cattle, sheep, goats, horses, pigs, cats and dogs. He found muscle in the ducts of all the animals dissected. In every species the muscle of the intramural portion of the common bile duct formed a well-developed ring independent of the duodenal musculature.

In 1916 Scammon (314) studied the development of the biliary system in the petromyzon, the pigeon and the rat - three species which normally lack a gall bladder. He found vestiges of the gall bladder in the embryos of each species. He suggests that the organ disappears during later development on account of premature consolidation of the hepatic and cystic portions of the liver bud.

In 1920 Mann (238) studied the anatomy of the sphincter at the duodenal end of the common bile duct in 14 species, including 4 without a gall bladder. He found that species without a gall bladder did not differ from species possessing a gall bladder. The bile ducts of all the animals dissected were surrounded by a bundle of smooth muscle which he regarded as an independent sphincter.

In 1920 Mann, Brimhall and Foster (243) studied the distance from the pylorus to the duodenal papilla, and the dimensions of the common bile duct in 15 species, including 4 species without^a gall bladders. They found that no differentiation could be made between groups of animals having a gall bladder and those without one.

In 1920 Mann, Foster and Brimhall (245) studied the relation of the common bile duct to the pancreatic duct in 15 species, including 4 species without^a gall bladders. They found that each of the species could be included in one of the following three groups:-

Type A. - See Fig. 50 Page 156.

The ducts retain their individuality as far as the duodenum, where they enter either separately, but very close together, or unite into a common ampulla.

/Type B.

Type B. - See Fig. 50. Page 156.

The ducts enter the duodenum separately,
but at a variable distance from each other.

Type C. - See Fig. 50 Page 156.

The pancreatic duct empties into the bile
duct at a variable distance from the duodenum.

They failed to find a reason for the various
relationships of the ducts in the different groups.

In 1926 Higgins (160) investigated the problem of
the absence of the gall bladder in species representing
groups which normally possess the organ. He found that
the phenomenon could not be explained on a basis of diet,
feeding habits or food relations of the ancestors.

In 1926 Boyden (36) reported his observations on
approximately 10,000 domestic animals (equal numbers of
cats, calves, sheep and pigs). He was interested in
the problem of congenital duplication of the gall bladder,
and found a distinct species difference which he explain-
ed on embryological grounds. The accessory vesicles
arise from additional buds of the primitive hepatic
diverticulum, which are particularly common in cats
(1 in 8) and in calves (1 in 28), less common in sheep
(1 in 85) and in pigs (1 in 198), and extremely uncommon
in human beings (1 in 3,000 to 4,000).

In 1927 Giordano and Mann (138) studied the intramural part of the common bile duct in more than 20 species of animals. In each species they found a definite bundle of smooth muscle surrounding the duct.

In 1935 Zimmermann (376) reviewed the comparative anatomy of the biliary system.

He noted that three main types of biliary systems were found amongst animals, viz:-

Group 1 - See Fig. 51 page 156.

Multiple hepatic ducts: A gall bladder is present and frequently connected to the liver by cyst-hepatic ducts. The cystic duct is joined by several hepatic ducts.

Group 2 - See Fig. 51 page 156.

Arrangement as in man: A gall bladder is present. All the bile from the liver flows through the hepatic duct, which joins the cystic duct to form a common bile duct.

Group 3 - See Fig. 51 page 156.

Absence of the gall bladder: The two main hepatic ducts unite to form a common hepatic duct which passes directly to the intestine.

He failed to find a reason for the various groups, but suggests that animals without gall bladders are

/probably

probably phylogenetically of more recent date than those possessing the organ.

In 1936 Boyden (49, 50) studied the sphincter of Oddi in man, opossums, guinea pigs and dogs. He found that the intramural portion of the common bile duct was surrounded by a sheath of independent muscle in each species. The degree of development of the muscle and its relation to the duodenal wall differed markedly in the four species, but he suggests that his studies provide a clue to the phylogenetic origin of the sphincter, viz: that it has arisen as a compensation for the loss of functioning muscle in the upper regions of the biliary tract.

In 1937 Siwe (328) recorded data on a large series of animals, including fishes, reptiles and amphibia. He found that there was a tendency towards early fusion of the primitive subdivisions of the hepatic bud in mammalian embryos, and suggests that in animals that normally lack a gall bladder the fusion is even earlier than usual.

In 1938 Gorham and Ivy (140) tabulated data on the presence and absence of the gall bladder. They state that the organ is present in all lower vertebrates, but that it tends to disappear from the more highly-specialised forms, being retained in those

/species

species that resemble the ancestral type most closely.

The gall bladder is constantly present in carnivora and insectivora, frequently present in omnivora and often lacking in herbivora, but it adapts itself less rapidly to dietary habits than other parts of the digestive tract do. They concluded that the gall bladder is a primitive structure which is not easily lost.

In 1939 Mentzer (cited by 340) studied the biliary systems of 24 species representing 5 orders of African mammals. He noted that the duodenal papilla was close to the pylorus in carnivora and further removed in most artiodactyla.

In the same year (259) he reviewed the comparative anatomy of the biliary system and pointed out that many human anomalies represent the normal arrangement in lower forms.

In 1940 Thomson (340) reported on dissections of the biliary tract in 31 species of mammals, including 7 species without gall bladders and several rare animals. He found that the animals could be grouped into the three groups suggested by Mann et alia (245) on a basis of the relation between the bile and pancreatic ducts, but he failed to find a reason for the differences. There were marked differences in the

size of the duodenal papilla and in its distance from the pylorus which he could not correlate with any other finding.

PRESENT STUDY:

For this work the biliary systems of 148 animals representing 36 species were dissected. Fresh material was used for all dissections. The measurements recorded for each species represent average figures of the various specimens dissected.

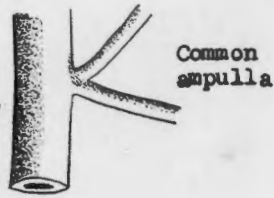
Histological sections of the ducts of most of the specimens were prepared for studies of the musculature. The method of preparation was similar to that used for the human bile ducts.

In this section the findings are briefly described and illustrated. To render the work complete, descriptions of the biliary systems of species reported on in the literature, but which were not available for ^{the} present study, are included.

The descriptions cover only the points considered important for the purpose of the investigation. To facilitate comparison and also to render the accounts as brief as possible, the data on each species are arranged under the following headings:-

RELATIONS BETWEEN THE BILE AND THE PANCREATIC DUCTS.

Type A.



Type B.



Type C.

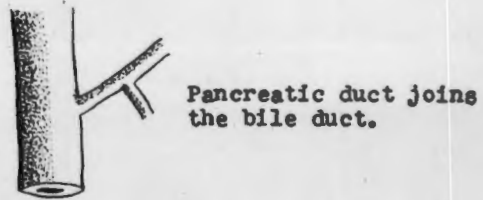
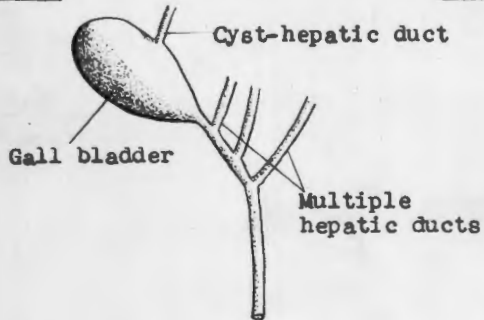


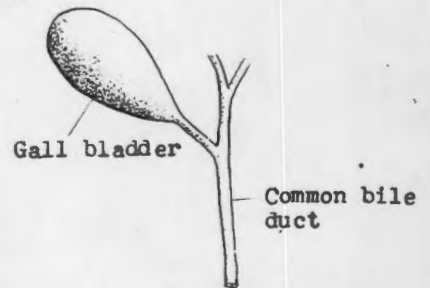
FIG. 50

ARRANGEMENTS OF THE COMPONENT PARTS OF THE BILIARY SYSTEM.

Group I.



Group II.



Group III. (Gall bladder absent)

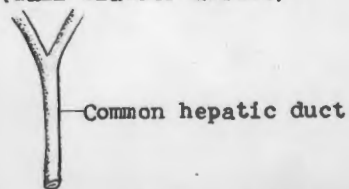


FIG. 51.

1. Anatomy:

(a) The liver.

(b) The biliary system.

(1) Form, i.e., the arrangement of the component parts of the system.

The various arrangements are referred to as Group I, II or III, according to the classification suggested by Zimmermann (376) - See Fig.5A, pg.156.

(2) Capacity - the size of the gall bladder and the dimensions of the common bile duct are noted.

(3) Relation of the bile duct to the pancreatic duct. The various relations are described as Type A, B or C, according to the system used by Mann et alia (243) - See Fig.5D, pg.156.

(4) Distance between the pylorus and the duodenal papilla.

2. The Musculature of the ducts:

(a) Supraduodenal portion.

(b) Intramural portion.

The various species are classified according to their phylogenetic relations, which are briefly described. Short notes on the diet and alimentary tracts of the different groups are included in the introductory paragraphs. In the discussion on each group the findings are compared with those of other workers on similar and related species.

"PREVERTEBRATES".

In the more highly-developed invertebrates belonging to the phylum chordata, there are organs

/which

which are often referred to as the liver of these animals. These organs are the hepatic caeca of *Balanoglossus* (140, 280), the gastric glands of sea squirts (140, 280) and the hepatic diverticulum of *Amphioxus* (140, 272, 280) - see Fig. 52, pg.159. Although these structures apparently have some digestive function (168), there is no evidence that they represent the vertebrate hepato-biliary system (103, 168, 194).

VERTEBRATES.

The liver, with its biliary system, is found in all vertebrates. It first appears in cyclostomes and is highly characteristic of the group (140).

CLASS I - FISHES:

The following representatives of the three main subgroups of this order were dissected:

- A. Cyclostomes - 2 specimens of the Hagfish,
- B. Cartilaginous fishes - 3 specimens of the Banded Dog-fish,
- C. Bony fishes - 5 specimens of the Cape Hottentot.

Total - 10 specimens.

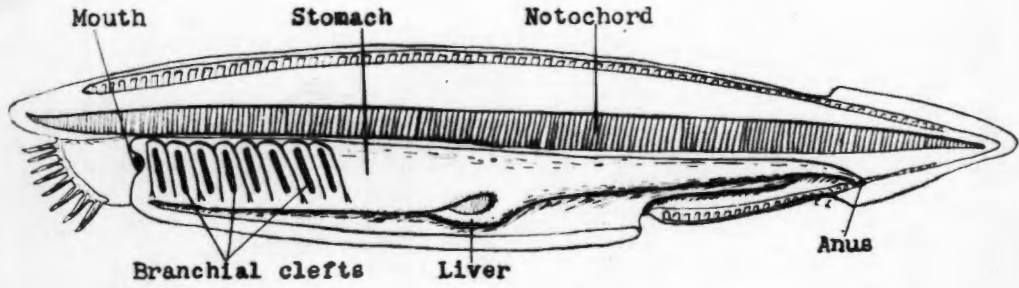
The findings are described and discussed under their respective headings:

A. Cyclostomes:

The group consists of Hags and Lampreys,

/These

THE HEPATIC DIVERTICULUM IN AMPHIOXUS.



Redrawn after T.J.Parker and W.A.Haswell (1940) A Text-Book of Zoology Vol. 2, p. 44, Fig. 39.

Fig. 52.

BILIARY SYSTEM IN CYCLOSTOMATA.

Myxinidae - The Hag-fish.

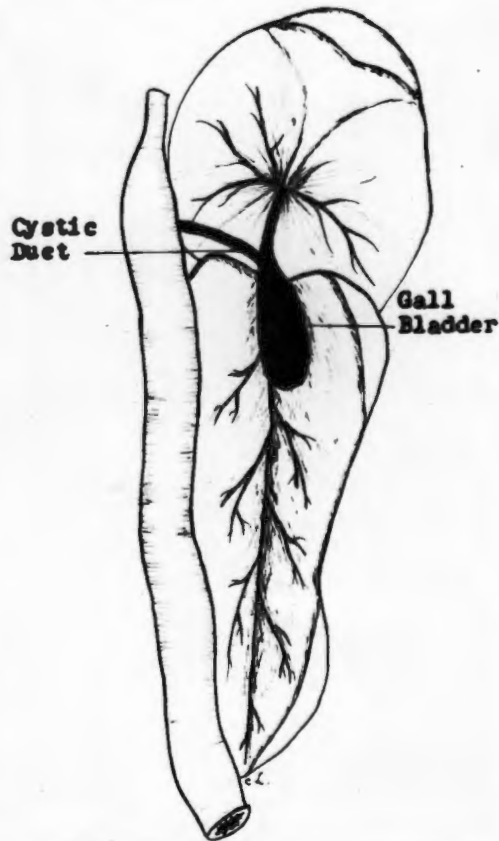
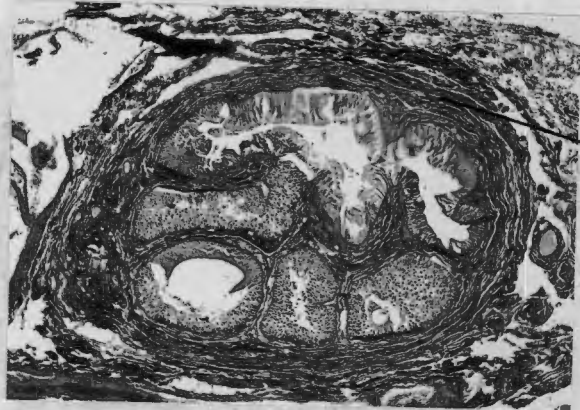


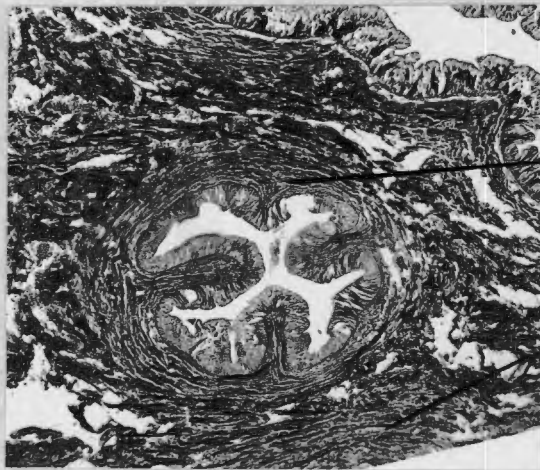
Fig. 53

A.
Upper third.
(X24).



Muscle
fibres
in wall
of bile
duct.

B.
Intramural portion.
(X 24).



Muscle
fibres in
wall of
bile duct

Duodenal
muscle.

Fig. 54.

The histology of the
common bile duct of
the hag-fish.

These animals are the lowest type of living vertebrates (140, 280, 325). Their digestive canal consists of a simple straight tube and they feed on fishes (221, 325).

Example Dissected - the Hagfish.

Anatomy - See Fig. 53, pg. 159.

1. The liver consists of two separate lobes situated astride the gut.
2. The biliary system.
 - (a) Form - Group 1. Cyst-hepatic ducts open into the gall bladder.
 - (b) Capacity - The gall bladder is large. The cystic duct is short and wide.
 - (c) No pancreatic duct was found.
 - (d) Distance between the pylorus and the papilla - short.

The Musculature of the Bile Ducts - See Figs. 54A & B, Pg. 160.

The most striking feature of the biliary and intestinal muscle of the Hag is that it stains as poorly as that of the 40 mm. human embryos dissected.

1. Supraduodenal - Muscle fibres are present at all levels but they are overshadowed by fibrous tissue.
2. Intramural - The scanty fibres of the duct are separated from the duodenal muscle by a thin layer of fibrous tissue.

Discussion:

The anatomical findings agree with other descriptions of the biliary system of Hags (140, 280, 325). A gall bladder is present in all Hags (140). Lampreys, however, possess no biliary apparatus in

/the

the adult stage (63, 140, 221, 280, 312, 314, 325), but the larval form (Ammocoete) has a large gall bladder and well-formed bile ducts (280, 314, 325).

The musculature of the biliary system of Cyclostomes has not been described before.

B. Cartilaginous Fishes. (Elasmobranchii and Holocephali).

This group includes Rays, Sharks and shark-like fishes. These fishes are more primitive than bony fishes (280) but they have become highly specialised in certain respects (325). Their alimentary tracts have remained relatively simple and they feed on other fishes and marine organisms.

Example Dissected - the Banded Dog-fish.
(*Haploblepharus edwardsii*).

Anatomy - See Fig. 55A, pg. 164.

1. The liver is a large bilobed organ.
2. The biliary system.
 - (a) Form - Group I. The gall bladder is embedded in the left lobe of the liver and cyst-hepatic ducts are present.
 - (b) Capacity - The gall bladder is large.
The bile ducts are long and wide.
 - (c) Relation to the pancreatic duct - Type A.
 - (d) Distance between the pylorus and the papilla - very short.

The Musculature of the Bile Ducts - See Fig. 56, pg. 165.

1. Supraduodenal - The muscle is well-developed and arranged in a thick sheath around the ducts. The fibres are mostly circular.

2. Intramural - The muscle is more scanty. It is separated from the duodenal muscle by connective tissue fibres.

Discussion:

The anatomical findings are fairly well representative of the biliary system of cartilaginous fishes in general.

A gall bladder is present in the vast majority of species (140, 279). It may be intrahepatic, attached to either lobe of the liver, or suspended by a long mesentery (259, 312, 313). Occasionally it is absent in species of the shark family (169, 258, 279, 314, 325, 328). Owen (279) failed to find a gall bladder in the saw-fish, the hammerheaded shark and the sunfish.

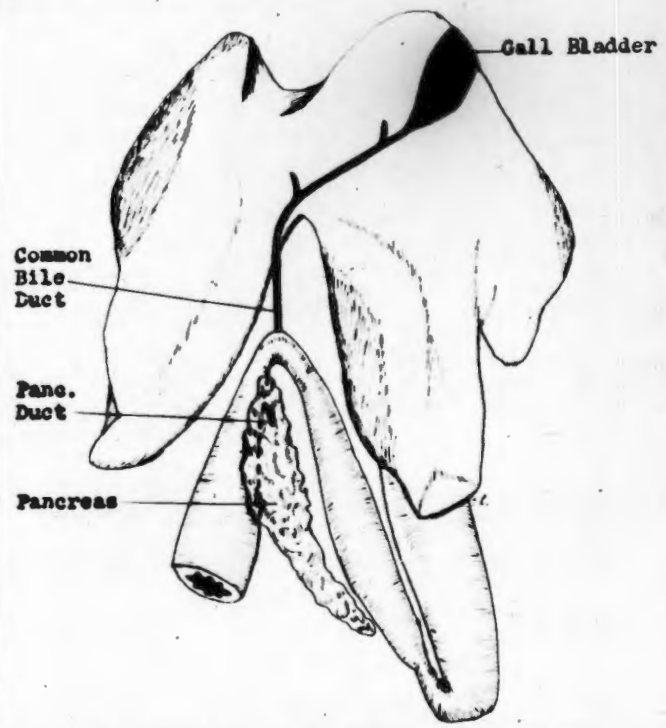
Cyst-hepatic ducts are usually present (259, 279) and the two main hepatic ducts may open separately into the intestine as in the saw-fish (279). The relation to the pancreatic duct is usually Type A (63).

The musculature of the bile ducts of cartilaginous fishes has not been described before.

C. Bony Fishes:

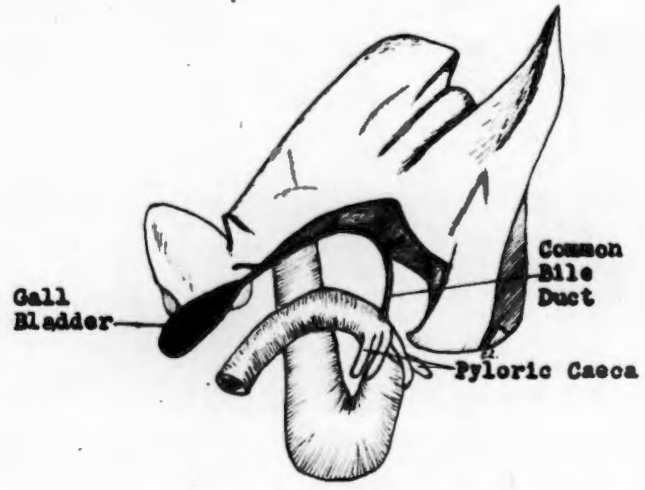
The group includes Ganoids, true bony fishes and lung-fishes. Fishes are regarded as the ancestors of amphibia (280, 325). They have attained tremendous
/development,

A.



BILIARY SYSTEM IN CARTILAGINOUS FISHES.
 The Banded Dog-fish (*Haploblepharus edwardsii*)

B.



BILIARY SYSTEM IN BONY FISHES.
 The Hottentot or Hangberger (*Spondyliosoma blochii*)

Fig. 55

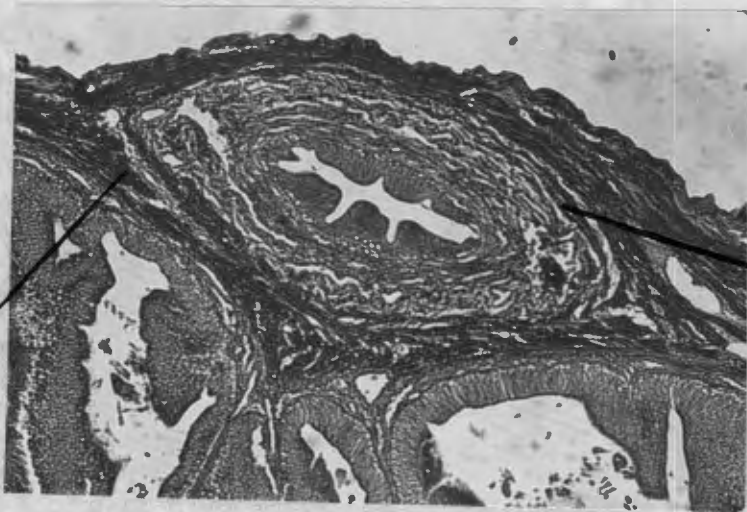
The biliary system in fishes.

A.
Upper Third.
(X140).



Muscle
layer.

B.
Intramural
Portion.
(X140).



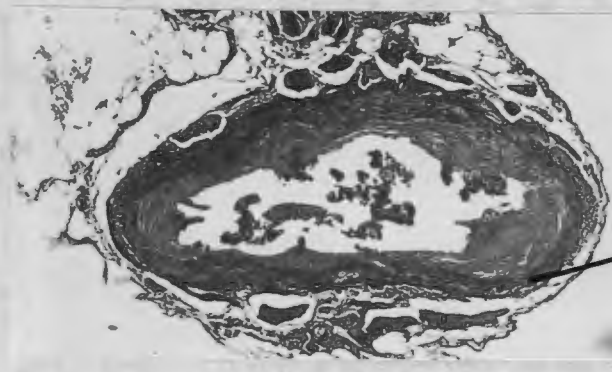
Duodenal
Muscle

Bile
duct
muscle.

FIG. 56

The histology of the common
bile duct of the Dog-fish.

A.
Upper Third.
(X140).



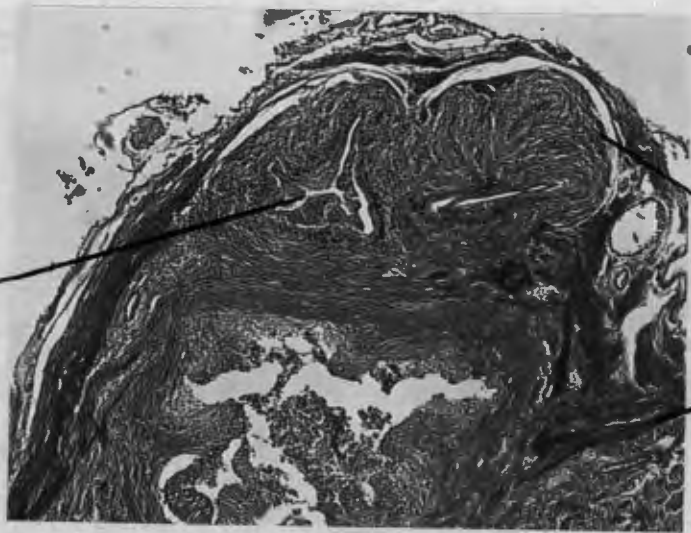
Muscle Layer

B.
Lower Third.
(X140)



Muscle layer.

C.
Intramural
Portion.
(X 140).



Panc. duct.

Bile duct muscle.

Duodenal Muscle.

FIG. 57

The histology of the common bile duct of the Hottentot.

development, but retain several primitive characteristics and, among others, a relatively simple gastrointestinal canal. They feed on other fishes, crustaceans and molluses.

Example dissected - The Cape Hottentot (Spondyliosoma blechii).

Anatomy - See Fig. 55B, pg.164.

1. The liver is bilobed.
2. The biliary system.
 - (a) Form - Group I.- Cyst hepatic ducts were present in two specimens.
 - (b) Capacity - The gall bladder is medium-sized.
The terminal part of the common bile duct is slightly expanded.
 - (c) Relation to the pancreatic duct - Type A.
 - (d) Distance between the pylorus and the papilla - very short.

The musculature of the Bile Ducts. - See Fig. 57, pg.166.

1. Supraduodenal - a conspicuous band of muscle lies external to a layer of fibrous tissue. The muscle fibres are mainly circular.
2. Intramural - The muscle is poorly-developed and consists of scattered circular fibres only. These are separated from the duodenal wall by a layer of fibrous tissue.

Discussion:

The anatomical findings agree with descriptions of the biliary system of bony fishes in general (63, 103, 162, 279, 280, 312, 325).

A gall bladder is present in the majority of species (279) and the Cod occasionally has two (259).

/Several

Several authors report that the organ is lacking in some species (241, 259, 279). Owen (279) mentions 12 such species, including mainly Wrasses, Perches, Barracudas and Gurnards.

Cyst-hepatic ducts are often present (162, 259, 279) and multiple hepatic ducts are the rule (259, 279).

A dilatation of the common bile duct is described in Lophins and Turbets (279) and in the American Bullhead (162).

The bile duct usually opens into ^{the} duodenum close to the pylorus and near the pancreatic duct (63), but in the Bream it opens into the stomach (279).

The histological findings agree with Higgins' (162) description of the musculature of the bile ducts of the American Bullhead. He found the muscle of the intramural part of the duct as well-developed as that of the supra-duodenal part.

CLASS II - AMPHIBIA.

This class, which includes frogs, toads, newts and salamanders, represents a transition stage between fishes and reptiles (140, 280). Many primitive characteristics are retained (280, 325), and among these a simple alimentary tract. The animals are insectivorous and carnivorous (221).

/Example

Example dissected - The Plathander
(*Xenopus laevis*) -
10 specimens.

Anatomy - See Fig. 58A, pg.170.

1. The liver has two large lateral lobes connected by a small median mass.
2. The biliary system.
 - (a) Form - Groups I. and II. Accessory hepatic ducts and cyst-hepatic ducts were found in several specimens.
 - (b) Capacity - the gall bladder is relatively large.
The bile ducts are long and attenuated.
 - (c) Relation to the pancreatic ducts - Type C.
 - (d) Distance between the pylorus and the papilla - very short.

The musculature of the ducts - See Figs. 58 B & C., pg. 170.

1. Supraduodenal - The walls of the ducts are composed almost entirely of muscle tissue. The fibres are mostly circular.
2. Intramural - The muscle is less well-developed. It is separated from the duodenal muscle by loose connective tissue.

Discussion:

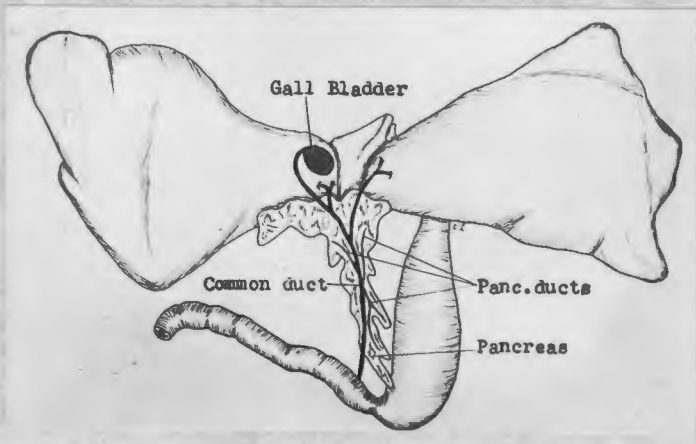
The anatomical findings agree with descriptions of the biliary system in amphibia in general (152, 280, 318, 325, 328).

A gall bladder is constantly present (63, 140, 279, 280, 328).

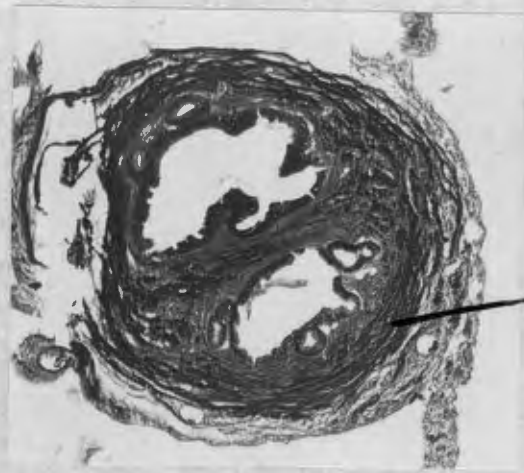
Accessory hepatic ducts are found in most frogs (152, 328) and cyst-hepatic ducts are common in Salamanders (279).

The pancreatic ducts usually join the bile duct at some distance from the intestine (328).

A.
Anatomy.



B.
Histology of
the Bile Ducts.
(X215).



C.
Histology of
the Intramural
Portion of the
Bile Duct.
(X700).



Fig. 58.

The biliary system of *Xenopus laevis*.

The musculature of the bile ducts in Amphibia has not been studied before.

CLASS III - REPTILES.

This class includes lizards, snakes, tortoises, turtles and crocodiles. Cynodont reptiles of the Permian period are regarded as the ancestors of birds and mammals (140, 280, 325). Although the present species do not approximate the ancient forms, many primitive characteristics are retained (140, 325). They are carnivorous and herbivorous, but have the habit of intermittent feeding, and the alimentary tract resembles the primitive uncomplicated type.

Examples of the Class Dissected:

- A. The Cape Monitor - 1 specimen;
- B. The Girdle-tailed Lizard - 2 specimens;
- C. The Gecko - 2 specimens;
- D. The Mole Snake - 2 specimens;
- E. The Tortoise - 1 specimen.

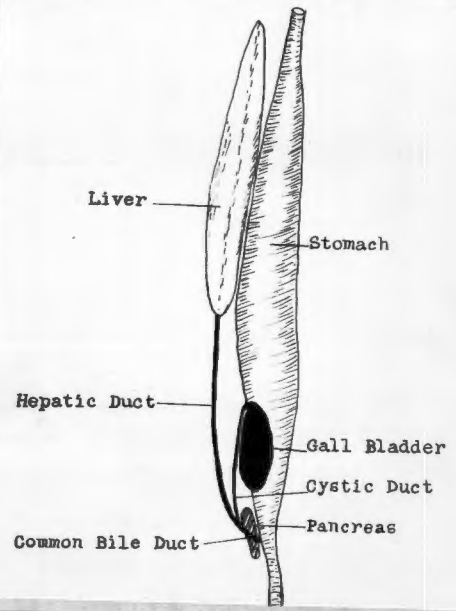
Total: 8 Specimens.

- A. The Cape Monitor or Leguan (*Varanus albigularis*),

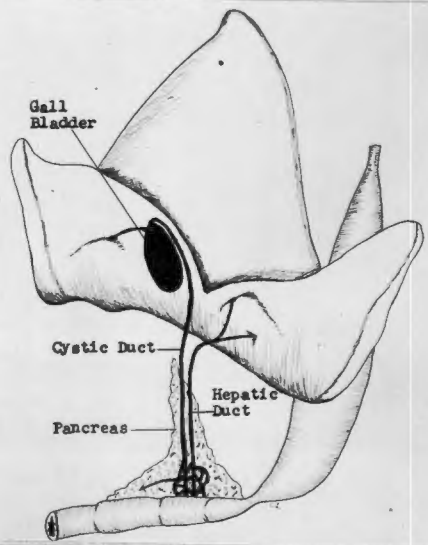
Anatomy - See Fig. 59B, pg. 172.

1. The liver is bilobed.
2. The biliary system.
 - (a) Form - Group I. A cyst-hepatic duct is

A.
The Mole Snake.



B.
The Cape Monitor.



C.
The Tortoise.

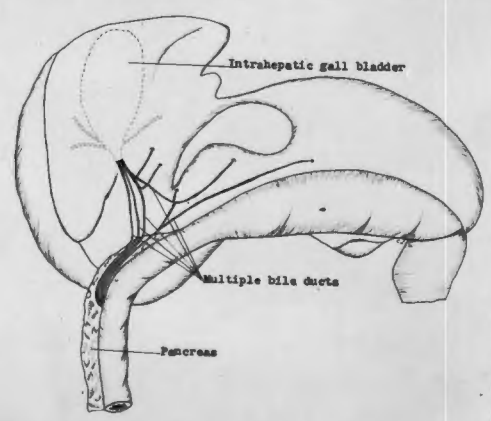


Fig. 59.
The biliary system in Reptiles.

A.

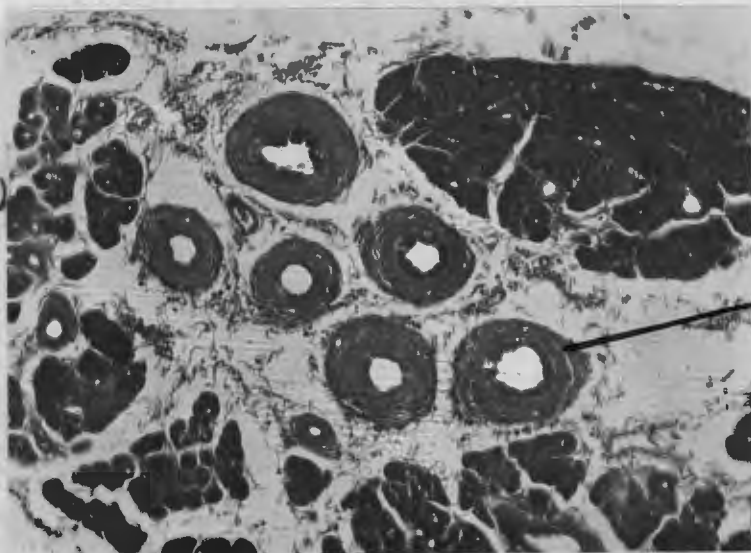
Upper Third
of the
Hepatic Duct.
(X24).



Muscle
bundles

B.

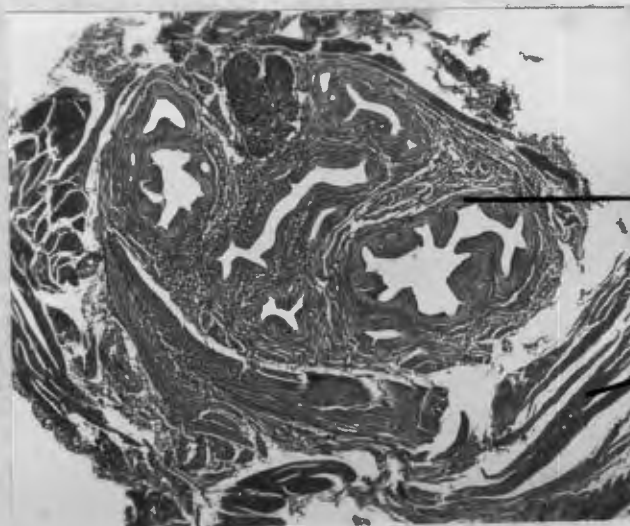
Intrapaneat-
ic Plexus. (X24)



Very
scanty
muscle.

C.

The intramural
Portion. (X24).



Scanty
muscle

Duo-
denal
muscle.

FIG. 60.

The histology of the bile
duots of the Cape Monitor.

A.
Upper Third
of Hepatic
Duct. (X24)



B.
Ampulla.
(X30).

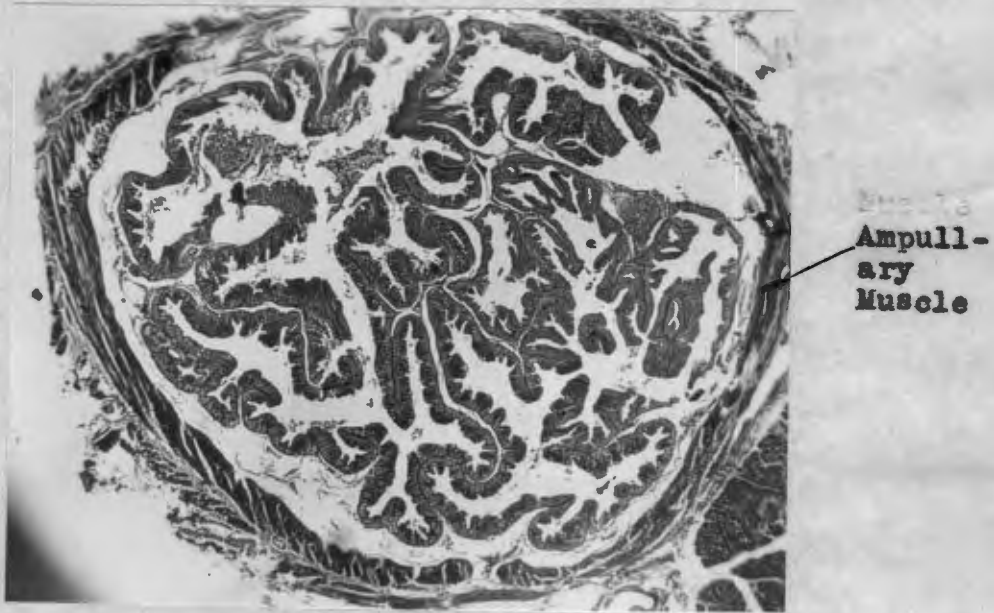


Fig. 61.

The histology of the bile
ducts of the Mole Snake.

present and the cystic and hepatic ducts do not unite into a single common bile duct.

- (b) Capacity - The gall bladder is fairly large. The bile ducts are long and comparatively wide.
- (c) Relation to pancreatic ducts - Type C.
In the posterior part of the pancreas the cystic and hepatic ducts break up into an anastomosing network of ducts. This plexus receives additional ducts from the pancreas. Before entering into the duodenum, the various ducts unite into three main channels.
- (d) Distance between the pylorus and the openings of the ducts - short.

The musculature of the ducts - See Figs. 60 A, B & C, pg.173.

1. Supraduodenal: The upper two-thirds of both cystic and hepatic ducts are well supplied with muscle which comprises most of their walls. The fibres are mainly longitudinal.
Where the ducts split up into the plexus the muscle disappears almost entirely and is replaced by fibrous tissue - See Fig. 60B, pg.173.
2. Intraduodenal - Very little muscle is present.

B. & C. - The Girdle-tailed Lizard and the Gecko.

The anatomy of these species closely resembles that of the leguan. The musculature of the bile ducts was not studied.

D. - The Mole Snake (Pseudaspis cana).

Anatomy - See Fig. 59A pg.172.

1. The liver is comparatively small, elongated and non-lobulated.
2. The biliary system.
 - (a) Form - Group II. The gall bladder is situated about 2 inches distal to the liver and just below the pylorus.

/(b).

- (b) Capacity - The gall bladder is medium-sized. The hepatic duct is very long and the cystic duct short.
- (c) Relation to pancreatic duct - Type C. The common duct breaks up into a plexus, as in the Leguan.
- (d) Distance between the pylorus and the bile duct openings - short.

The musculature of the bile ducts - See Figs. 61A & B, pg. 174.

- 1. The supraduodenal - a thin but complete outer muscular layer surrounds a thick, inner fibrous layer. The fibres are circular and longitudinal. Where the common duct breaks up into the plexus the muscle fibres disappear.
- 2. Intramural - A well-defined band of muscle tissue, separate from the duodenal muscle surrounds the apex of the ampulla.

E. The Tortoise (Testudo geometricus).

Anatomy - See Fig. 59C, .pg. 172.

- 1. The liver is large and bilobed.
- 2. The biliary system.
 - (a) Form - Group I. The gall bladder is embedded in the right lobe of the liver. Several cyst-hepatic ducts join the vesicle. The three main ducts from the gall bladder are joined by hepatic ducts, and four ducts remain distinct as far as the duodenum.
 - (b) Capacity - the gall bladder is very large. The ducts are long and medium-sized.
 - (c) Relation to the pancreatic duct - Type C.
 - (d) Distance between the pylorus and the bile duct openings - long.

The Musculature of the Bile Ducts.

The muscle resembles that of the bile ducts of the snake and leguan in every respect. The four ducts penetrate the duodenal wall separately, but a common sphincter surrounds them.

/Discussion:

Discussion:

The anatomical findings agree with other descriptions of the biliary systems in these species of reptiles (279, 280, 312, 328, 336) and represent the common arrangements found in the class as a whole.

A gall bladder is present in all species (140, 241, 279, 280, 318, 328). It may lie in a notch in either lobe of the liver or it may be deeply embedded in the right lobe as in the tortoise (241, 259, 279). The great distance between the gall bladder and liver which was noted in the mole-snake, is a common arrangement in snakes (279, 312, 336). The organ is apparently placed so far distally to escape being compressed by food in the stomach (279, 336).

Cyst-hepatic ducts and multiple hepatic ducts which were found in the monitor and the tortoise are common to most species (259, 328). These ducts were also found in the girdle-tailed lizards and the geckos dissected, and Owen (279) describes them in turtles, iguanas, alligators and crocodiles.

The plexiform arrangement of the ducts in the pancreas is best-known in snakes and monitors (328). It was also found in the girdle-tailed lizards dissected, and Owen (279) describes it in the pythen.

The musculature of the bile ducts has not been described before.

CLASS IV - BIRDS.

Birds evolved from reptiles at the same period as mammals did (140). In many respects they are the most highly-specialised vertebrates (280), but several primitive characteristics are retained (280, 325).

Their diet varies considerably, and anatomical complexities of the alimentary tract are common (279). These complexities are, as a rule, more marked in herbivorous and insectivorous species than in carnivorous varieties (279). Some insectivorous birds are descendants of an old herbivorous stock (14C).

Examples dissected:

The following examples of the class were dissected:

- A. The domestic fowl - 6 specimens,
- B. The pheasant - 2 specimens,
- C. The partridge - 2 specimens,
- D. The domestic pigeon- 3 specimens.

Total: 13 specimens.

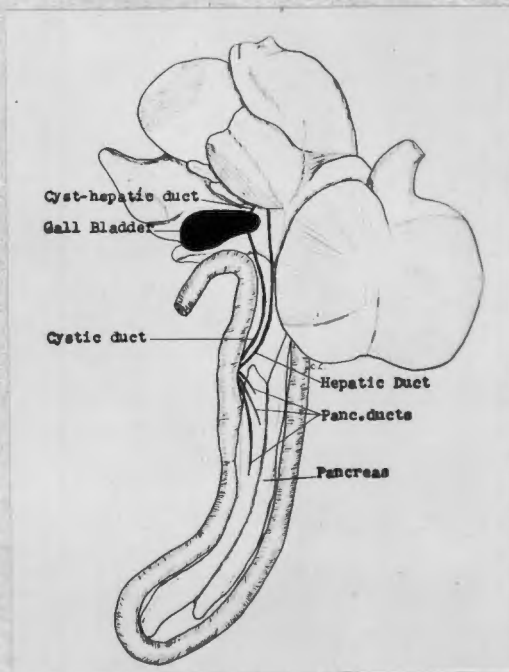
A. The domestic fowl (gallus ferrugineus).

Anatomy - see Fig. 62A, pg. 179.

1. The liver consists of a large right lobe and a smaller left lobe, both of which are deeply fissured.
2. The biliary system.
 - (a) Form - Group I. A cyst-hepatic duct opens into the gall bladder and the cystic duct and hepatic duct open separately into the duodenum.

/(b)

A.
The Domestic
Fowl.



B.
The Domestic
Pigeon.

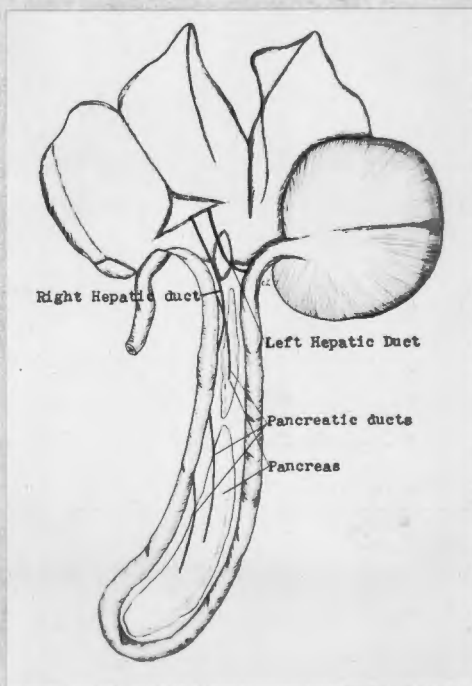
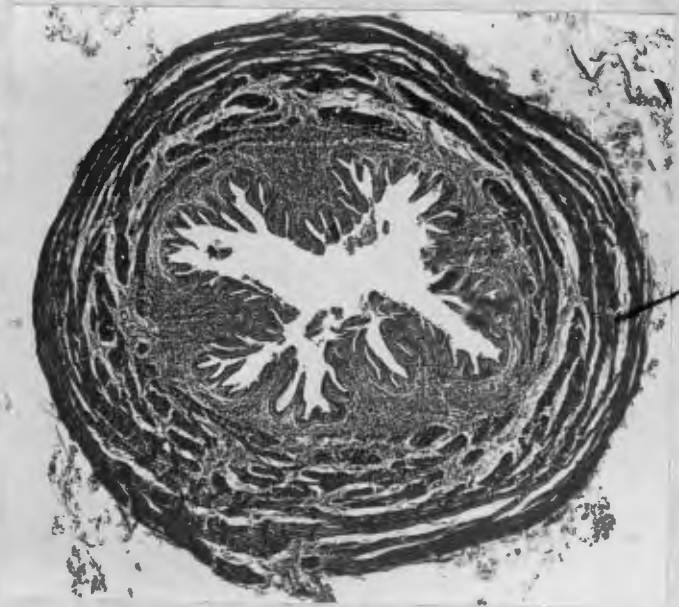


FIG. 62.

The biliary system in Birds.

A.

Upper Third of
Hepatic Duct.
(X180).



Muscle
layer.

B.

Intramural
Portion.
(X36)



Bile
duct
muscle

duodenal
muscle

FIG. 63

The histology of the bile
ducts of the Fowl.

Upper Third
of Hepatic
Duct (X180).



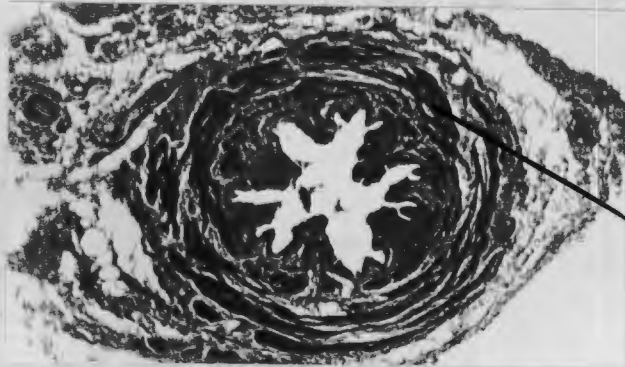
Muscle
layer

Fig. 64.

The histology of the bile
ducts of the Pheasant.

A.

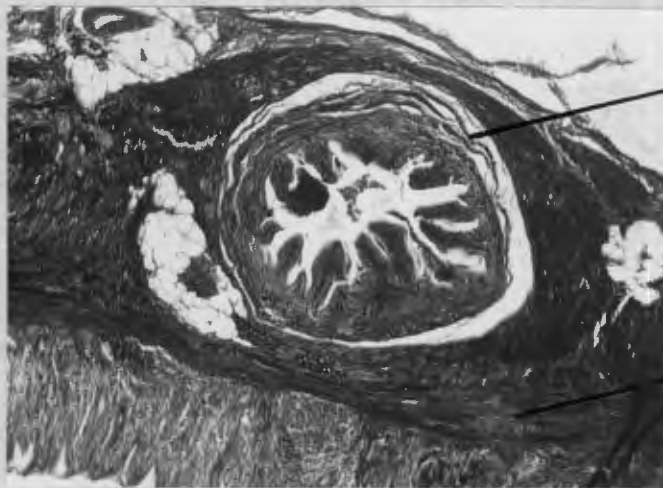
Upper Third
of Right
Hepatic Duct.
(X180).



Muscle layer

B.

Intramural
Portion.
(X180).



Bile duct
muscle.

Duodenal
muscle.

Fig. 65

The histology of the bile ducts
of the Domestic Pigeon.

- (b) Capacity - the gall bladder is large. The bile ducts are long and wide.
- (c) Relation to the pancreatic ducts - Type A. The two bile ducts and the three pancreatic ducts open in close proximity.
- (d) Distance between the pylorus and the openings of ducts - very long.

The Musculature of the ducts - see Figs. 63A & B, Pg. 180.

- 1. Supraduodenal - A large amount of muscle is present in both ducts. It forms a thick layer consisting of outer circular and inner longitudinal bundles.
- 2. Intramural - The muscle is not so well-developed, but a thin layer, separate from the duodenal muscle, surrounds the apex of the common entrance --see-Fig.

B. & C. The Pheasant and the Partridge.

The biliary systems of these species resemble that of the fowl in all details. The muscle of the bile ducts is very well-developed - see Fig. 64, Pg.181.

D. - The Domestic Pigeon (Columba livia).

Anatomy: - See Fig. 62B, Pg. 179.

- 1. The liver resembles that of the fowl.
- 2. The biliary system.
 - (a) Form - Group III modified. Although there is no gall bladder, the two hepatic ducts remain separate and enter opposite limbs of the duodenal loop.
 - (b) Capacity - the ducts are no larger than those of the pheasant, which is of comparable size and possesses a gall bladder.
 - (c) Relation to the pancreatic ducts - Type B.
 - (d) Distance between the pylorus and the openings of ducts, - variable.

The musculature of the bile ducts - see Fig. 65, Pg. 181.

The muscle of both ducts is very well-developed and resembles that of the fowl's bile ducts in every respect.

Discussion:

The anatomical findings agree with other descriptions of the biliary system in birds (279, 280, 312, 325, 328, 336) and represent the two main variations encountered in this class.

A gall bladder connected to the liver by a cyst-hepatic duct is present in the vast majority of species (140, 279, 312, 336) including all carnivorous birds (140). It is usually large and oval, but in the Toucan it is elongated like a loop of intestine. In the Hornbill the cyst-hepatic duct communicates with the gall bladder and with the cystic duct (279). In the Pelican the bile ducts and gall bladder are arranged in such a manner that the latter looks like a dilatation of the right hepatic duct (169).

Several authors (42, 140, 160, 169, 231, 279, 280, 312, 314, 325, 328) mention the absence of the gall bladder in some herbivorous and insectivorous species. Owen (278) mentions 8 families which lack the organ. Gorham and Ivy (140) collected data on 177 species representing 83 families and found the gall bladder wanting in 45 species representing 21 families.

TABLE 8

GALL BLADDER CONSTANTLY ABSENT.

1.	Struthioniformes	- South African ostrich.
2.	Rheiformes	- South American Rhea.
3.	Opisthocanidae	- Stink-bird.
4†	Columbidae	- Pigeons and doves.
5.	Psittacidae	- Parrots.
6.	Trochilidae	- Humming birds.
7.	Alcedinidae	- Kingfishers.
8.	Pecidae	- Woodpeckers.
9.	Pittidae	- Tropical perching birds.
10.	Philippitidae	- Tropical perching birds.
11.	Dicouridae	- Indian sparrows.
12.	Paridae	- Tits.
13.	Bambycillidae	- Type of sparrow.
14.	Nectariniidae	- Sun-birds.
15.	Turnicidae	- Marsh birds related to cranes.

TABLE 9.

GALL BLADDER OCCASIONALLY ABSENT IN SOME SPECIES.

1.	Apterygidae	- Kiwis.
2.	Hellamithidae	- Finfoots.
3.	Scelopacidae	- Snipe.
4.	Cuculidae	- Cuckoos.
5.	Caprimulgidae†	- Goat-suckers.
6.	Munidae	- Guinea fowl.
7.	Ramphastidae	- Toucons.
8.	Timelidae	- Type of sparrow.
9.	Muscicapidae	- Fly-catchers.

In tables 8 and 9, page 184 the birds lacking a gall bladder are enumerated. Although the organ is constantly lacking in many species, it is equally constantly present in closely-related species, e.g.,

<u>Absent.</u>	<u>Present.</u>
Ostrich	Emu,
Parrot	Cockatoo
Kingfisher	Hornbill
Sun-bird,	Flower-bird
Woodpecker.	Honey-guide.

Two ducts which open separately into the duodenum are found in practically all birds (279, 280, 328, 336). Owen (279) states that a single common bile duct is never found, but others (241, 259, 336) describe such a variation. Felix (cited by 328) found only one duct in the ostrich, but Owen (279) describes two.

Occasionally there are multiple ducts, the usual arrangement then being a single cystic duct and two hepatic ducts, as in the Curassaw (279).

The musculature of the bile ducts of birds has not been described before.

CLASS V - MAMMALS.

Mammals are the most highly-organised vertebrates (280). It is generally believed that they originated from reptiles through the medium of primitive insectivore-carnivorous mammals (140, 280, 328).

The diet of mammals varies considerably and the alimentary tract is more complex than that of the lower
/vertebrates.

vertebrates. As a rule, the digestive canal of herbivora is more capacious and complex than that of carnivora and insectivora (279). The parts of the digestive apparatus where the differences are most noticeable are the stomach and the caecum (279).

The class consists of three main subclasses, viz: Monotremes, Marsupials and Placentals.

SUB-CLASS I - MONOTREMES.

These oviparous animals are the most primitive mammals alive, and probably represent a line which descended directly and independently from the mammal-like reptiles (140, 280). They retain several reptilian characteristics and, in many respects, they have failed to become specialised (280). They are insectivorous (221, 325) and their alimentary canal is relatively simple (279).

Examples of the Sub-Class:

No specimens were available for dissection. The following descriptions are based on data obtained from accounts by Owen (279) and others (140, 325).

A. The Duck-billed Platypus (Ornithorhynchus).

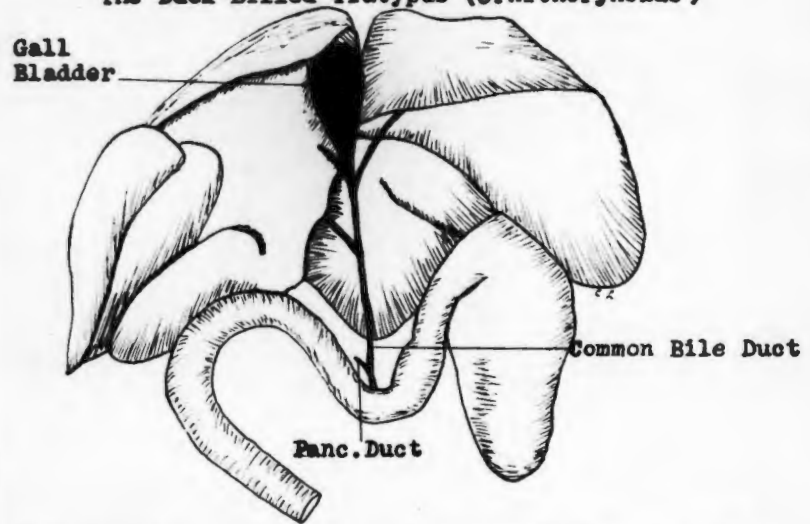
Anatomy - see Fig. 66, Pg. 187.

1. The liver consists of four lobes (325).
2. The biliary system.
 - (a) Form - Group I. A gall bladder is constantly present (140, 279) and multiple hepatic ducts join the cystic duct (279).

/(b)

BILIARY SYSTEM IN MONOTREMES.

The Duck-Billed Platypus (*Ornithorynchus*)

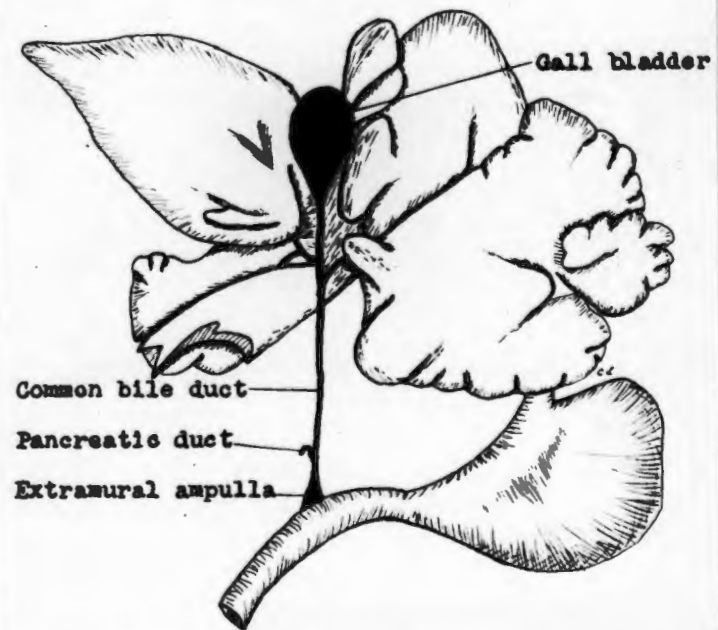


Redrawn after R.Owen (1866) *Comparative Anatomy and Physiology of Vertebrates* Vol. 3, p. 410, Fig. 308.

Fig. 66

BILIARY SYSTEM IN MARSUPIALS.

The Opossum (*Didelphys virginiana*)



Redrawn after F.S.DuBois and E.A.Hunt (1932) *Anatomical Record* Vol. 54, p. 297, Fig 4.

Fig. 67

- (b) Capacity - The gall bladder is large (140, 279).
- (c) Relation to the pancreatic duct - Type A. A large extraduodenal ampulla is present (279).
- (d) Distance between the pylorus and the papilla - 17 mm. (279).

The muscle of the bile ducts has not been described.

B. The Spiny Anteater (Echidna).

The biliary system of this species resembles that of the ornithorhynchus (140, 279). A gall bladder is constantly present (140) and the bile duct enters the intestine 25 mm. from the pylorus (279). The bile duct musculature has not been described.

SUB-CLASS II - MARSUPIALS.

The marsupials are more highly developed than monotremes, but lower in the scale of mammalian evolution than placentals (140, 280, 325). They have developed extensively and today there are forms that parallel superficially most placental orders (279, 325). Carnivorous, insectivorous, herbivorous and even ruminant species are found (140, 279, 325).

The alimentary canal shows corresponding adaptations and in herbivorous species the stomach is complicated by sacculi, while the caecum may reach an extraordinary size (279).

/Example

Example of the Sub-class:

No specimens were available for dissection. The following description of the Virginian Opossum is based on data obtained from accounts by Du Bois and Hunt (114, 115) and others (50, 279).

The Virginian Opossum (*Didelphys virginiana*).

Anatomy - see Fig. 67, Pg. 187.

1. The liver is multilobed (115, 279).
2. The biliary system.
 - (a) Form - Group II (115).
 - (b) Capacity - the gall bladder is large and the bile ducts are tenuous (115).
 - (c) Relation to the pancreatic duct - Type A. A large extramural ampulla is present (50, 114, 279). A short duct passes from it to open into the duodenum (50, 114).
 - (d) Distance between the pylorus and the papilla: 25 mm. (279).

The musculature of the bile ducts.

1. Supraduodenal portion: The lower two-thirds of the common bile duct possesses well-developed muscle consisting of outer circular and inner longitudinal layers (114).
2. Ampulla and intramural portion: The muscle of the ampulla is extremely well-developed and the muscle of the duct of the ampulla is completely separated from the duodenal muscle by a layer of fibrous tissue (50, 114).

Discussion:

The biliary systems of other marsupials resemble that of the opossum.

A relatively large gall bladder is present in all species (140, 279, 340). It may be loosely attached to

/the

the liver (279, 340) or embedded in the hepatic tissue (259) or attached to the left of the ligamentum teres (259). Accessory vesicles are reported (279).

The form of the biliary tract usually resembles that of the opossum, i.e., Group II.

The ampulla is usually extraduodenal and of large size (279), but it may be intramural as in the Tree Kangaroo (340) or absent as in the Tasmanian Devil (340).

The relation between the bile and pancreatic ducts always conforms to Type A (279, 340).

The distance between the pylorus and the duodenal papilla varies considerably and depends largely on the size of the animal. In the Tasmanian Devil the long-nosed Bandicoot and the Long-tailed Dasyure it measures approximately 25 mm. (279, 340). In the Wallaby it measures 65 mm. (340) and in the Great Kangaroo 125 mm. (279).

SUB-CLASS III - PLACENTALS.

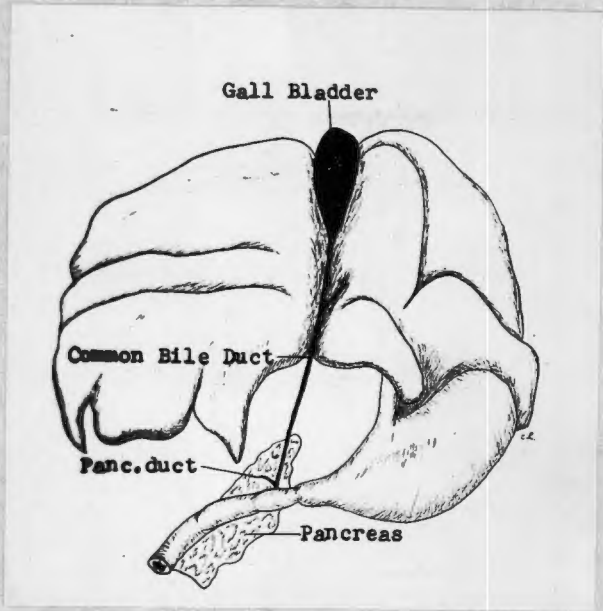
The placentals are the most highly-organised mammals. The degree of specialisation of the various orders differs considerably, and each will be discussed separately.

ORDER - INSECTIVORA.

The insectivora are regarded as the most primitive placental mammals (280, 325). They represent the only living order that existed during the reptilian age (140).

/Many

A.
The Cape Golden
Mole.



B.
The Elephant
Shrew.

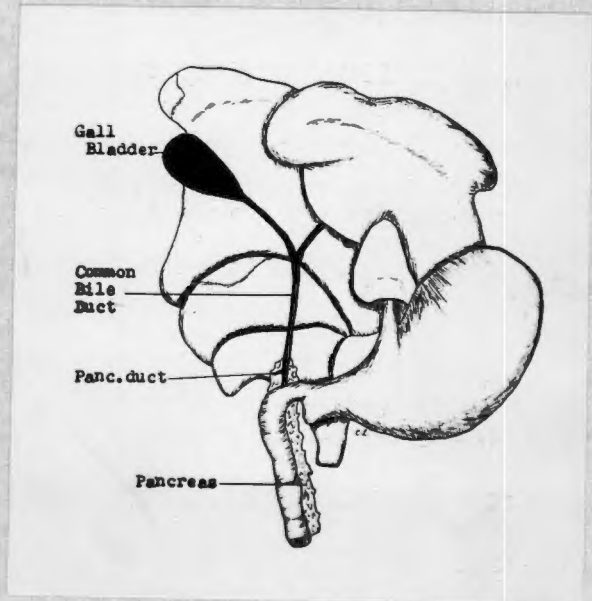
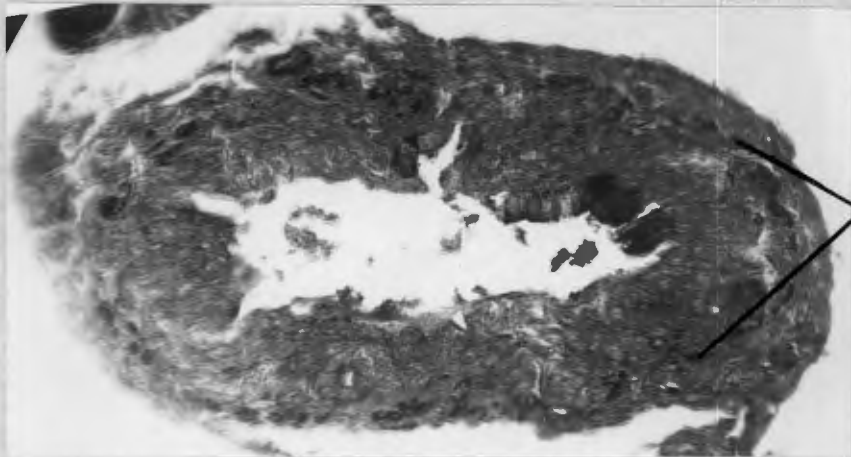


Fig. 68.

The biliary system in Insectivora.

A.
Lower Third.
(X700)



Muscle
bundles

B.
Intramural
Portion.
(X215).



Duodenal
muscle

~~Amphibian~~
bile duct
muscle.

Fig. 69

Histology of the common bile
duct of the Cape Golden Mole.

Anatomy - see Fig. 68B, Pg. 191.

1. The liver is multilobed.
2. The biliary system.
 - (a) Form - Group II.
 - (b) Capacity - the gall bladder is large.
The common bile duct is
12 mm. long and very thin.
 - (c) Relation to the pancreatic duct - Type C.
 - (d) Distance between the pylorus and the
papilla - 7 mm.

The musculature was not studied.

Discussion:

The anatomical findings agree with descriptions of other insectivora (279, 328). A gall bladder is present in all species (140, 341, 279).

The musculature of the bile ducts has not been described before.

ORDER - CHIROPTERA.

Bats are derived from insectivora (140, 280) and embryologically they are closely related to primates (personal communication from Professor Goetz). They are frugivorous and insectivorous (221) but all species have very simple alimentary tracts (279).

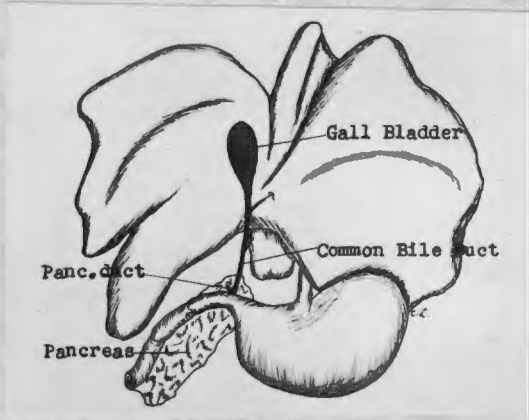
Example dissected:

The Cape Black Bat (Rhinolephus capensis). -
6 specimens.

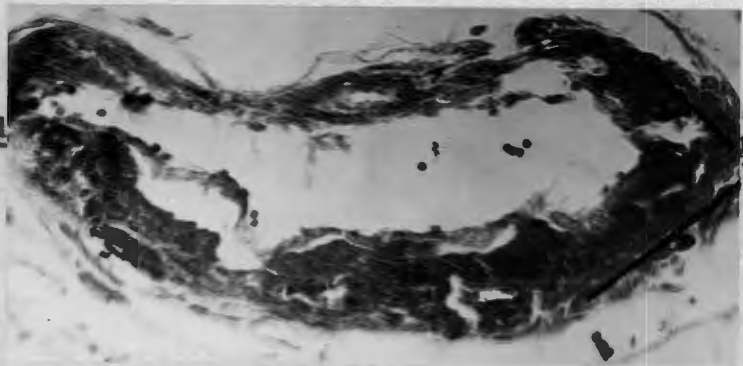
Anatomy - see Fig. 70A, Pg. 195.

1. The liver is only slightly subdivided.
2. The biliary system.

A.
Anatomy.

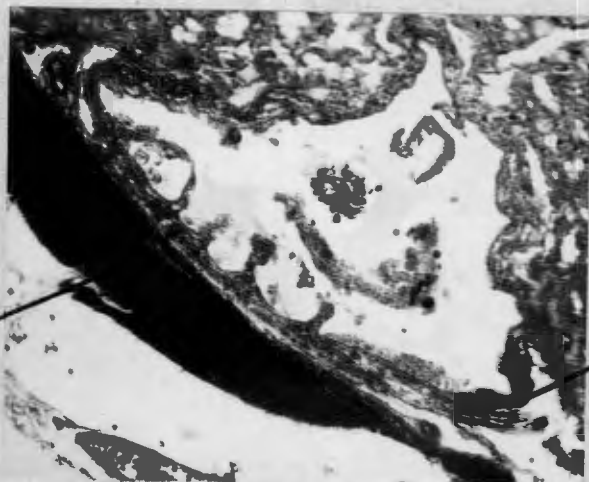


B.
Histology of
the lower third
of the Common
Bile Duct.
(X780).



Scattered
muscle
bundles.

C.
Histology of
the Intramural
Portion of the
Bile Duct.
(X780).



Duodenal
muscle.

Scanty
bile duct
muscle.

Fig. 70

The biliary system of the Cape
Black Bat.

(a) Form - Group II.

(b) Capacity - the gall bladder is medium-sized. The common bile duct is 8 mm. long and extremely thin.

(c) Relation to the pancreatic duct - Type A.

(d) Distance between the pylorus and the papilla - 5 mm.

The musculature of the ducts - see Figs. 70 B & C, Pg. 195

1. Supraduodenal - A few scattered muscle bundles are present in the lower third of the common bile duct.
2. Intramural - The wall of the duct consists mainly of fibrous tissue which contains scattered circular muscle fibres. These are obviously separated from the duodenal muscle.

Discussion:

No detailed account of the biliary system in bats could be found, but it is agreed that all species possess a gall bladder (140, 241, 279). (This applies also to the closely-related Dermoptera (140)).

ORDER - PRIMATES.

Phylogenetically and structurally the primates are closely related to primitive arboreal insectivores, the chief advances being made in the development of the brain and stereoscopic vision (140, 280). They are omnivorous and the gastrointestinal tract is relatively simple (279).

Examples dissected:

The biliary systems of the following species (excluding man) were dissected:-

- A. The monkey - 4 specimens,
- B. The baboon - 1 specimen.
- Total: 5 specimens.

A. The Monkey (Cercopithecus ethiops).

Anatomy - see Fig. 71A, Pg. 198.

1. The liver consists essentially of right and left lobes.
2. The biliary system.
 - (a) Form - Group II. The gall bladder is partially intrahepatic.
 - (b) Capacity - the gall bladder is small.
The common bile duct is 3.5 cm. long and 3 mm. wide.
 - (c) Relation to the pancreatic duct - Type A.
 - (d) Distance between the pylorus and the papilla - 25 cm.

The musculature of the bile ducts - see Figs. 72, Pg. 199.

1. The supraduodenal portion: Muscle bundles surround the entire length of the bile duct. They consist of circular and longitudinal fibres which are well-developed in the lower third of the duct, but a continuous sheath is not formed.
2. The intramural portion: A complete but thin layer of muscle surrounds the duct as far as the tip of the ampulla. Reinforcing fibres from the duodenum surround this layer, which is clearly separated from the duodenal muscle.

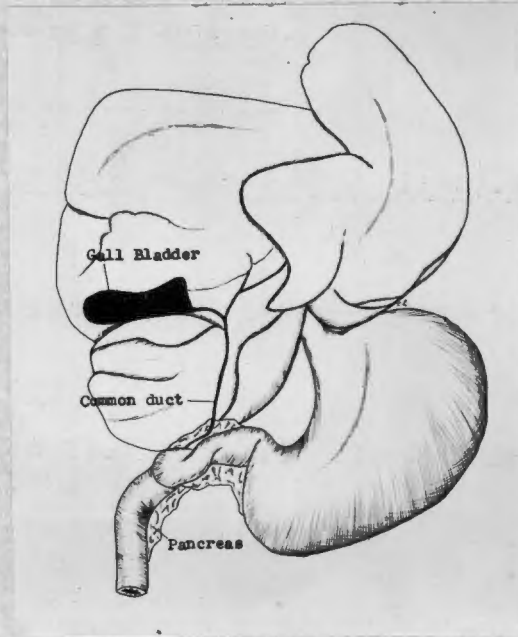
B. The Baboon (Papio ceanus).

Anatomy - see Fig. 71B, Pg. 198.

1. The liver is essentially bi-lobed but more subdivided than that of man.
2. The biliary system.
 - (a) Form - Group II.

/(b)

A.
The Monkey



B.
The Baboon

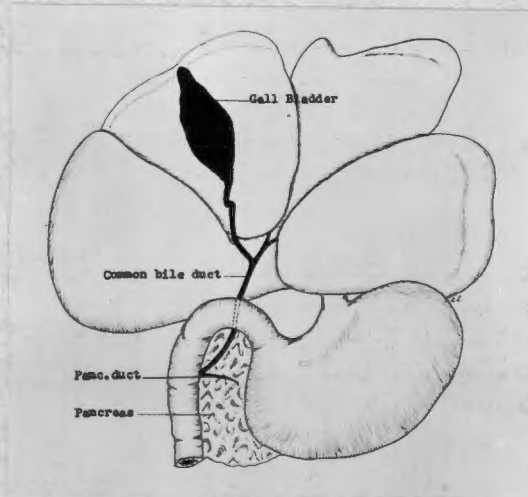
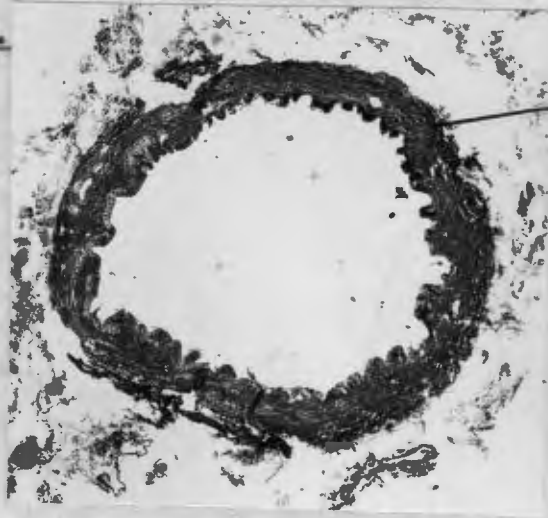


Fig. 71
**The Biliary System
in Primates.**

A.

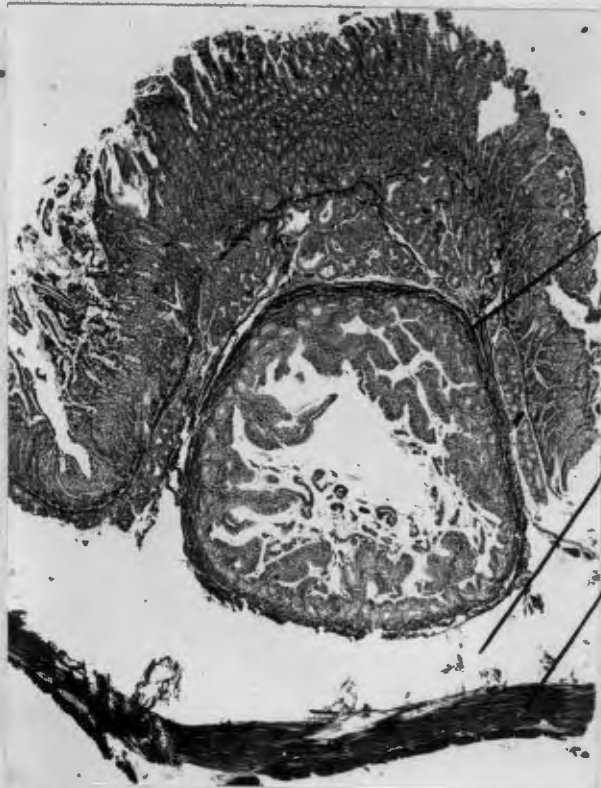
Middle Third.
(X30).



Muscle
bundles

B.

Ampulla.
(X24).



Ampullary
muscle

Large
gap

Duodenal
muscle

Fig. 72

The histology of the common
bile duct of the monkey.

- (b) Capacity - the gall bladder is relatively small.
The common bile duct is 5.5 cm. long and 5 mm. wide.
- (c) Relation to the pancreatic duct - Type A.
- (d) Distance between the pylorus and the papilla - 5 cm.

The musculature of the bile ducts was not studied.

Discussion:

The anatomical findings agree with other descriptions of the biliary system in primates (147, 340, 341). A gall bladder is present in all species (140). It may be situated in a deep fossa as in the Rhesus monkey and the Marmoset (340). Accessory vesicles are very rare but have been noted in the Rhesus monkey (341). The other anatomical features described above are well representative of these in all species (340).

The muscle of the bile ducts. The musculature of the supraduodenal portion of the bile ducts in primates has not been described before.

The observations on the muscle of the intramural portion of the bile duct of the monkey agree with Boyden's (51) description of the choledocho-duodenal junction in the chimpanzee. This author found that the "sphincter choledochus superior" and "sphincter ampullae" were better-developed in the chimpanzee than in man.

ORDER - EDENTATA (BRUTA).

This is an ancient order which is supposed to be

/related

related to early carnivora and rodentia (280, 325), and many primitive characteristics are retained (140). Most species are insectivorous, but the Sloths are herbivorous and, according to Wagner (cited by 140), the three-toed sloth is more highly specialised than the others. In all species the stomach is complex, but in most the colon is fairly short and without a caecum (279).

The order includes Armadillos, Anteaters, Sloths, the South African Aardvark, and Pangelins. No species were available for dissection.

The following data on the group as a whole were compiled from the literature:-

The biliary system of Edentata:

Anatomy.

1. The liver is only slightly lobulated (279).
2. The biliary system:
 - (a) Form - a gall bladder is present in all species except the three-toed sloth (140, 279). In armadillos, anteaters and the two-toed sloth the organ is partially intrahepatic (147, 279, 340). The sardvark has a double gall bladder (259, 279).
 - (b) Capacity - In anteaters the terminal portion of the common bile duct forms a large, dilated, intramural ampulla (12). A similar receptacle is not described in other species (340).
 - (c) Relation to the pancreatic duct - Type A in anteaters and armadillos (12, 340).
 - (d) The distance between the pylorus and the papilla is short in the armadillos (340) and the aardvark (279), but long in the two-toed sloth (279).

The musculature of the bile ducts has not been described.

ORDER - CARNIVORA.

The carnivora have descended directly from primitive Insectivore-carnivorous mammals (140, 280). They have retained the habit of intermittent feeding. The stomach is relatively simple and the caecum is either small or absent (279).

The order is divided into two main sub-orders, viz: *Fissipedia* and *Pinnepedia*.

SUB-ORDER I. Fissipedia.

The terrestrial carnivores belong to this sub-order.

Examples dissected:

The biliary systems of the following species were dissected:-

- A. The domestic cat - 12 specimens,
- B. The domestic dog - 2 specimens.
- C. The skunk - 1 specimen.

Total: 15 specimens.

A. The Cat (*Felis domestica*).

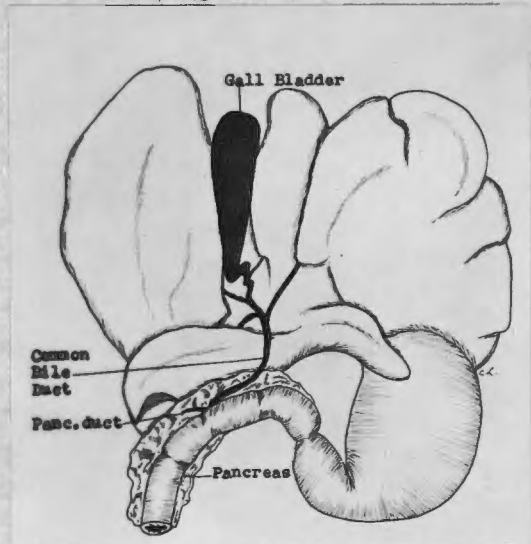
Anatomy - see Fig. 73A, Pg. 203.

1. The liver is multi-lobed.

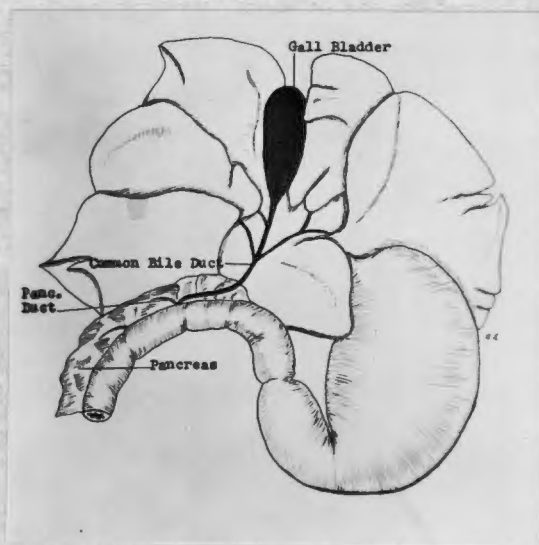
2. The biliary system.

- (a) Form - Group I. Multiple hepatic ducts are present. In two specimens diverticula of the gall bladder were found.

A.
The Cat.



B.
The Dog.



C.
The Skunk.

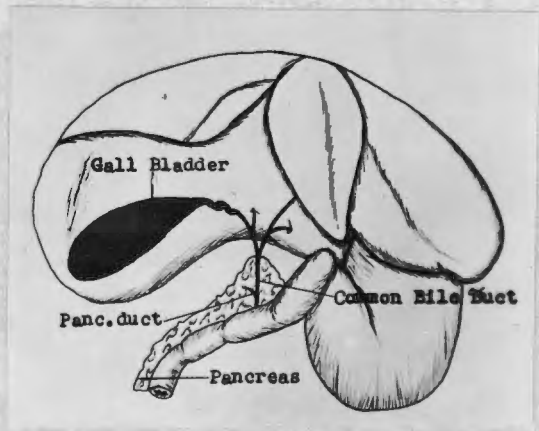


Fig. 73

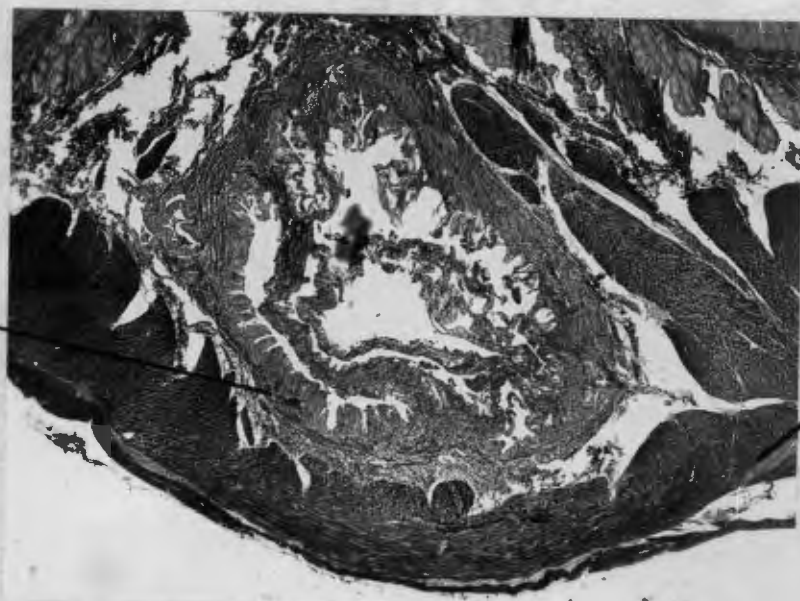
The biliary system in Carnivora.

A.
Lower Third
(X30).



B.
Intramural
Portion
(X30).

Bile duct
muscle



Duodenal
Muscle

Fig. 74.

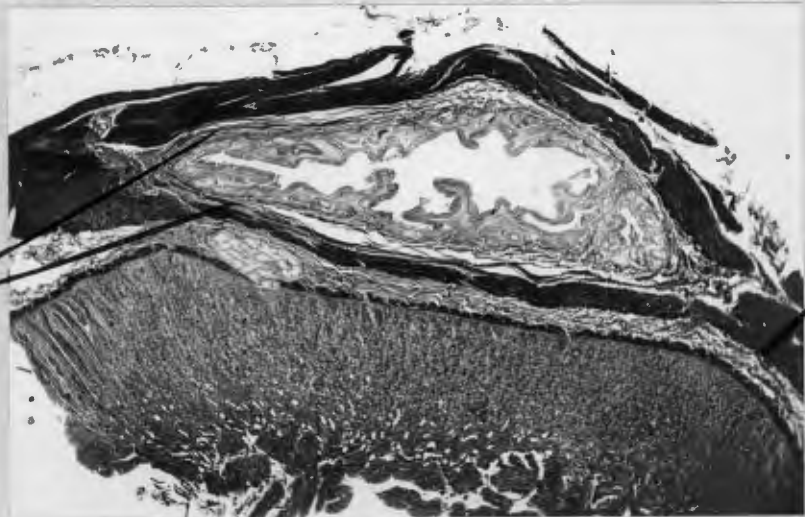
The histology of the common
bile duct of the cat.

A.
Lower third
(X30).



Muscle
Layer.

B.
Intramural
Portion.
(X18).



Bile
duct
muscle.

Duo-
denal
muscle

FIG. 75

The histology of the common bile duct
of the Dog.

- (b) Capacity - the gall bladder is relatively large.
The common bile duct is 3.5 cm. long and 2 mm. wide.
- (c) Relation to the pancreatic duct - Type A.
- (d) Distance between the pylorus and the papilla - 3 cm.

The musculature of the bile ducts - see Figs. 74A and 74B, Pg. 204.

- 1. Supraduodenal. - Scanty muscle tissue is recognizable in all parts of the bile ducts. It consists mainly of circular bundles which are best developed in the lower $\frac{1}{3}$ of the common bile duct.
- 2. Intramural. The muscle forms a complete layer around the duct; although it blends with the duodenal muscle it is obviously a separate layer.

B. The Dog (Canis domestica).

Anatomy: - see Fig. 73B, Pg. 203.

- 1. The liver is multi-lobed.
- 2. The biliary system.
 - (a) Form - Group I.
 - (b) Capacity - the gall bladder is medium-sized.
The common bile duct is 6.5 cm. long and 2.5 mm. wide.
 - (c) Relation to the pancreatic duct - Type A.
 - (d) Distance between the pylorus and the papilla is 4.5 cm.

The musculature of the bile ducts - see Figs. 75A and 75B, Pg. 205.

The muscle of the bile ducts resembles that of the cat's bile ducts in every way.

G. The Skunk (Mustela putorius).

Anatomy - see Fig. 73C, Pg. 203.

- 1. The liver is less sub-divided than that

of cats and dogs.

2. The biliary system.

- (a) Form - Group I.
- (b) Capacity - the gall bladder is large. The common bile duct is 1.6 cm. long and very narrow.
- (c) Relation to the pancreatic duct - Type C.
- (d) Distance between the pylorus and the papilla - 1.6 cm.

The musculature of the bile ducts was not studied.

Discussion:

The anatomical findings agree with other descriptions of the biliary system in cats and dogs (36, 115, 126, 140, 243, 245, 279, 301, 302, 315, 340), and are well representative of the findings in the group.

A gall bladder is present in all carnivora (140). Accessory vesicles are particularly common among cats (11, 33, 35, 36, 126, 147, 211) and are also described in lions (147). The organ is usually intra-hepatic in the Marten, the Skoat, the Ferret and the Weasel (259).

Multiple hepatic ducts are described in most species (115, 126, 279, 301, 302, 315).

The relation to the pancreatic duct is either Type A or Type C, e.g.,

Type A - the otter (259), the Civet (139), the dog and the cat.

Type C - Lions and tigers (279), the Bintureng (340), the Panda (340), and the Skunk.

A large dilated, intra-mural ampulla is found in the otter (259) and in the civet (139), see Fig. 76,

Fig. 76

Ampulla of the Civet
(After Gordon-Taylor - 139)

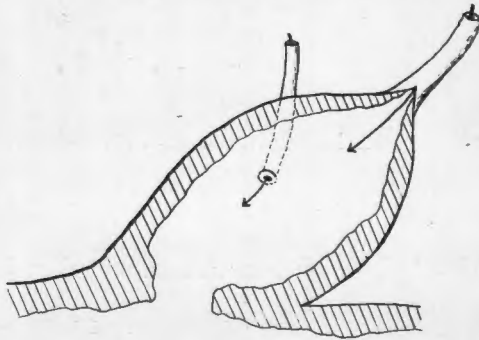
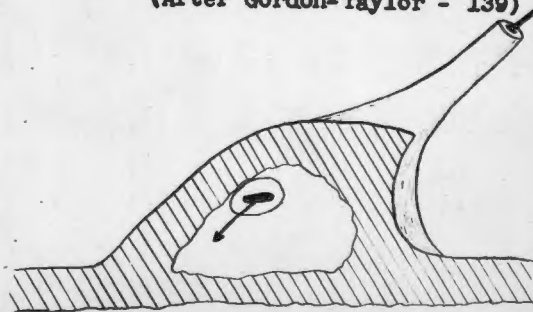


Fig. 77

Ampulla of the Seal
(After Gordon-Taylor - 139)



The musculature of the bile ducts.

There are differences of opinion on the musculature of the bile ducts of carnivora. All workers agree that some muscle tissue is present in the ducts of cats and dogs (15, 50, 148, 154, 238, 315, 321, 322). Many state that the sphincter of Oddi in these species is an independent structure (50, 154, 238, 315, 322), but others disagree with this view (139, 147, 196) and Gordon-Taylor (139) holds that in lions, tigers and civet-cats the muscle of the intramural portion of the duct is derived entirely from the duodenal muscle.

The present study supports the view that the muscle of Oddi is independent of the duodenal muscle.

SUB-ORDER II - PINNIPEDIA.

This sub-order, which includes seals, walruses and sea lions is of more recent origin and more highly specialised than the Fissipedia (140, 280). No specimens were available for dissection. The following data on the group as a whole were obtained from the literature.

The biliary system of Pinnepedia.

Anatomy:

1. The liver is more subdivided than that of Fissipedia (279).
2. The biliary system.
 - (a) Form - Group I. (259, 279). Owen (279) describes cyst-hepatic ducts in the Seal.
 - (b) Capacity - The gall bladder is large (279). In all species the bile duct terminates in a large intramural ampulla (70, 139, 169, 259, 279) - see Fig. 77 pg. 208
 - (c) Relation to the pancreatic duct - Type A. (70, 139, 279).

The musculature of the bile ducts.

Gordon-Taylor (139) states that in the seal the ampullary muscle originates from the intestinal muscle, but this author holds similar views on the bile duct muscle of other carnivora.

ORDER - ARTIODACTYLA.

The even-toed ungulates are derived from primitive carnivores (140, 280). The Chevretains (Traguline deer) which are hornless and have well-developed canines, are regarded as the direct descendants of the ancestral type (140, 221), while the musk-deer is said to represent a transitory form between the primitive tragulines and the present-day highly specialised genera (140).

All artiodactyla are herbivorous and the majority ruminant (221).

Complexities of the alimentary tract (particularly

particularly of the stomach) are present in all species (279). They are not well-marked in pigs, but are very well-developed in all ruminants (279).

Examples dissected:

A. The domestic pig	-	8 specimens,
B. The steenbok	-	3 "
C. The sheep	-	6 "
D. The goat	-	3 "
E. The domestic cow	-	12 "
F. The duiker	-	<u>4</u> "
<u>Total.</u>		<u>36</u> "

A. The Domestic Pig (*Sus scrofa domestica*).

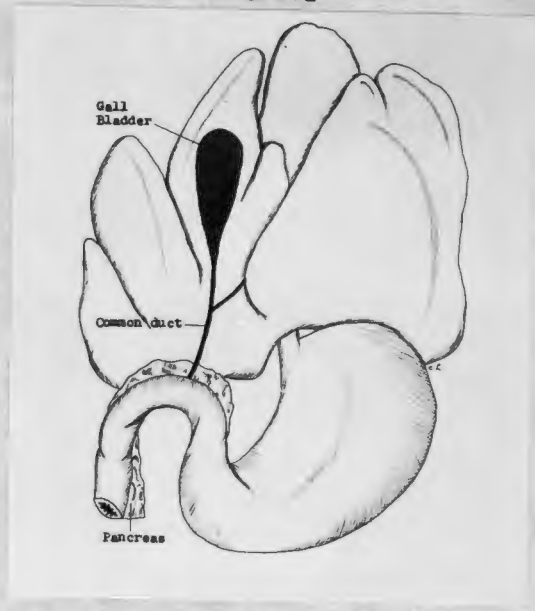
Anatomy - see Fig. 78A pg. 212.

1. The liver is large and multilobed.
2. The biliary system.
 - (a) Form - Group II.
 - (b) Capacity - the gall bladder is medium-sized. The common bile duct is 10 cm. long and 5 mm. wide.
 - (c) Relation to the pancreatic duct - Type B.
 - (d) Distance between the pylorus and the papilla - 3.5 cm.

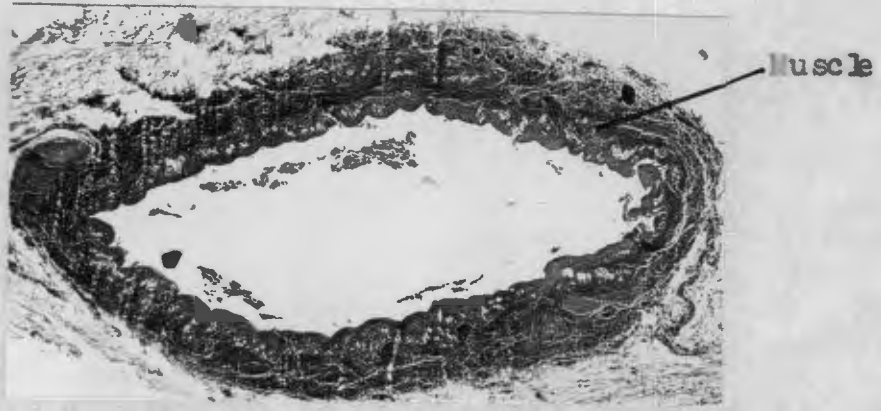
The musculature of the bile ducts - see Figs 78B and C. Pg. 212.

1. Supraduodenal - Scattered muscle bundles which are best-developed in the lower third of the common bile duct are present. They are mainly circular.
2. Intramural - The muscle is better-developed and forms a complete layer around the duct. It intermingles with the duodenal muscle.

A.
Anatomy.

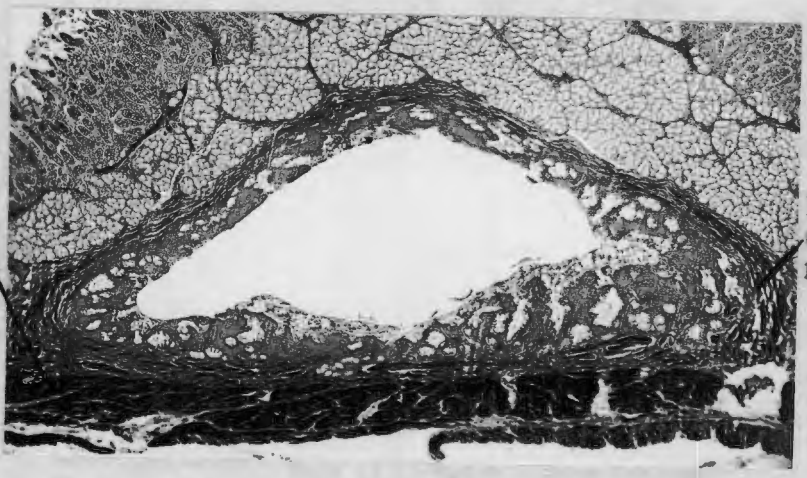


B.
Lower third
of Bile Duct
(X4).



C.
Intramural
part of
Bile Duct
(X18).

Duodenal
muscle.



Bile
duct
muscle.

Fig. 78

The Biliary System of The Pig.

B. The Steenbok (*Raphicerus campestris*).

Anatomy. - Sec Fig. 79A pg. 214

1. The liver is bilobed and small.
2. The biliary system.
 - (a) Form - Group II.
 - (b) Capacity - The gall bladder is small. The common bile duct is 7.5 cm. long and 4 mm. wide.
 - (c) Relation to the pancreatic duct - Type C.
 - (d) Distance between the pylorus and the papilla - 16 cm.

The musculature of the bile ducts - See Figs⁷⁹B & C. Pg. 214.

1. Supraduodenal - Longitudinal muscle bundles are present in all parts of the common bile duct. They are best-developed in the lower third of the duct.
2. Intramural - The muscle forms a coherent but thin layer around the duct. It is separate from the duodenal muscle.

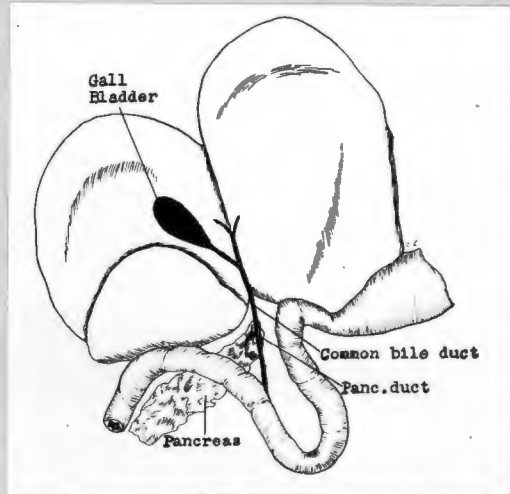
C. The Sheep - (*Ovis* sp.)

Anatomy.

1. The liver is bilobed and small.
2. The biliary system.
 - (a) Form - Group II.
 - (b) Capacity - The gall bladder is small. The common bile duct is 10 cm. long and 4 mm. wide.
 - (c) Relation to the pancreatic duct - Type C.
 - (d) Distance between the pylorus and the papilla - 31 cm.

The musculature of the bile ducts. - Resembles that of the bile ducts of the steenbok in every respect.

A.
Anatomy



B.
Lower third
of Bile Duct
(X30).



C.
Intra-
mural
part of
Bile
Duct
(X30).

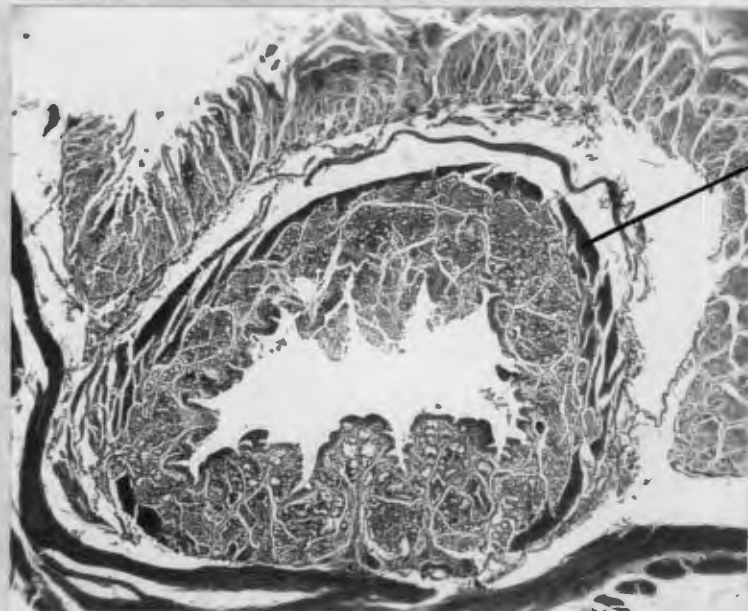


Fig. 79.

The Biliary System
of The Steenbok.

D. The Goat (*Capra* sp.).

Anatomy.

1. The liver is small and bilobed.
2. The biliary system.
 - (a) Form - Group II.
 - (b) Capacity - The gall bladder is medium-sized.
The common bile duct is 10 cm. long and 4 mm. wide.
 - (c) Relation to the pancreatic duct - Type C.
 - (d) Distance between the pylorus and the papilla - 60 cm.

The musculature of the bile ducts resembles that of the steenbok's bile ducts.

E. The Domestic Cow. (*Bos taurus*).

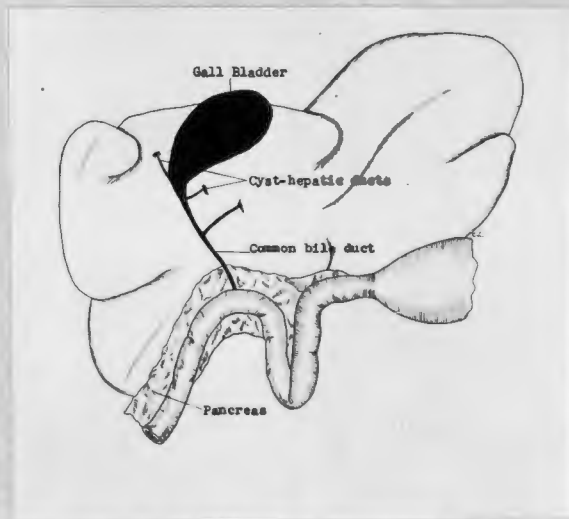
Anatomy - see Fig. 80A. pg. 216.

1. The liver is small and bilobed.
2. The biliary system.
 - (a) Form - Group I. Accessory hepatic ducts open into the cystic duct and into the gall bladder.
 - (b) Capacity - The gall bladder is very large.
The common bile duct is 7 cm. long and 8 mm. wide.
 - (c) Relation to the pancreatic duct - Type B.
 - (d) Distance between the pylorus and the papilla - 59 cm.

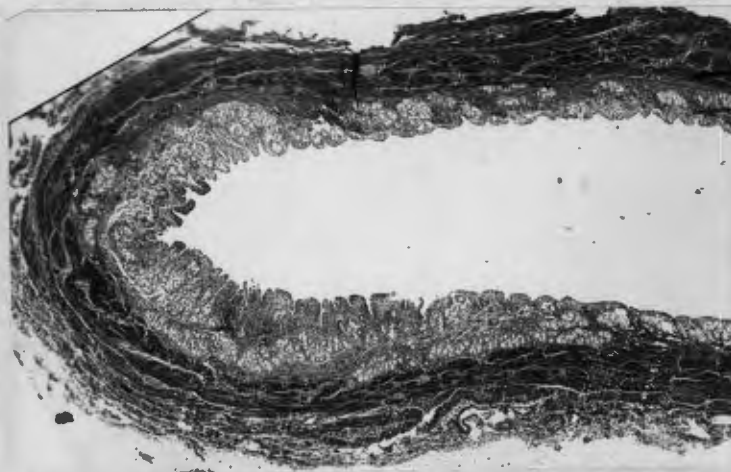
The musculature of the ducts - see Figs. 80B and C., Pg. 216.

1. Supraduodenal - The muscle is so well-developed that it is visible to the naked eye. It forms a compact layer consisting mainly of longitudinal bundles.
2. Intramural - The muscle is well-developed and extends as far as the apex of the papilla.

A.
Anatomy

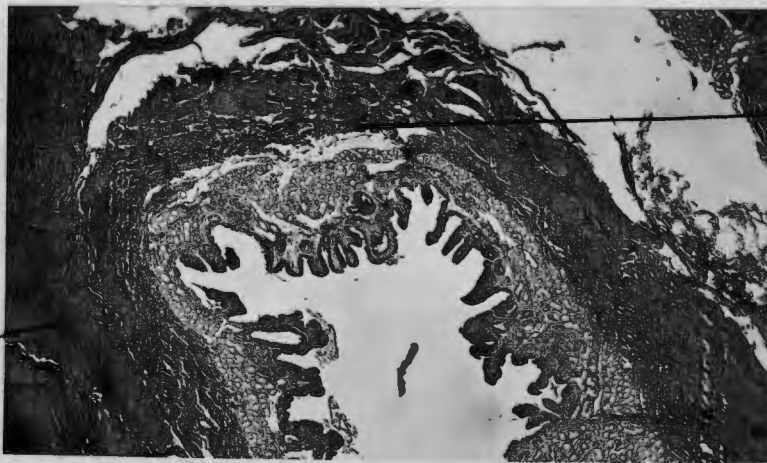


B.
Middle
third of
Bile Duct
(X18).



Muscle bundles.

C.
Intra-
mural
part of
Bile Duct
(X18).



Bile duct muscle.

Duodenal muscle.

Fig. 80

The Biliary System of the Cow.

It consists of circular and longitudinal bundles which are separate from the duodenal muscle.

F. The Duiker (*Cephalophus grimmi*).

Anatomy - see Fig. 81A, pg. 218.

- (a) Form - Group III, i.e., no gall bladder.
- (b) Capacity - the common hepatic duct is 3 cm. long and 2.5 mm. wide. The right and left hepatic ducts are 7 mm. long and 5 mm. wide.
- (c) Relation to the pancreatic duct - Type C.
- (d) Distance between the pylorus and the papilla - 9.5 cm.

The musculature of the bile duct. - See Figs. 81B & C., Pg. 218.

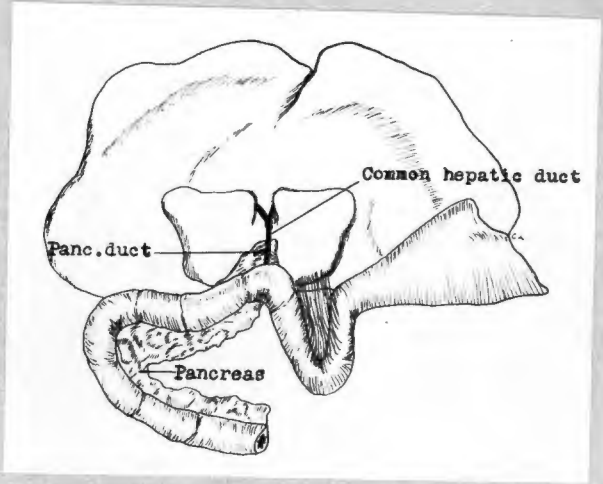
- 1. Supraduodenal - The muscle is very scanty. The fibres are mainly longitudinal.
- 2. Intramural - The muscle forms a coherent sheath around the duct. It is separate from the duodenal muscle.

Discussion:

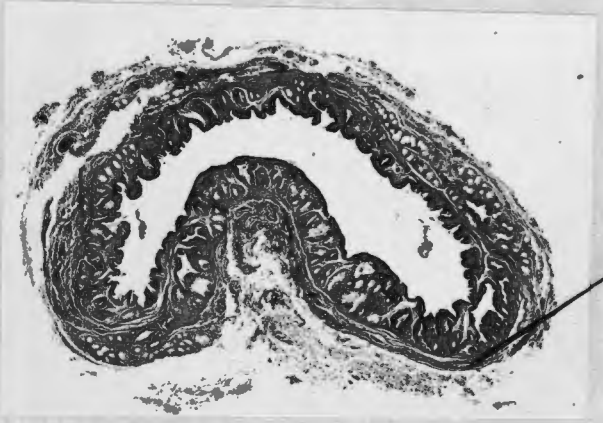
The anatomical findings - The biliary systems of the steenbok and the duiker have not been described before. The findings in the other species agree with those of other workers (36, 126, 243, 245, 315, 340, 376). A gall bladder is constantly present (140). It may be intrahepatic in pigs (147, 259) and accessory vesicles are described in pigs, sheep and cattle (36). Cyst-hepatic ducts are described in cattle and in sheep (126).

The marked differences found among the six specimens described illustrate the variability of the biliary tract

A.
Anatomy

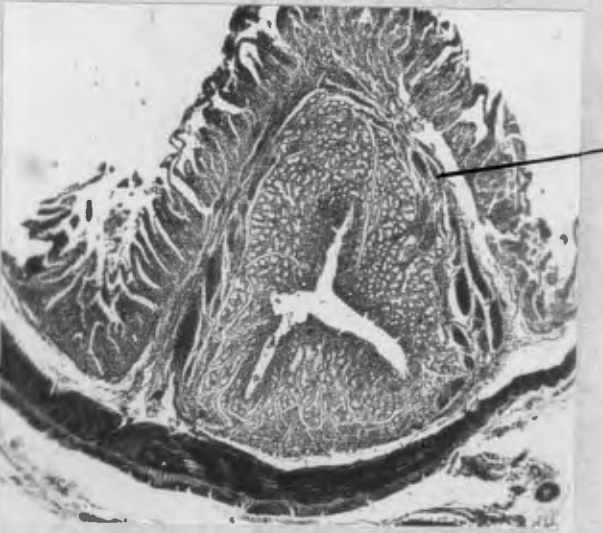


B.
Lower third
of Bile Duct
(X30).



C.
Intramural
part of
Bile Duct
(X24).

Duodenal muscle.



Bile duct muscle.

Fig. 81

The Biliary System of The Duiker.

in Artiodactyla. The main variations of the form of the biliary system and of the relation between the bile and pancreatic ducts are indicated below.

The form of the biliary system.

<u>Groups I and II.</u> <u>(Gall bladder present).</u>	<u>Group III.</u> <u>(Gall bladder absent).</u>
Traguline deer (140)	Deer (140, 169, 231, 238, 243).
Musk deer (140)	Camels (332).
American prongbuck (140)	Duikers.
All species of Bovinae except the duiker.	A variant among Bontebuck.
Pigs (259)	Peccaries (131, 140, 142, 328)
Hippopotami (140).	A variant among Hippopotami (140).
A variant among giraffes (279, 328).	Giraffes (140, 279, 328).

The relation of the bile duct to the pancreatic duct.

Type A.	Giraffes (279).
Type B.	Cattle and pigs.
Type C.	Steenbuck, sheep, goats, duikers, camels. (332) and true deer (62, 245, 340).

Histological findings: The findings in the pig, sheep, goat and cow agree with other descriptions of the musculature in these species (238, 315, 376). Mann (238) and Schache (315) regard the muscle of the intramural portion as an independent sphincter. The muscle in the camel (332) and the deer (238) resembles that of the duiker.

ORDER - RODENTIA.

The rodent order is an extremely ancient one (280), but its exact origin is obscure (325). The animals present a great diversity of life (325) and in form there is a considerable range of adaptive radiation (280). The whole order is in rather a plastic state and evolutionary tendencies are perceptible (140).

Rodents are all essentially herbivorous (140, 325), but omnivorous and even carnivorous species are found (140, 221, 280, 325). The stomach usually consists of a well-marked cardiac compartment and a small pyloric antrum, and complexities of the inner surface are found (279, 325). Modifications in the alimentary tract are manifested chiefly in the caecum, which is present in all species except the dormouse (279). The liver is multilobed in all species.

Examples dissected:

Seven species belonging to this order were studied. Several specimens were personally dissected and, in addition, the form of the biliary system was noted in specimens dissected by others. The respective numbers are indicated below.

<u>Species.</u>	<u>Personal Dissections</u>	<u>Other Dissections.</u>
A. Guinea Pig	4	6
B. Rabbit	4	6
C. Squirrel	1	-
D. White rat	7	14
E. African gerbil	8	20
F. Cape mole rat	2	-
G. White mouse	3	-
Total	<u>29</u>	<u>46</u>

The musculature of the bile ducts of guinea pigs, rabbits, rats and gerbils was studied.

A. The Guinea Pig (*Cavia porcellus*).

Anatomy of the biliary system - see Fig. 82A., pg. 222

- (a) Form - Group II (In one of the specimens there was no gall bladder).
- (b) Capacity - The gall bladder is small. The common bile duct is 1.5 cm. long and 2 mm. wide. The lower end of the bile duct is dilated into an ampulla which is situated like a cap on the anterior surface of the duodenum. From this ampulla a narrow duct penetrates the duodenal wall.
- (c) Relation to the pancreatic duct - Type B.
- (d) Distance between the pylorus and the papilla - 6 mm.

Musculature of the bile ducts - see Figs. 82B & C., Pg. 222.

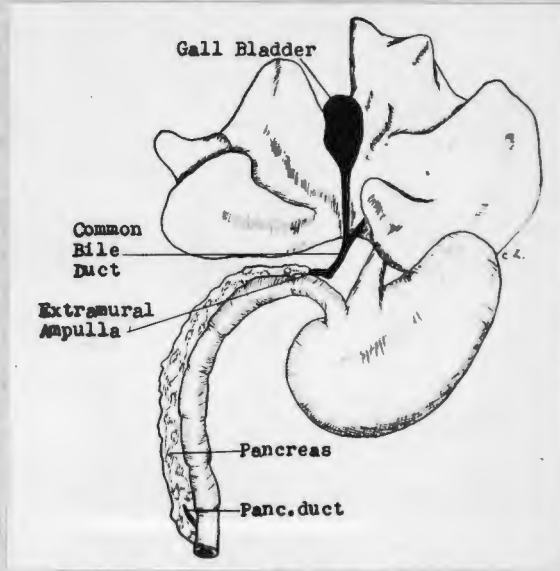
1. Supra-ampullary portion - The hepatic duct and upper half of the common bile duct possess only isolated muscle fibres. Just above the ampulla a thick band of circular muscle is present.
2. Ampulla - A very well-developed layer of muscle surrounds the ampulla. It blends with the duodenal muscle.
3. The duct of the ampulla. - The muscle layer is still present but not so well-developed. It extends as far as the papilla.

B. The Rabbit (*Lepus cuniculus*).

Anatomy of the biliary system - see Figs. 83A., Pg. 223.

1. Form * 2 specimens - Group I.
6 specimens - Group II.
2 specimens - Group III.
2. Capacity - The gall bladder is relatively small.

A.
Anatomy



B.
Lower third
of Bile Duct.
(X30).



C.
Ampulla
(X30).

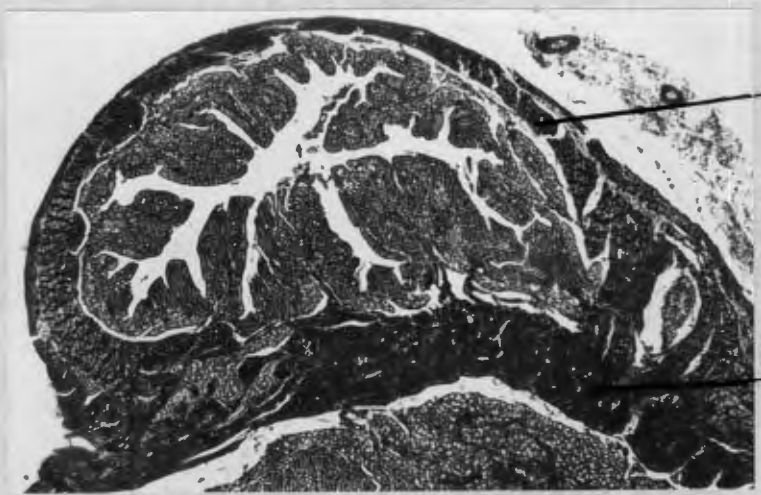
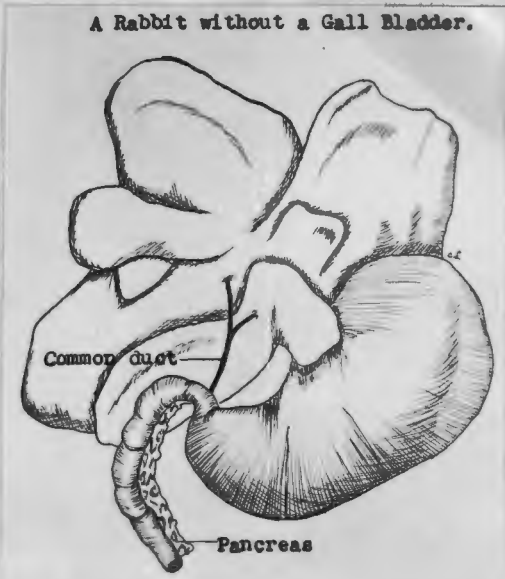
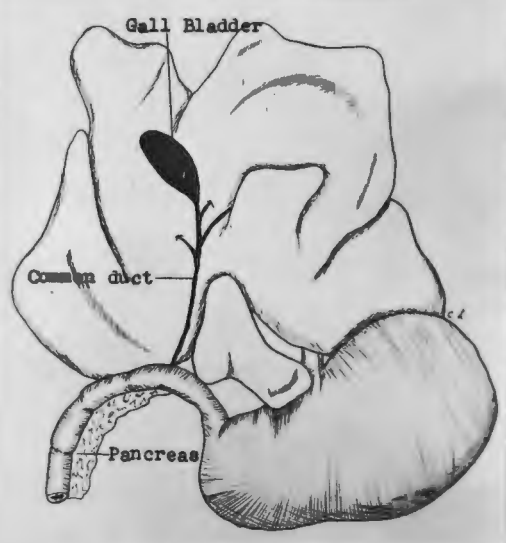


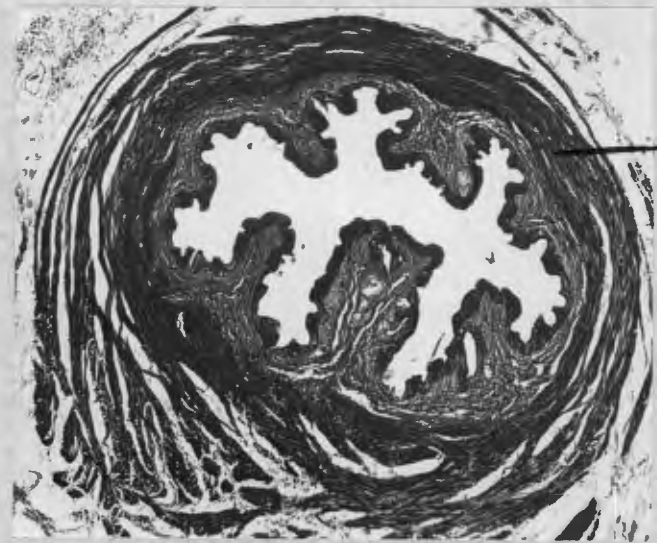
Fig. 82

The Biliary System of The Guinea Pig.

A.
Anatomy



B.
Lower third
of Bile Duct
(X140).



C.
Ampulla
(30).

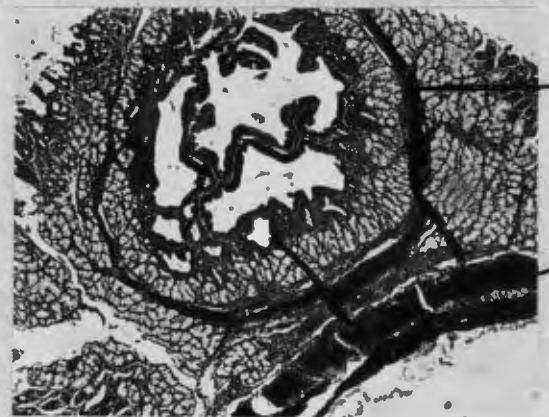


Fig. 83.

**The Biliary System
of The Rabbit.**

The common bile duct is 4 cm. long and 2 mm. wide (in all specimens).

3. Relation to the pancreatic duct - Type B.
4. Distance between the pylorus and the papilla - 1 cm.

The musculature of the bile ducts - see Figs. 83B & C, Pg.223.

1. Supraduodenal - The muscle is very scanty in the upper part of the common bile duct and in the hepatic duct. In the lower third of the common bile duct a thick cohesive layer of circular muscle surrounds the duct.
2. Intramural - The muscle is less well-developed. It continues as a thin layer, distinct from the duodenal muscle as far as the papilla.

C. The Grey Squirrel (Sciurus caroliensis).

Anatomy of the biliary system. - See Fig.85C, Pg.227.

- (a) Form - Group II.
- (b) Capacity - The gall bladder is very small. The common bile duct is 2 cm. long and very thin.
- (c) Relation to the pancreatic duct - Type B.
- (d) Distance between the pylorus and the papilla - 7 mm.

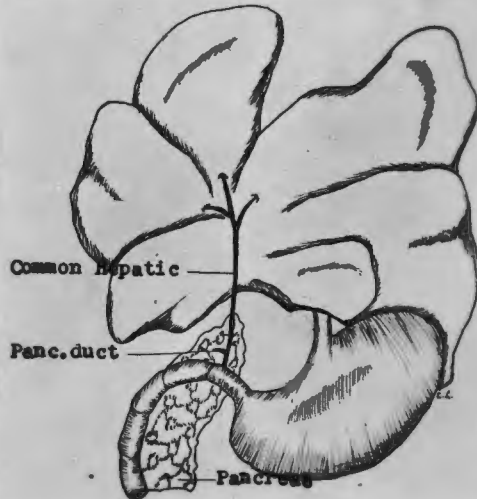
D. The White Rat (Mus rattus).

Anatomy of the biliary system - see Fig. 84A, pg. 225

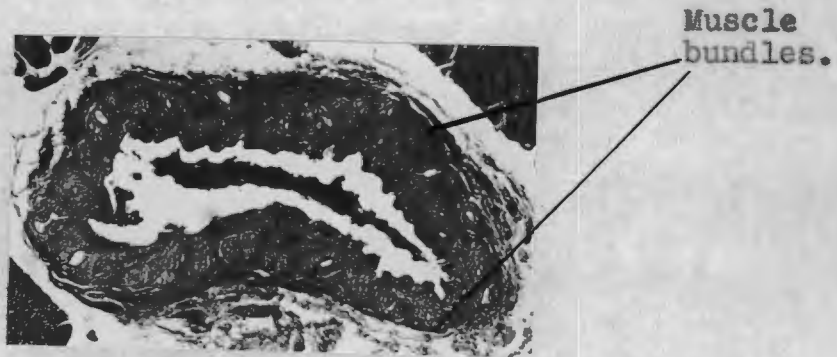
- (a) Form - Group III, i.e., no gall bladder.
- (b) Capacity - The common bile duct is 3 cm. long and thin.
- (c) Relation to the pancreatic duct - Type C.
- (d) Distance between the pylorus and the papilla - 2.5 cm.

The musculature of the bile ducts - see Fig. 84B & C., Pg.225.

A.
Anatomy



B.
Lower third
of Bile Duct
(X180).



C.
Ampulla
(X180).



Fig. 84.

The Biliary System of The White Rat.

1. Supraduodenal - Scattered and poorly-developed muscle bundles are present in all parts of the duct. A continuous layer is not formed.
2. Intramural - A thin, well-defined layer of muscle surrounds the duct as far as the papilla. It is separate from the duodenal muscle.

E. The African Gerbil (Tatera afra.)

Anatomy of the biliary system - see Fig. 85A., pg. 227

- (a) Form - Group II In one of the specimens there was no gall bladder.
- (b) Capacity - The gall bladder is very small. The common bile duct is 2.5 cm. long and extremely thin.
- (c) Relation to the pancreatic duct - Type C.
- (d) Distance between the pylorus and the papilla - 4 mm.

The musculature of the bile ducts. - Resembles that of the hepatic duct of the rat but it is even more scanty, being practically absent from the supraduodenal portion.

F. The Cape Mele-rat (Bathyergus capensis).

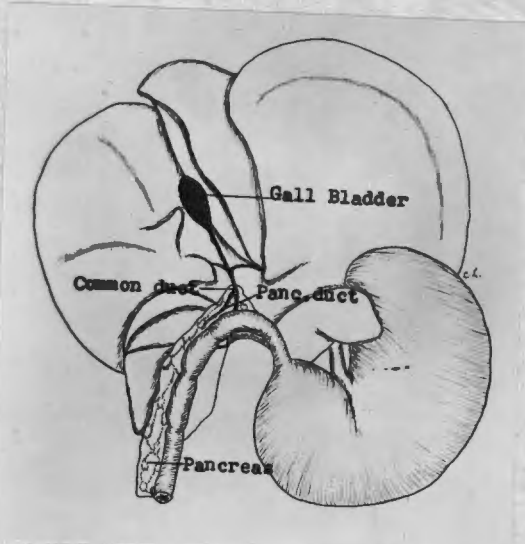
Anatomy of the biliary system - see Fig. 85B., pg. 227.

- (a) Form - Group II.
- (b) Capacity - The gall bladder is medium-sized. The common bile duct is 2.0 cm. long and thin.
- (c) Relation to the pancreatic duct - Type C.
- (d) Distance between the pylorus and the papilla - 5 mm.

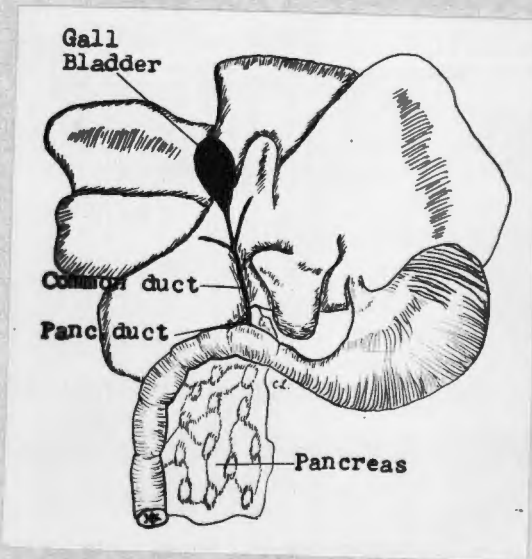
G. The White Mouse (Mus musculus).

Anatomy of the biliary system.

A.
The Gerbil



B.
The Cape Mole Rat



C.
The Grey Squirrel

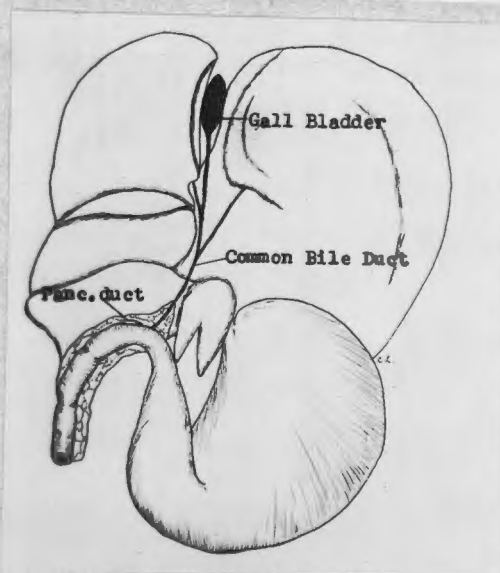


Fig. 85

The Biliary System in Rodents.

- (a) Form - Group II.
- (b) Capacity - The gall bladder is small. The common bile duct is 1.5 cm. long and extremely thin.
- (c) Relation to the pancreatic duct - Type C.
- (d) Distance between the pylorus and the papilla - 14 mm.

Discussion:

Anatomy. The biliary systems of the gerbil, mole rat and grey squirrel have not been described before.

The findings in the remaining species agree with other descriptions (50, 138, 140, 154, 160, 161, 169, 170, 231, 238, 241, 243, 245, 279, 280, 314, 328, 340) of their biliary systems. Accessory hepatic ducts are described in guinea pigs (161) and rabbits (154).

The different findings in the seven species illustrate the marked variability of the biliary system among rodents. The main variations are indicated below:

The form of the biliary system.

Groups I and II,
i.e., gall bladder present.

Nice
 Cape mole rats,
 African porcupines (340)
 Striped gophers (243, 245)
 Beavers (279)
 Squirrels
 Gerbils
 Rabbits
 Guinea pigs
 At least 10 other families,
 (140).

Group III.
Gall bladder absent.

Rats,
 Kangaroo rats (140)
 Canadian porcupines (333),
 Pocket gophers (243, 245)
 Australian water rat (140),
 A variant among squirrels,
 (140),
 A variant among gerbils,
 A variant among guinea pigs,
 At least 8 other families,
 (140).

The relation of the bile duct to the pancreatic duct.

<u>Type B.</u>	<u>Type C.</u>
Guinea pigs	Gerbils,
Rabbits,	Mice,
Squirrels,	Rats,
Canadian porcupines (333)	Cape Mole-rats.
African porcupines (340)	Pocket gophers (243)
Beavers (279)	
Striped gophers (243).	

Histological findings.

The findings in the guinea pig, rabbit and rat agree with other descriptions (50, 68, 154, 161, 170, 238) of the musculature of the ducts in these species. It is generally agreed that an independent sphincter of Oddi is present in rodents (238).

ORDER - CETACEA.

In common with carnivora and artiodactyla, whales have descended from primitive terrestrial carnivora (140, 280). They have become extremely highly specialised (140), and stand far apart from other mammals (325).

Whales are carnivorous (140, 221, 325), but, being fully aquatic, they live under the most adverse conditions for the maintenance of body temperature and they have to absorb a large quantity of food from the alimentary tract for energy purposes (279). Their digestive system has accordingly become perfected to meet the contingencies of their habits (140, 279). The stomach is extremely complex (140, 279, 325), the duodenum is large and the intestinal canal is long (279).

No specimens of whales nor of porpoises could be obtained for this study. The following account of the biliary system in the group as a whole has been compiled from descriptions by various authors (140, 169, 279, 280, 285, 328, 340.).

The biliary system of cetacea.

Anatomy.

1. The liver is a compact organ (279).
2. The biliary system.
 - (a) Form - Group III. In all species, i.e., gall bladder absent (140).
 - (b) Capacity - The common hepatic duct is short (285).
In a good many edentoceti a dilated bile reservoir is found in the course of the common duct (140, 169).
 - (c) Relation to the pancreatic duct - Type A. in edentoceti (169).
Type C. in porpoises (285).
 - (d) Distance between the pylorus and the papilla - short in porpoises (285) and long in finback whales (340).

The musculature of the bile duct.

The muscle of the hepatic duct of a foetus of an antarctic whale was studied by Broman (cited by 138, 139). He found a well-formed sphincter at the duodenal end of the duct.

ORDER - PROBOSCIDEA.

Elephants have descended from a herbivorous stock of African origin. They present features of resemblance

/to

to Sirenia (325), Hyracoidea (280) and Rodents (325). They have, however, acquired a number of adaptive characteristics which render them highly specialised and clearly distinguish them from other mammals (221, 280, 325).

Elephants are strictly herbivorous (221). The stomach has a large cardiac pouch, the caecum is large and sacculated and the intestine is long (279).

No specimens were available for dissection. The following account is based on Owen's (279) descriptions.

The biliary system of elephants.

Anatomy.

1. The liver is bilobed.
2. The biliary system.
 - (a) Form - Group III, i.e., gall bladder absent.
 - (b) Capacity - the hepatic duct is wide and very long and expands between the coats of the duodenum into an oval receptacle irregularly divided into compartments.
 - (c) Relation to the pancreatic duct - Type A.

The musculature of the bile duct.

Owen (279) states that the ampulla is surrounded by circular muscle fibres, but it is not clear from his description whether they are derived from the duodenal muscle or not.

Note: Several other authors (140, 169, 314, 328) confirm the absence of the gall bladder from elephants, and some (140, 169, 259) mention the large ampulla.

ORDER - HYRACOIDEA.

Most authorities (221, 280, 325, 338, 340) regard Hyracoidea as a separate order. These animals show a curious mixture of primitive and specialised characters and superficially they resemble several different mammalian orders (279, 280, 325).

Together with Proboscidea and Sirenia, the Hyracoidea originated in Africa, a fact which may indicate near affinity between the early ancestors of these orders (221, 280). Embryologically they are most nearly related to elephants (personal communication from Professor Goetz), which they resemble in their plantigrade manner of walking (221, 280) and in the crossed radius and ulna (280). Beyond these characteristics there is little in common between these two orders (221).

The dassies are herbivorous. The stomach is simple but, in addition to the usual caecum at the beginning of the colon, there is a pair of smaller caeca placed more distally (This arrangement is unknown among other mammals (280)).

Example dissected:

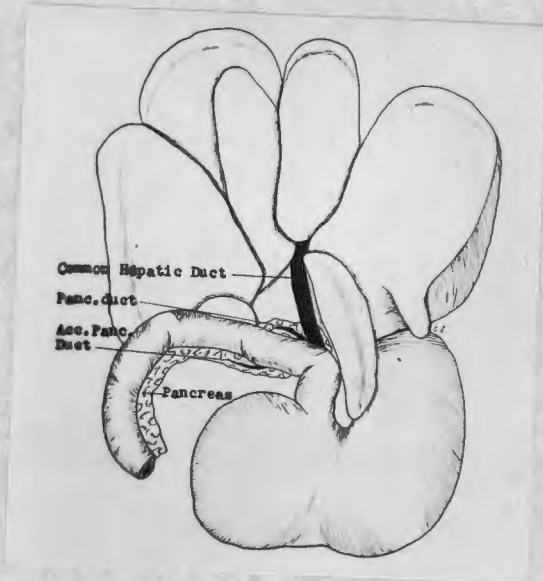
Two specimens of the Cape Hyrax or Dassie were dissected.

The biliary system of the Cape Hyrax (Procavia capensis).

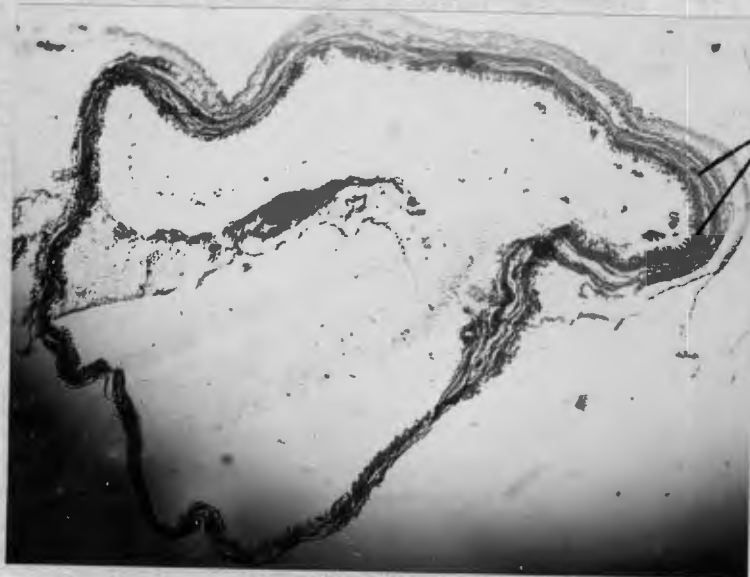
Anatomy - see Fig. 86A., pg. 233.

1. The liver is multilobed.

A.
Anatomy

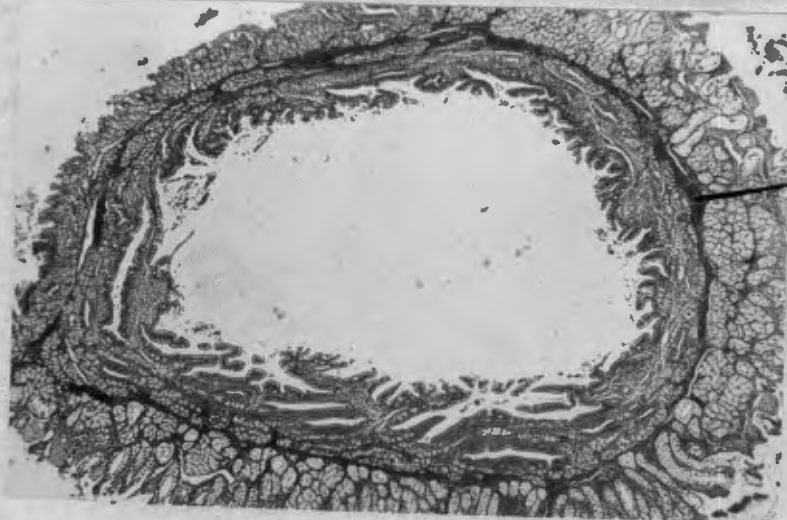


B.
Lower
third of
Bile Duct
(X18).



Isolated
muscle
fibres
(identified
with larger
magnifica-
tion).

C.
Ampulla
(X18).



Muscle
layer.

Fig. 86

The Biliary System of the Dassie.

2. The biliary system.

- (a) Form - Group III, i.e., gall bladder absent.
- (b) Capacity - The common hepatic duct in both specimens was 3 cm. long and 6 mm. wide, while the average measurements for the left and right hepatic ducts were:
Left: 14 mm. long and 7 mm. wide,
Right: 7 mm. long and 3 mm. wide.
Although the ducts of one specimen contained liver flukes, they were no larger than those of the other specimen.
- (c) Relation to the pancreatic duct - Type B.
- (d) Distance between the pylorus and the papilla - 2 cm.

The musculature of the hepatic duct - see Figs. 86B & C, Pg 233

- 1. Supraduodenal - This portion of the duct has practically no muscle. Its walls are very thin and convoluted and consist mainly of loose fibrous tissue with isolated muscle fibres.
- 2. Intramural - A definite but thin layer of muscle surrounds this part of the duct and extends as far as the papilla. It is reinforced by, but separate from, the duodenal muscle.

Discussion:

Anatomy: Thomson (338) recently reviewed the literature on the biliary system in hyracoidea. He collected reports by twelve authors, and eleven of these state that these animals do not possess a gall bladder. Mentzer (259) is the only author who notes the presence of a gall bladder in dassies, and his description is based on secondhand information (338).

Owen (279) states that the right and left hepatic ducts are so wide that their united capacity equals

/that

that of an ordinary-sized gall bladder. In the specimen dissected by him, liver flukes were present in the larger duct.

Thomson (338, 340) studied one specimen which had several concretions in the ducts. His findings agree with those of this study. He attributes the large size of the ducts to the presence of the concretions, a conclusion which is not supported by the similarity of the ducts in the two specimens dissected for this work.

Histology: This has not been described before.

ORDER - SIRENIA.

This order is said to have descended from a herbivorous African ancestor (140, 280) but its exact origin is obscure (280). Andrews (cited by 325) has recently pointed out that the sirenia have a number of proboscidian affinities, but there are gross differences between the two orders.

Sirenia are herbivorous and fully aquatic (221, 280). The stomach is complex, the intestine is long and the caecum is sacculated.

No specimens were available for dissection. The following data have been obtained from the literature (279, 340).

The biliary system of sirenia.

Anatomy.

1. The liver is flattened and transversely oblong (279).
2. The biliary system.
 - (a) Form - Group II. in the two living genera (279, 340), but according to Gerham and Ivy (140), Steller's sea-cow did not possess a gall bladder.
 - (b) Relation to the pancreatic duct - Type B. in the Florida Manatee (340) and Type A in the Dugong (279).

The musculature of the bile ducts has not been described.

ORDER - PERISSODACTYLA.

The odd-toed ungulates are derived from primitive herbivorous stock (280). They have been exposed to evolutionary tendencies over a long period and have become highly specialised (140).

Perissodactyla are herbivorous and feed more or less continuously (169, 279). Although their stomachs are relatively simple, the colon is large and sacculated and the caecum is immense (140, 279).

Example dissected.

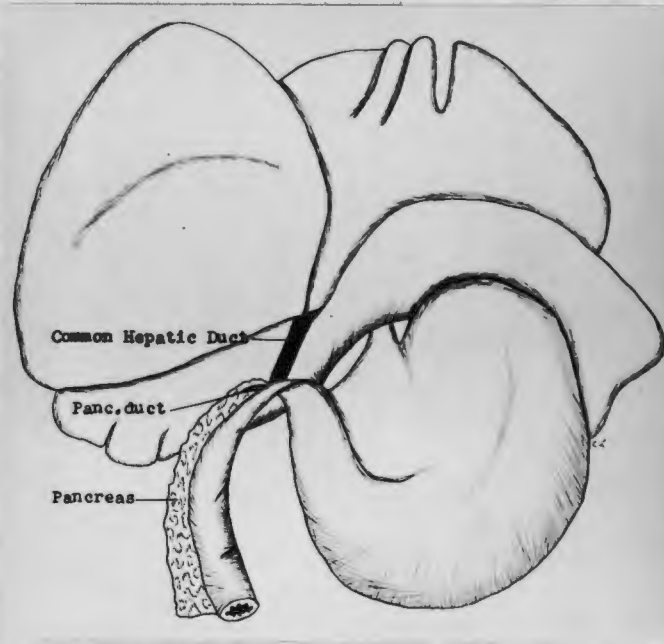
The biliary system of 4 specimens of the domesticated horse were dissected and the histology of two of the biliary systems was studied.

The biliary system of the horse (Equus caballus).

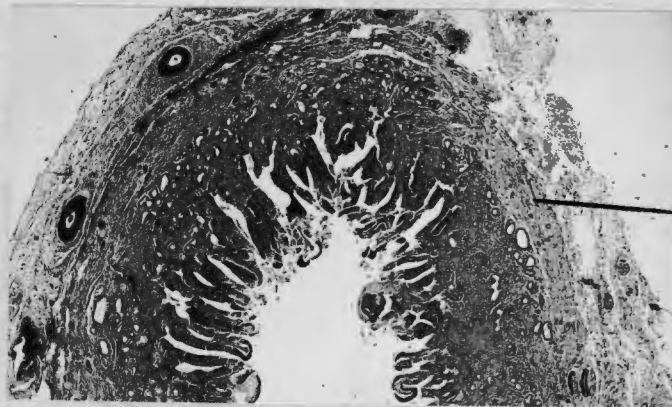
Anatomy - see Fig. 87A., pg. 237.

1. The liver is larger and more sub-divided than that of artiodactyla.
2. The biliary system.

A.
Anatomy.

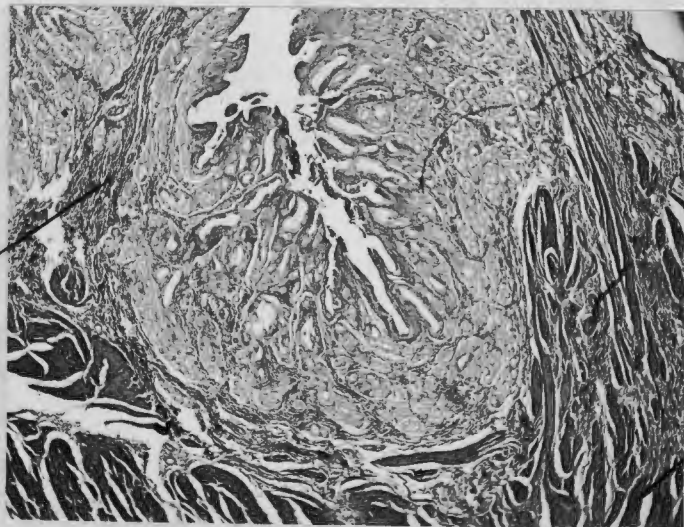


B.
Lower
third of
Bile Duct
(X18).



Scanty
muscle
fibres.

C.
Intramural
part of
Bile Duct.
(X18).



Bile
duct
muscle.

Duodenal
muscle.

FIG. 87

The Biliary System of the Horse.

- (a) Form - Group III, i.e., gall bladder absent.
- (b) Capacity - The hepatic duct is 4 cm. long and 11 mm. wide, the duct being large enough to admit a finger. The parietal sacculi are so large that they are visible to the naked eye.
- (c) Relation to the pancreatic duct - Type A (The papilla is so formed that it acts as a one-way valve to prevent regurgitation of the duodenal contents).
- (d) Distance between the pylorus and the papilla - 14 cm.

The musculature of the hepatic duct - see Figs. 87B & C, Pg. 237.

- 1. Supraduodenal - Muscle tissue is extremely scanty and consists of isolated circular and longitudinal bundles.
- 2. Intramural - The muscle is better-developed and forms an incomplete circular sheath around the duct. It is closely intermingled with the duodenal muscle, but can be identified as a separate layer.

Discussion:

The anatomical findings agree with those of other workers (126, 243, 245, 279, 332, 340, 376). All horses lack a gall bladder (140, 142, 160, 169, 231, 238, 280, 314, 328, 336). Many authors (126, 140, 142, 315, 336) mention the large size of the duct and of the parietal sacculi. Several authors (140, 142, 336, 376) claim that this compensates for the absence of a gall bladder, but Mamm and his co-workers (238, 243, 245) and Higgins (160) disagree with this view.

The gall bladder is lacking in all perissodactyla (140, 279, 280, 328). The duct of the rhinoceros is as wide as that of the horse (279) and in the donkey and in the mule the parietal sacculi are very large (126).

In the zebra (340) and in the rhinoceros (279) the relation of the bile duct to the pancreatic duct resembles that found in the horse, i.e., type A.

DISCUSSION.

Table 10, page 240 presents the findings of this study briefly and in comparative terms. This table illustrates the following points:-

1. The biliary system in different species varies tremendously. These variations affect not only the anatomy of the system but also the musculature of the bile ducts.
2. There is a close relation between the form of the biliary system, the capacity of the gall bladder and bile ducts and the musculature of the bile ducts, and all these features are related to the phylogenetic development of the various species.
3. There is no obvious reason for the three types of relation between the bile and the pancreatic ducts, nor for the site of the duodenal papilla in the various species studied.
4. All the animals possess muscular tissue in the walls of their bile ducts.

The relationships of the form and capacity of the biliary system and of the musculature of the bile ducts will be discussed in greater detail.

TABLE 10.

Class and Order.	Form of Biliary System.	Gall Bladder	Capacity of Ducts.	Relation to pancreatic ducts.	Distance between pylorus & papilla.	Musculature.
Most fishes	I	Variable	No differences in species of comparable size	A	Short	Very well developed.
Amphibia	I	Large		C	Short	" " "
Reptiles	I	Large		C	Variable	" " "
Carnivorous birds	I	Large		-	Variable	-
Other birds	I	Large		A	Variable	Very well developed.
	III (Modified)	Absent		B	Variable	Very well developed
Monotremes	I	Large		A	Short	-
Marsupials	II	Large		A	Variable	Well developed
Insectivora	II	Large		A & C	Short	Poorly developed
Chiroptera	II	Medium		A	Short	Poorly developed
Primates	II	Medium		A	Short	Fairly well developed
Most edentata	II	Variable		A	Variable	-
Carnivora	I	Large		A & C	Short	Fairly well developed
Artiodactyla	I	Large		B & C	Long	Well developed
	II	Medium		B & C	Long	Fairly well developed
	III	Absent		A & C	Long	Fairly well developed
Rodents	II	Usually small		B & C	Variable	Variable
	III	Absent		B & C	Variable	Poorly developed
Cetacea	III	Absent	A & C	Variable	?Fairly well developed sphincter	
Proboscidea	III	Absent	A	-	?Sphincter present.	
Hyracoidea	III	Absent	A	Short	Very poorly developed	
Sirenia	II & III	-	A & B	-	-	
Perissodactyla	III	Absent	A	Short	Very poorly developed	

A. THE RELATIONSHIP OF THE FORM OF THE BILIARY SYSTEM TO THE CAPACITY OF THE SYSTEM.

In this study a close relationship has been detected between the form and the capacity of the biliary system, e.g.,

1. Form - Group I: The gall bladder is usually large.
2. Form - Group II. The gall bladder varies in size but tends to be small, e.g.,
 - (a) in orders where the organ is present in all species, e.g., marsupials and primitive placentals, the gall bladder is relatively large.
 - (b) In orders where some species do not possess a gall bladder, i.e., artiodactyla and rodents, the organ is relatively small and tends to be congenitally absent from some individuals, e.g., hippopotami, bontebuck, gerbils, guinea pigs and rabbits.
3. Form - Group III. There is no increase in the size of ^{the} bile ducts to compensate for the absence of the gall bladder. This finding, which confirms the observations of others (160, 328, 332, 333), is illustrated by the following comparisons between species without a gall bladder and those possessing the organ:
 - (a) The horse's hepatic duct has a capacity of 3,800 c.mm., while the capacity of the cow's common bile duct is 3,500 c.mm.
 - (b) Although the hepatic duct of the dassie is larger than the common bile ducts of species of comparable size (rabbit, cat and dog), the capacity of the duiker's hepatic duct is much less than that of the common bile ducts of the steenbek, the sheep and the goat.
 - (c) The rat's hepatic duct is no larger than the common bile duct of the gerbil and of the mole rat.

- (d) The dimensions of the pigeon's bile ducts equal those of the partridge's ducts.
- (e) Although a large, dilated ampulla is found in some species without a gall bladder, a similar ampulla is present in some species possessing the organ, e.g.,

Gall bladder absent:

Whales
Elephants

Gall bladder present:

Civets and others,
Seals and walruses.
Anteaters.

Note: This relationship between the form and the capacity of the biliary system has not been described before.

B. THE RELATIONSHIP OF THE MUSCULATURE OF THE BILE DUCTS TO THE FORM OF THE BILIARY SYSTEM.

The findings in this study show that a close relation exists between the form of the biliary system and the musculature of the bile ducts.

1. Form - Group I. In the vast majority of species the muscle of the bile ducts is very well developed. The muscle of the intramural portion of the common bile duct is usually separated from the duodenal muscle by a layer of fibrous tissue.
2. Form - Group II. The muscle varies considerably, e.g.,
 - (a) It is well-developed in the lower third of the bile duct in primates, in some species of rodents and in some species of artiodactyla.
 - (b) It is poorly-developed in most of the other species.
In most species a well-developed sphincter surrounds the lower end of the common bile duct.
3. Form - Group III. The muscle is very poorly-developed

in all species. Practically no muscle fibres are present in the supraduodenal portions of the bile ducts of the horse and the dassie.

Note: Since previous studies of the musculature of the bile ducts have been confined to a limited number of species, the close relationship between the form and structure of the biliary system has not been noticed before.

C. THE RELATIONSHIP OF THE ANATOMY OF THE BILIARY SYSTEM TO THE BODY FORM AND DIGESTIVE PROCESSES OF THE VARIOUS ANIMALS.

This relationship is illustrated in Table 11. page 244. Data on the capacity of the biliary system and the musculature of the bile ducts are not included in the tables, since the relationship of these anatomical features to the form of the biliary system has already been pointed out.

This table referred to reveals the following general facts:

1. Form - Group I. This type of biliary system is found in all the lower vertebrates and in carnivora (some species of birds and cattle are the only exceptions). The vast majority of these animals are either carnivorous or insectivorous and their alimentary canal is generally simple.
2. Form - Group II. This group includes the following
/animals:

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TABLE 11

GROUP I.			
Order	Body Form and Phylogeny	Diet	Alimentary tract.
Most fishes	Primitive	Carnivorous & insectivorous	Simple
Amphibians	Primitive	Carnivorous & insectivorous	Simple
Reptiles	Primitive	Carnivorous, Insectivorous & herbivorous	Simple
Carnivorous Birds	Specialised	Carnivorous	Fairly simple
Other birds	Specialised	Insectivorous & herbivorous	Complex
Monotremes	Primitive mammals	Insectivorous	Simple
Carnivora	Direct descent	Carnivorous	Relatively simple
GROUP II.			
Order	Body Form and Phylogeny	Diet	Alimentary tract
Marsupials	Less specialised than placentals	Carnivorous, Herbivorous & insectivorous	Variable
Insectivora	Primitive	Insectivorous	Simple
Chiroptera	Primitive	Insectivorous & frugivorous	Simple
Primates	Related to Insectivora & chiroptera	Omnivorous	Relatively simple
Most edentata	Primitive	Insectivorous & herbivorous	Moderate
Most Artiodactyla	Resembling ancestral type	Herbivorous	Complex
Many rodents	Tending towards specialisation	Essentially herbivorous	Complex
Sirenia	Specialised	Herbivorous	Complex
GROUP III.			
Order	Body Form and Phylogeny	Diet	Alimentary Tract
Some birds	Specialised	Essentially herbivorous	Complex
Some Artiodactyla	Differing from ancestral type	Herbivorous	Complex
Many rodents	Specialised	Essentially herbivorous	Complex
Cetacea	Highly specialised	Carnivorous	Complex
Proboscidea	Highly specialised	Herbivorous	Complex
Hyracoidea	Many highly specialised characteristics.	Herbivorous	Complex colon
Perissodactyla	Highly specialised	Herbivorous	Complex colon with tremendous caecum

- (a) All marsupials. The diet of these animals varies considerably and many species possess complex gastro-intestinal tracts, but they are less highly specialised than placentals.
- (b) All primitive placentals. The majority of these are insectivorous and their alimentary tract is relatively simple.
- (c) Some species of artiodactyla. The species that fall into this group include the primitive traguline deer and, in general, those species which have descended with the least specialisation of body form from the ancestral type. Congenital absence of the gall bladder is not uncommon among some species, e.g., hippepotami and bontebuck (140).
- (d) Some species of rodents.- The species that fall into this group do not differ materially from those included in Group III. The whole order, however, is in a plastic state and evolutionary tendencies are perceptible (140). Congenital absence of the gall bladder is not uncommon among guinea pigs, rabbits and gerbils.

Form - Group III. The body form of species included in this group has departed considerably from that of their ancestors (140). These animals are essentially herbivorous (excepting the whales) and well-marked anatomical complexities of the gastro-intestinal tract exist in all species.

Note: Although other workers (140, 376, 241, 340, 279, 328) have suggested that the presence or absence of the gall bladder may be related to the diet and phylogenetic development of the various species, the close relationship of these factors to the three groups of biliary system has not been described before.

D. CORRELATION OF ALL THE FINDINGS.

The following facts emerge from the above discussions:-

1. There is a close relationship between body form and the form and structure of the biliary tract, e.g.,

- (a) The primitive biliary system is a complex structure. It consists of multiple hepatic ducts and a large gall bladder, and the bile ducts possess very well-developed muscle.
- (b) The biliary systems of more highly specialised species adopt a simpler structure. There are no accessory hepatic ducts and the gall bladder tends to be small. The musculature of the bile ducts is not very well developed.
- (c) The biliary systems of species whose body forms have departed considerably from that of their ancestors are extremely simple. No gall bladder is present and the bile ducts are not dilated. The musculature of the bile ducts is very poorly developed.

2. There is a similar relationship between the form of the gastro-intestinal tract and that of the biliary system and both are related to the diet of the animal, e.g.,

- (a) Species with simple digestive canals have a primitive form of biliary apparatus. They are carnivorous and insectivorous.
- (b) Species with minor complexities of the gastro-intestinal tract usually possess a gall bladder, but not accessory hepatic ducts, and the musculature of the bile ducts is not very well developed. They are insectivorous and herbivorous.
- (c) Species with the most highly specialised alimentary systems tend to lose the gall bladder. They are essentially herbivorous.

As a general rule, however, the gastro-intestinal tract adapts itself more readily to changes in

the body form and mode of life of the animal, and anatomical complexities of the digestive system precede structural changes in the biliary tract, e.g.,

- (a) A gall bladder is present even in herbivorous marsupials which possess most complex gastrointestinal tracts.
- (b) No species with a very simple alimentary tract lacks a gall bladder.

3. Although some of these relationships have been noticed by others, data on the form, capacity and structure of the biliary system have not been previously correlated and no author has described the three phases in the phylogenetic development of the system.

E. THE RELATIONSHIP OF THE FINDINGS OF THE PRESENT STUDY TO OBSERVATIONS ON THE FUNCTIONS OF THE BILIARY SYSTEM.

It is well-known that form and structure are largely governed by function (29, 379) and that a decrease in function eventually leads to degradation of tissue (29). The findings of this study, therefore, suggest that there is a progressive diminution in the functional activity of the biliary system from the lower to the higher vertebrates. This may be determined by a study of the functional activity of the various types of biliary systems described.

It is agreed that the primary function of the biliary system is that of concentrating and storing bile for digestive purposes (140, 170, 171, 241, 275, 301, 318).

TABLE 12

(After Schmidt and Ivy (318)).

<u>Species.</u>	<u>Physiological capacity.</u>	<u>Form of biliary system.</u>
Fowl	5-7	I
Duck	4	I
Cat	6-7	I
Dog	12	I
Cow	4-6	I
Man	12	II
Mouse	7-8	II
Striped gopher	5-7	II
Goat	1-2	II
Sheep	1-2	II
Pig	0.4 - 0.6	II
Bush rat	0.9	II
Rabbit	0.6	II
Guinea pig	0.3	II
Rat	Nil	III
Pocket gopher	nil	III
Horse	nil	III
Pigeon	nil	III (modified).

Schmidt and Ivy (318) have determined the efficiency of this function, i.e., the physiological capacity of the biliary system, in a large series of animals. They did this by calculating what portion of bile secreted in 24 hours could be accommodated in the system. Their findings are shown in column 2 of table 2. page 248

The data on the form of the biliary system reflected in column 3 of the same table are based on the findings of this study.

A comparison of columns 2 and 3 of the same table reveals the following:-

1. The Group I. type of biliary system has a high physiological capacity.
2. The physiological capacity of the Group II type of biliary system tends to be lower; although the capacity varies considerably, the following facts are significant:
 - (a) In man the physiological capacity is high and man represents an order in which all species possess a gall bladder.
 - (b) In species of rodents and artiodactyla possessing a gall bladder the physiological capacity is low and closely related species do not possess the organ.
 - (c) In rabbits and guinea pigs the physiological capacity is negligible and congenital absence of the gall bladder is not uncommon.
3. The physiological capacity of the Group III type of biliary system is nil, i.e., the bile ducts fail to concentrate or store bile.

The anatomical findings of this study are, therefore, corroborated by the work of others on the functions of the biliary system.

A correlation of the various observations shows that the progressive loss of form and structure of the biliary system from the lower to the higher vertebrates is an indication of the declining need for a highly-efficient bile-concentrating mechanism. Since bile is necessary for the digestion and absorption of fats, it is significant that carnivora possess the primitive type of biliary system, while the biliary systems of herbivora tend to lose their complexity.

F. THE HUMAN BILIARY SYSTEM FROM THE COMPARATIVE POINT OF VIEW.

A comparison of the findings of the present section of this study with those of previous sections reveals the following:-

1. Anatomy.

- (a) The human biliary system occupies an intermediate position in the phylogenetic development of the biliary system.
- (b) Accessory hepatic ducts represent the arrangement of the primitive biliary system.
- (c) Congenital absence of the gall bladder represents the type of biliary system of species with a highly specialised body form.

It is evident, therefore, that these anomalies are not obscure and meaningless, but represent different stages in the phylogenetic development of the biliary system.

The frequency of accessory hepatic ducts suggests that the human biliary system tends to approximate the primitive type, and this suggestion is borne out by the fact that the human gall bladder concentrates very well (318). This tendency may be related to the human inclination towards a carnivorous diet.

On the other hand, evolutionary tendencies manifest themselves in the occasional congenital absence of the gall bladder, but the great rarity of this anomaly suggests that these tendencies are being suppressed.

From the comparative point of view, therefore, the human gall bladder is not a useless organ and its indiscriminate removal has to be condemned. Nevertheless, it is tending to become vestigial, and, like other vestigial structures, it is notoriously prone to disease.

2. Histology. The findings of this section show that muscle is present in the bile ducts of all vertebrates and that it is fairly well developed in the type of biliary system that resembles the human biliary system. From the comparative viewpoint, therefore, the findings described in the section on the musculature of the human bile ducts are fully corroborated. Moreover, it is significant that the muscle of the bile ducts in cases with congenital absence of the gall bladder is poorly-developed like that of animals normally lacking the organ.

SUMMARY AND CONCLUSIONS.

1. The literature on the comparative anatomy of the biliary system has been reviewed.
2. The anatomy of the biliary system and the musculature of the bile ducts of a large series of animals representing all the vertebrate classes and every placental order have been described. Examples of 36 species were studied by personal dissection and the musculature of the bile ducts of amphibia, reptiles, birds, insectivora and chiroptera have been described for the first time.
3. The following facts have emerged from a correlation of the various findings:-
 - (a) The biliary system is a typical vertebrate structure. It first appears in cyclostomes and is highly characteristic of the group.
 - (b) The primitive biliary system consists of multiple hepatic ducts and a large gall bladder which concentrates very well. Well-developed muscle is present in the bile ducts.
There is progressive diminution in the functional efficiency of the biliary system from the lower to the higher vertebrates. This is associated with a loss of form and of structure. First, the accessory hepatic

ducts disappear and later the gall bladder diminishes in size until it finally disappears. At the same time the muscle of the bile ducts decreases, but it does not disappear completely. This concept of the phylogenetic history of the biliary system has not been described before.

- (c) There is no obvious reason for the variations in the relation between the bile and pancreatic ducts. These variations cannot be correlated with the form and the structure of the biliary system. This finding agrees with those of others (245,340).
- (d) The site of the duodenal papilla cannot be connected with the other findings of the study.
- (e) The normal human biliary system occupies an intermediate position in the phylogenetic development of the biliary system, and anomalies represent other stages in this development. From the point of view of comparative anatomy, the human gall bladder is not a useless structure and its indiscriminate removal is condemned.
- (f) There is overwhelming comparative evidence in favour of the view that the human bile ducts possess reasonably well-developed muscle and that the sphincter around the lower end of the common bile duct is independent of the duodenal muscle.

EXPERIMENTAL AND CLINICAL

OBSERVATIONS.

EXPERIMENTAL AND CLINICAL OBSERVATIONS ON
THE MUSCULATURE OF THE BILE DUCTS.

The property of contractility is much more highly developed in muscular tissue than it is in any other. In fact, active movements of the body as a whole or of any of its parts, are entirely dependent on the contractions of muscles (29, 144, 379). The presence of muscular tissue in an organ may therefore be taken for granted if it can be shown that the organ is actively motile.

The purpose of this section is to corroborate the findings of previous sections by presenting experimental and clinical evidence that the bile ducts are contractile. The data were obtained from personal studies and from a review of the vast literature on the subject.

The section is divided into two parts :

In Part I the personal experiments are described and the results of each investigation are correlated with those of similar methods of study by other workers.

Part II deals with clinical and radiological observations.

PART I.

EXPERIMENTAL WORK

METHODS AND MATERIAL USED.

Three methods of observing and recording contractions of the bile ducts were employed, viz:

A. Direct observation of the movements of the bile ducts in anaesthetised animals. The following species were used:

1. 1 Leguan.
2. 3 Fowls.
3. 2 Pigeons.
4. 2 Guinea pigs.

B. Cannulation of the common bile duct of 3 cats and observations on the flow of bile from the duct.

C. Observations on isolated strips of the bile ducts of the following animals:

1. Cattle - 10 specimens
2. Sheep - 6 specimens
3. Pigs - 6 specimens
4. Horses - 2 specimens

A. DIRECT OBSERVATIONS OF THE MOVEMENTS OF THE BILE DUCTS.

1. DESCRIPTION OF PROCEDURE.

The leguan was pithed and its cerebrum was crushed. The other species were anaesthetised with nembutal and ether.

The abdomen of each animal was opened. The bile ducts were then exposed and watched for periods of $\frac{1}{2}$ - 1 hour.

In each case witnesses were present to confirm the personal observations.

2. THE OBSERVATIONS AND THEIR INTERPRETATION.

a. The Leguan. No spontaneous movements were observed, but mechanical stimulation of the hepatic duct was followed by a writhing movement of the duct passing from the liver to the duodenum. No duodenal contractions were seen.

This movement, which was elicited several times, was regarded as an active contraction of the duct.

b. The Birds. Spontaneous movements of the bile ducts of all the fowls and pigeons were observed. During the intervals between the movements the bile ducts were distended with green bile. During the movements the ducts became narrower and paler from above downwards. Each movement lasted 2 - 3 seconds and the intervals between movements varied from 10 - 20 seconds.

The movements were independent of respiratory excursions and no contractions ~~and no contractions~~ of the gall bladder nor of the duodenum were noticed. The two ducts moved independently of each other and in each a movement could be initiated by mechanical stimulation.

These movements were interpreted as active contractions of the bile ducts.

c. The guinea pigs. Movements of the bile duct similar to those observed in birds were seen in guinea pigs. In these animals however, the movements were limited to the ampulla and the lower third of the common bile duct. They occurred spontaneously at intervals of 15 - 30 seconds and could be initiated by mechanical stimulation. They were regarded as active contractions of the bile duct.

3. OBSERVATIONS BY OTHER WORKERS ON THE BILE DUCTS OF SIMILAR AND OTHER SPECIES.

a. The leguan - Contractions of the bile ducts of this animal have not been observed before.

b. Birds - Movements of the bile ducts of birds were first noticed by Claude Bernard in 1856 (60) and later by DOYON in 1893 (92, 170). Several authors mention that the bile ducts of birds are motile (60, 92, 162, 169, 170, 318). COPHER and ILLINGWORTH (92) state that the movements of the bile ducts of fowls and pigeons are of a peristaltic nature.

c. Guinea pigs - Active contractions of the bile ducts of guinea pigs has been observed by many workers (68,69,161,170, 249,286,318). BURGET and BROCKLEHURST (68) found that the contractions of the ampulla could be initiated by distention of the gall bladder and common bile duct, by vagus stimulation and by injection of pilocarpine. HIGGINS (161) noted contractions of the common bile duct above the ampulla.

d. Fish. HIGGINS (162) experimented on the American Bullhead. He noted contraction waves over the whole of the common bile duct. The waves appeared every 2 - 4 minutes, and throughout the period of activity the duodenum remained inactive.

e. Opossums. DU BOIS and HUNT (114) conducted experiments on anaesthetised opossums. They observed contractions in the lower two-thirds of the common bile duct. These contractions recurred at intervals of 10 - 15 seconds, and after each contraction the ampulla became distended with yellow bile. The movements were independent of duodenal movements.

f. Dogs. IVY (170) states that LABORDE and AUDIGE noted that the common bile duct of dogs contracted on direct electrical stimulation, and that DOYON observed contractions of the dog's bile duct on stimulation of its splanchnic nerves.

g. Rabbits. SCHMIDT and IVY (318) claim that they have observed contractions of the common bile duct of the rabbit. IVY(170) states that WESTPHAL recorded similar observations.

h. Horses. According to IVY (170) contractions of the common bile duct of the horse were observed by COLIN in 1873.

i. Elephants - OWEN (279) states that the ampulla of the elephant contracts.

B. CANNULATION OF THE COMMON BILE DUCT.

1. DESCRIPTION OF PROCEDURE.

The cats were anaesthetised with nembutal supplemented by ether. Their abdomens were opened and the bile ducts /were

were exposed.

A simple apparatus was constructed for observing the rate of flow of bile from the common bile duct - see Fig. 88 page 259 . A glass manometer containing a fluid meniscus as an indicator was mounted horizontally on the same level as the experimental table. The right limb of a glass T tube was attached to the manometer. The left limb of this tube was connected to an outlet tube. The third limb was connected to a glass cannula by a thin rubber tube.

The terminal end of the common bile duct was tied, and the glass cannula was inserted into the duct just above the ligature. The mouth of the cannula pointed towards the liver.

The gall bladder was excluded from the circuit by clamping the cystic duct.

The outlet tube was clamped and the normal rate of flow of bile from the common bile duct was determined by observing the rate of movement of the meniscus in the manometer. The animals were then given 0.1 mgm. of pilocarpine and the effects of this drug were noted. Approximately three minutes later 1 mgm. of atropine was given and its effects were noted.

2. THE OBSERVATIONS AND THEIR INTERPRETATION.

a. Before the drugs were given, the meniscus moved slowly and continuously towards the right of the manometer at the rate of approximately 1 cm. per minute - see A to B Fig. 89 page 259.

/This

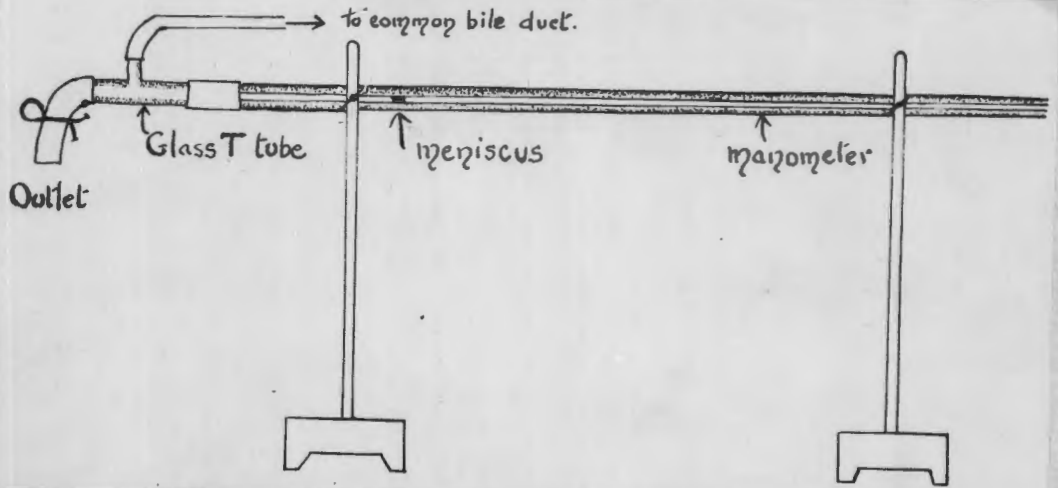


Fig. 88

Apparatus for recording the flow of bile from the bile duct.

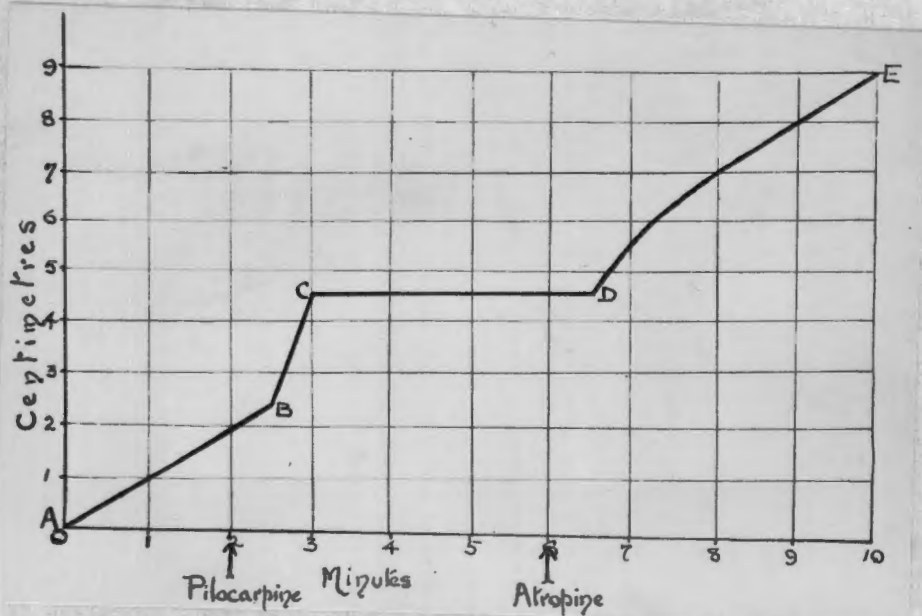


Fig. 89

Graphic representation of rate of movement of the meniscus (See text for explanation).

This suggests that the flow of bile is a continuous process, a finding which agrees with the work of others (32, 155, 244, 264, 271).

b. 15 - 30 seconds after the pilocarpine had been given, the meniscus moved more rapidly to the right, passing across 2 cms. in approximately 30 seconds - see B to C Fig. 89 page 259. This was followed by a complete cessation of movement which lasted until the atropine was given - see C to D Fig. 89 page 259.

Approximately 30 seconds after the atropine had been given, the meniscus resumed its former movements. The rate of movement was at first more rapid than it had been at the commencement of the experiment, but it soon returned to its former rate. - See D to E, Fig. 89, page 259.

This sequence of events is interpreted as indicative of active contractions of the bile duct for the following reasons :

- i. Other workers have shown that pilocarpine and atropine do not produce a sudden alteration in the secretion of bile by the liver (201, 264, 271).
- ii. There were no gross movements to affect the movement of the meniscus and it was shown that this movement was not affected by slight body movements nor by respiratory excursions.
- iii. It has been established that pilocarpine stimulates the smooth muscle of the biliary tract and that atropine relaxes such muscle (68, 170, 201, 241, 235).

3. OBSERVATIONS OF OTHER WORKERS ON THE SUPRADUODENAL PORTION OF THE CAT'S BILE DUCT.

WHITAKER and BOYDEN (366) recorded pressure changes in the bile ducts of cats and demonstrated that the common bile duct exhibited a continuous rhythm. They state that

/this

this rhythm represents contractions of the common bile duct.

COPHER and ILLINGWORTH (92) filled the common bile ducts of cats with lipiodol after they had tied off the hepatic ducts. X-rays taken after 12 hours showed that no dye was left in the ducts. They state that this was due to active contractions of the ducts.

C. OBSERVATIONS ON ISOLATED STRIPS OF BILE DUCTS.

1. DESCRIPTION OF PROCEDURE.

The material was obtained from animals soon after they had been slaughtered. The bile ducts were dissected free from the surrounding pancreatic tissue and duodenal muscle. The supraduodenal and intramural portions of the bile ducts were separately investigated.

The usual type of Magnus apparatus was used - see Fig. 90 page 262. The experimental tube was filled with Ringer's solution and the surrounding beaker was filled with water which was maintained at a temperature of 38°C. Air was bubbled through the Ringer's solution.

The following drugs were added to the experimental tube:

1. Pituitrin.
2. Arecoline (Acetyl choline)
3. Atropine.
4. Barium chloride.

2. THE OBSERVATIONS AND THEIR INTERPRETATION.

- a. Strips from the supraduodenal portion of the bile ducts.

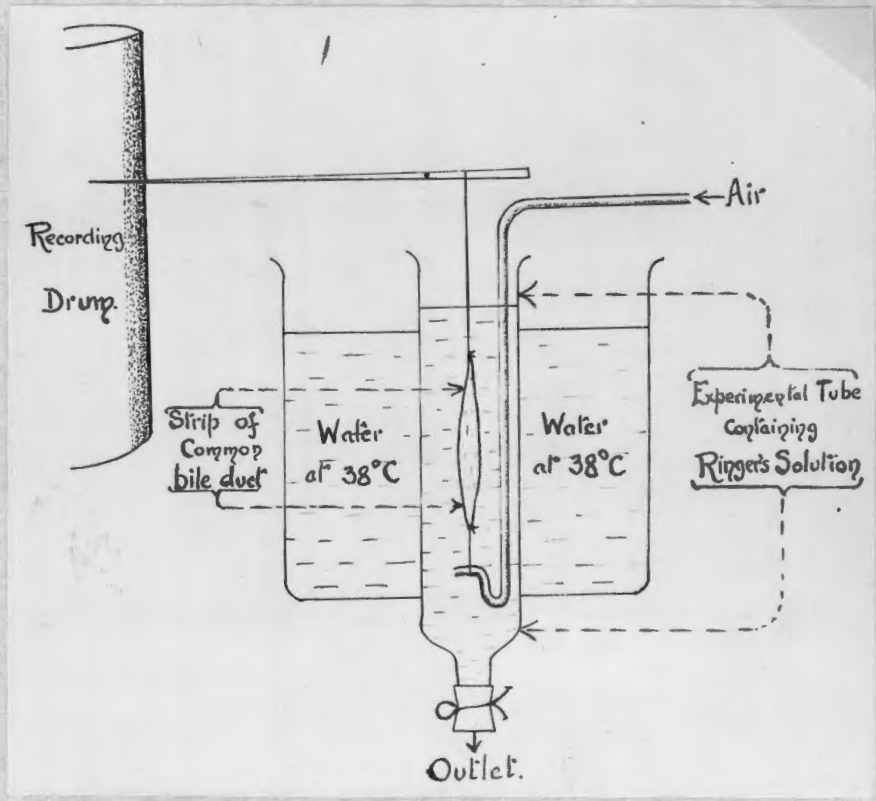


Fig. 90

Apparatus for recording contractions of isolated strips of tissue.

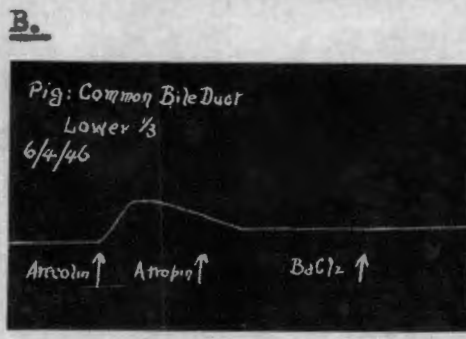
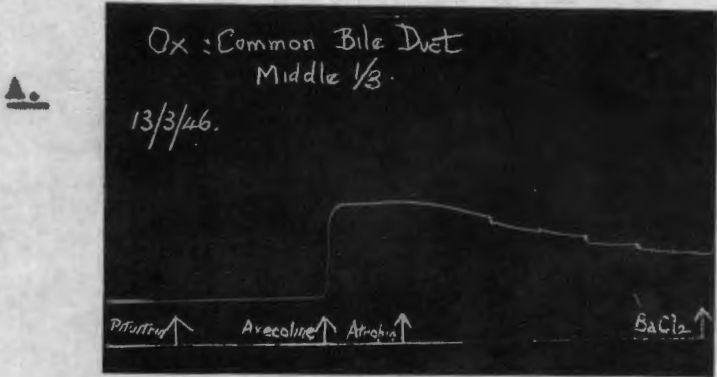


Fig. 91

The records of contractions of the bile ducts of three species.

No spontaneous movements were observed, and the drugs elicited contractions of the bile ducts of cattle only. In 5 of the 10 bile ducts of cattle a definite tonic contraction followed the addition of arecoline to the experimental tube, and in 2 of the bile ducts the contraction was well marked - see Fig. 91A page 262.

b. Strips from the intramural portion of the bile ducts.

No spontaneous movements were observed, but the drugs elicited contractions of the bile ducts of cattle, sheep and pigs. In about one fifth of the experiments, tonic contractions of the ducts followed the addition of arecoline to the experimental tube. In all cases the results were very slight - see Figs. 91B & C. page 262.

Although most of the experiments failed to demonstrate contractions of the bile ducts, it is felt that the poor results were largely due to the crude apparatus and the fact that the material was not sufficiently fresh. On the other hand, the positive results suggest that the bile ducts of cattle, sheep and pigs are contractile.

3. OBSERVATIONS BY OTHER WORKERS ON ISOLATED STRIPS OF BILE DUCTS.

Magee (235) studied the contractility of strips of the intramural portion of the bile ducts of cattle and of sheep. He found that the strips exhibited spontaneous rhythmical contractions and that they responded to a variety of drugs by tonic contractions. By comparing his results with the effects of the same drugs on the duodenal muscle, he concluded that the sphincter of Oddi of these species can contract independently of duodenal contractions.

Gerald (cited by 236) showed that isolated strips of the bile ducts of sheep responded to a variety of drugs.

DISCUSSION.

In previous sections it was pointed out that there are two problems in connection with the musculature of the bile ducts . These problems are:

- A. Do the bile ducts possess sufficient muscle to render them contractile ?
- B. Is the sphincter of the common bile duct independent of the duodenal muscle ?

These problems will be discussed.

A. Are the Bile Ducts contractile ?

Personal studies of the bile ducts of nine species of animals have shown that contractions of the ducts of examples of the following orders do occur :

1. Reptiles.
2. Birds.
3. Carnivora.
4. Rodents
5. Artiodactyla.

A review of the literature has shown that contractions of the bile ducts have been observed in additional species belonging to the following orders.

1. Fishes.
2. Marsupials.
3. Proboscidea.

These orders are well representative of vertebrates in general. As a rule, species belonging to the primitive orders exhibit the greatest motility of their bile ducts.

These findings therefore serve to answer the first

/question

question in the affirmative and they are in full agreement with the histological observations of this study.

B. Can the sphincter of Oddi contract independently of duodenal contractions ?

1. In personal experiments on the intramural portion of the common bile duct of animals belonging to 4 species, contractions were elicited in the ducts of some of the examples of cattle, sheep and pigs. These results show that the sphincter of Oddi of these species is capable of contraction. Moreover, it was pointed out that Magee (235) who obtained similar results in cattle and sheep, found that the biliary and intestinal musculature responded differently to various drugs. His findings suggest that the sphincter of these species can contract independently of duodenal contractions. Nevertheless, the evidence is not sufficient.
2. Additional evidence was found in the behaviour of the bile ducts of birds and guinea pigs. In these species active contractions of the supraduodenal portions of the bile ducts were observed quite apart from duodenal contractions. These contractions were associated with a flow of bile into the intestine. This suggests that simultaneous contractions of the intramural portions of the ducts were taking place and that these contractions were not dependent on duodenal activity. This suggestion, however, is open to criticism.
3. Further evidence was looked for in the literature.

A review of the numerous articles on the subject shows that all authorities agree that duodenal motility and tone play a role in controlling the flow of bile into the intestine (65, 66, 93, 138, 170, 177, 199, 200, 201, 219, 220, 273, 288, 308).

There is, however, much difference of opinion on the action of the sphincter of Oddi. Prominent authorities believe that the sphincter cannot contract independently of duodenal contractions (16, 65, 66, 67, 93, 94). On the other hand, there is a great deal of evidence in favour of the view that it can. This evidence will be presented under the following headings.

- a. Direct observations on the motility of the duodenal papilla.
- b. Observations on the flow of bile into the intestine.
- c. The filling and evacuation of the gall bladder.
- d. Measurements of the tone of the sphincter.

a. The motility of the duodenal papilla.

Several workers have noticed that the papilla remains open quite apart from duodenal activity (4, 177, 288). Moreover, it has been shown that stimulation of the papilla causes it to contract on its own (2, 4, 138, 177).

b. The flow of bile.

It is accepted that the secretion of bile by the liver is a continuous process (32, 138, 142, 170, 240, 241, 264, 271, 275, 288, 372). Nevertheless, numerous workers have observed that the flow of bile from the papilla of animals possessing a gall bladder

/occurs

occurs in intermittent spurts (128, 138, 142, 177, 275, 288, 372, 376). It is clear therefore, that resistance is encountered at the lower end of the common bile duct.

The following observations suggest that this resistance is due to the independent action of the sphincter of Oddi.

- i. The intermittent gushes of bile are frequently entirely independent of duodenal activity (170, 275, 288).
- ii. Ivy and his co-workers (174, 175) report that they have observed an independent flow of bile and of pancreatic juice in a human subject (by duodenal intubation). The bile flow was stopped by secretin and re-started by magnesium sulphate.
- iii. In animals normally lacking a gall bladder the bile flows continuously into the intestine, and yet the duodenal activity and bile secretion of these animals do not differ from that of animals possessing the organ (138, 140, 170, 241, 318).

c. Filling and evacuation of the gall bladder.

It has been conclusively shown that a sphincter mechanism at the lower end of the common bile duct is essential for the filling of the gall bladder and that this mechanism controls the evacuation of the organ to a large extent (27, 32, 40, 67, 94, 138, 142, 170, 171, 172, 173, 222, 232, 238, 253, 258, 275, 318, 365, 372, 374).

On the other hand, several investigators have demonstrated that the filling and the evacuation of the gall bladder can occur quite apart from duodenal activity (32, 56, 138, 177, 235, 240, 275, 288, 364). This suggests that the sphincter mechanism functions independently of duodenal contractions.

d. The tone of the sphincter.

This method of investigation, which was first undertaken by Oddi in 1888 (65, 128, 138, 199, 219, 241, 322), has provided the following evidence in favour of the view that the sphincter of Oddi can contract independently:

- i. The resistance is greater in animals possessing
/a

a gall bladder than in those without the organ. In the former group the resistance usually exceeds 75 mm. of water (2, 65, 128, 170, 171, 199, 219, 220, 234, 241, 288, 308, 318), while in the latter it approximates zero (140, 170, 237, 241, 318). On the other hand, there is no difference in the intraduodenal tension of the two groups of animals (138).

ii. There are often discrepancies between the sphincteric resistance and the intraduodenal tension both in man and in animals. Several workers have shown that the sphincteric resistance may increase while the duodenal tension falls or vice versa in response to various stimuli (17, 18, 19, 71, 201, 212, 219, 220, 228, 229, 273, 308, 353, 354). An interesting point stressed by many workers is that morphia causes spasm of the sphincter which is relaxed by the nitrites and atropine (17, 22, 32, 112, 171, 201, 219, 229, 273).

iii. Mann and Higgins (164, 247) have shown that the sphincteric resistance is not appreciably decreased after the bile duct has been dissected free from the duodenum.

iv. The effects of cholecystectomy.

Soon after cholecystectomy in experimental animals, the tone of the sphincter is lost and bile dribbles continuously into the duodenum (140, 142, 170, 171, 186, 232, 240, 275, 288, 289, 301, 318, 376). This loss of tone is not associated with a corresponding loss of duodenal tone (140, 170, 171, 186, 240, 275, 288, 318).

Later the bile ducts dilate due to a return of tone to the sphincter (140, 170, 286, 288, 318) but the duodenal tone remains the same (138).

SUMMARY AND CONCLUSIONS

1. Contractions of the bile ducts of examples of nine species of animals were personally studied.

2. The findings have been corroborated and supplemented

/by

by data obtained from the literature.

3. A correlation of the various findings has shown the following :

- a. The bile ducts of examples of at least nine vertebrate orders are contractile. The motility is more marked in the lower vertebrates than it is in the more highly specialised orders.
- b. There is overwhelming evidence in favour of the view that the lower end of the common bile duct can contract independently of the contractions of the duodenal wall.

4. Since the property of contractility is dependent on muscular tissue, these observations corroborate the findings of previous sections of this study.

PART II. CLINICAL AND RADIOLOGICAL
OBSERVATIONS.

METHODS:

In this section observations on the human bile ducts are discussed under the following headings:-

- A. The symptoms of choledocholithiasis.
- B. The results of cholecystectomy.
- C. Cholangiographic studies.

A. THE SYMPTOMS OF CHOLEDOCHOLITHIASIS.

The case-histories of 13 patients who had been operated upon for stones in the common bile duct were analysed. The findings are illustrated in table 13 page 271 and a comparison of this table with table 14 page 272 shows that the observations agree with those of other workers.

These tables show that pain occurs in over 80% of patients suffering from stones in the common bile duct: and that the pain is sufficiently characteristic to be called biliary colic in 60 - 70% of patients.

The most striking fact revealed by table 13 page 271 however, is that severe biliary colic occurred in two patients on whom a previous cholecystectomy had been performed. Other workers record similar observations (102, 210, 265, 343).

/ Discussion:

— 271 —
TABLE 13

THE SYMPTOMS OF CHOLEDOCHOLITHIASIS (PERSONAL STUDY).

<u>Initials</u>	<u>Gall Bladder</u>	<u>Pain</u>	<u>Biliary Colic</u>	<u>Jaundice</u>	<u>Stools</u>
S.D.	Present	Present	-	Present	-
A.D.	<u>Removed</u>	Present	Severe	-	-
H.S.	Present	Present	Severe	Present	-
L.K.	Present	Present	Slight	Present	-
D.L.	Present	Present	-	-	Present
F.R.	Present	Present	-	Present	Present
P.F.	Present	Present	Severe	-	-
M.V.	Present	-	-	Present	Present
M.F.	Present	Present	Slight	Present	-
K.F.	Present	Present	Severe	-	-
C.J.	Present	Present	-	Present	-
D.W.	<u>Removed</u>	Present	Severe	Present	-
<u>P.W.</u>	Present	<u>Present</u>	<u>Severe</u>	<u>Present</u>	<u>-</u>
13 cases		12	8	9	3
	<u>Percentage:</u>	92.	62	69	23

TABLE 14.

THE SYMPTOMS OF CHOLEDOCHLITHIASIS (FROM THE LITERATURE).

<u>Author</u>	<u>Pain (%)</u>	<u>Colic (%)</u>	<u>Jaundice (%)</u>	<u>Chills.</u>
Klingenstein 1931 (197).	95	?	?	?
Judd and Marshall 1931(191)	97	80	73	37
MacDonald 1935 (227)	44	?	?	?
Lahey and Swinton 1935 (210)	80	?	61	4
Zollinger and Kevorkian 1939 (378)	91	?	81	33
Walters and Snell 1940 (355)	96	75	?	?
Trueman 1940 (343)	77	64	61	34
Cutler and Zellinger 1940 (102)	90	?	85	30
Berk 1942 (21)	80	?	73	33
Bockus 1946 (32)	<u>80</u>	<u>?</u>	<u>?</u>	<u>?</u>
<u>Average:</u>	83%	73%	72%	29%

Discussion:

It is well-known that colic is caused by the forcible contractions of the walls of hollow muscular systems (256, 266). Many years ago, in 1895, Rutherford Morison (256) called attention to the fact that biliary colic is caused by excessive contractions of the unstriated muscle of the biliary system.

On general principles, therefore, the occurrence of biliary colic in choledocholithiasis suggests that the bile ducts possess muscle in their walls. Since the colic occurs even after the gall bladder has been removed, the presence of such muscle is even more probable.

B. THE RESULTS OF CHOLECYSTECTOMY.

Questionnaires were sent to 48 patients on whom cholecystectomy had been performed. Replies were received from 29, i.e., 60%. Most of the patients had been operated on by Dr. Cole Reus and gallstones were found in 20 of the 29 who had replied, and in two of these, stones were found in the common bile duct. The information received is shown in table 15 page 274. This indicates that 4 of the 29 patients complained of biliary colic similar to the colic they had experienced before their gall bladders had been removed. Although three of these patients had suffered from gall stones, no stones had been found in their common bile ducts at the original operation. Moreover, all these patients

/stated

TABLE 15.

PERSONAL STUDIES.

THE RESULTS OF CHOLECYSTECTOMY.

<u>Initials.</u>	<u>Total relief</u>	<u>Partial relief.</u>	<u>Post oper- ative Colic.</u>
H.B.	-	-	+
R le R.	+	-	-
A.F.N.	+	-	-
M.G.	+	-	-
S.M.	+	-	-
L.S.W.	+	-	-
W.H.O.	+	-	-
M.S.H.	+	-	-
C.J.R.	+	-	-
M.T.	+	-	-
A.L.	+	-	-
C.L.	-	-	+
G.C.M.	+	-	-
G.L.	-	+	-
D.M.	+	-	-
H.J.B.	-	+	-
R.F.	+	-	-
M.R.	-	+	-
M.C.O.	+	-	-
C.K.A.	+	-	-
B.L.	-	+	-
A.G.	-	+	-
F.R.	+	-	-
L.F.S.	+	-	-
D.V.	+	-	-
M.D.	-	+	-
J.L.	-	+	-
T.G.	-	-	+
M.S.	-	-	+
TOTAL 29	18	7	4
PERC- ENTAGE 100	62	24	14

stated that they had not been jaundiced since they had been discharged from hospital. A brief case-history of one of these patients is given below.

Case.7. C.L. a European female aged 25 years.

This patient had her gall bladder removed in January, 1944. She had suffered from severe attacks of biliary colic and at operation stones were present in the gall bladder but not in the common bile duct.

The operation was followed by complete relief of the symptoms.

In November, 1945, she was given $\frac{1}{4}$ gr. morphia for uterine haemorrhage, 5-10 minutes after the injection she developed typical biliary colic, which was as severe as the colic she had experienced before the operation. She was then given an injection of atropine and this was followed by relief of the pain.

There have been no similar attacks since.

Discussion:

These findings agree with those of others (24,91,105, 188,192,252,269,306,309,368,370). It is generally agreed that cholecystectomy is followed by total relief of symptoms in 60-70% of cases and by partial relief in an additional 20-30%. There are, however, 2-10% that are not relieved by operation. Among these there is usually an organic lesion to account for the persistence of symptoms (22,87,91,187,236,265,344,350) but in a small number no lesion can be detected even at a second operation (24,77,192,287,307,309,349). These patients often complain of biliary colic. As a rule the symptoms last for a short period only and subside spontaneously. Often the colic is precipitated by morphine and relieved by antispasmodics (25,26,27,71,157,228,349,352,353,354, 356).

It is generally believed that this colic is due to functional disorders of the sphincter of Oddi (24, 77, 192, 287, 295, 309, 310, 349, 350, 353). A tremendous amount has been written on this subject of "biliary dyskinesia" or "post-cholecystectomy syndrome" (23, 25, 26, 27, 71, 89, 136, 137, 138, 157, 170, 212, 214, 219, 228, 229, 275, 287, 353, 354) and many workers have demonstrated spasticity of the sphincter of Oddi in patients suffering from the condition (25, 26, 157, 174, 212, 214, 287).

Whatever the exact origin of the "post-cholecystectomy syndrome", however, the fact that biliary colic occurs after cholecystectomy emphasizes the findings discussed under the previous heading, and suggests that muscular contractions occur in the bile ducts.

3. CHOLANGIOGRAPHIC STUDIES.

The following investigation which was carried out by the author in conjunction with the staff of the Department of Radiology of the Groote Schuur Hospital was the first of its kind to be undertaken in this hospital.

Case 8. The patient, K.F., a coloured female aged 35 years, had been operated on by Mr. T. Schrire on August 5th, 1946. Cholecystectomy and choledochotomy had been performed. The fluoroscopic studies were carried out four days later.

(a) Description of Procedure.

After the choledochostomy and drainage tubes had been identified, about 15 cc. of lipiodol were slowly

/injected

injected into the former tube, which was then clamped.

About 5-10 minutes later the patient was given $\frac{1}{4}$ gr. morphia intravenously and its effects on the bile ducts were noted. After a further interval of 5-10 minutes a capsule of amyl nitrite was inhaled by the patient and the effects of this drug were noted.

(b). The observations.

Initial appearances.

The dye flowed freely into the bile ducts. It passed upwards into the intrahepatic ducts and downwards into the duodenum. The flow into the duodenum was uninterrupted and continued until the morphia was given. No spontaneous movements of the bile ducts were observed.

The appearances at this stage are illustrated in Fig. 92A page 278. This radiograph shows an ill-defined lower end of the common bile duct and dye in the duodenum adjacent to the papilla.

The effect of morphia.

Approximately 15-30 seconds after the morphia injection the dye stopped flowing into the duodenum and the lower end of the common bile duct assumed a conical shape with a clear-cut outline. No lipiodol passed into the duodenum until the amyl nitrite was inhaled, and during the interval the portion that had previously escaped from the bile ducts moved away from the duodenal papilla.

A.
Initial
appearances.

Drainage
tube.

Tube in
common
duct.

Lower end
of common
duct ill-
defined.

Dye in
duodenum.

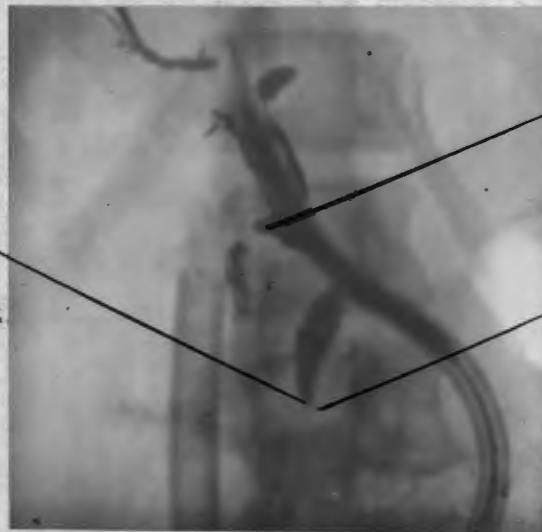


B.
After
Morphia.

Lower end
of common
duct conical
and clear-cut

Stump of
cystic
duct.

No dye in
duodenum.



C.
After amyl
nitrite.

Lower end
of duct
open

Dye in
duodenum

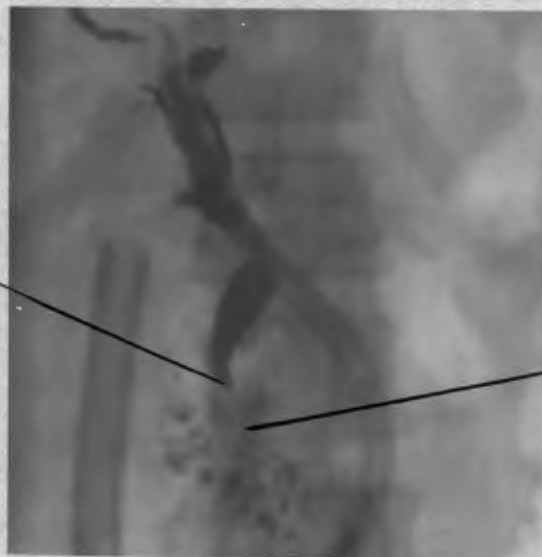


Fig. 92

Cholangiograms showing
contractions of the lower
end of the common bile duct.

Fig. 92B, page 278, illustrates the appearance at this stage. The lower portion of the common bile duct is conical and tapers to a well-defined point. There is no dye in the portion of the duodenum adjacent to the papilla.

The effect of amyl nitrite.

Soon after the inhalation of amyl nitrite, the lower end of the common bile duct lost its clear definition and the flow of dye into the duodenum was resumed. In fact, it flowed more freely than it had done at the commencement of the investigation.

Fig. 92C, page 278, illustrates the appearances at this stage. The lower end of the common bile duct is ill-defined and a large amount of dye is present in the duodenum close to the papilla.

(c) Interpretation of observations.

The free flow of dye into the duodenum at the commencement of the investigation showed that there was no mechanical obstruction at the lower end of the common bile duct.

It is, therefore, suggested that the obstruction to the flow of lipiodol after the morphia injection was due to tonic contraction of the sphincter of the bile duct, and that this contraction was relieved by amyl nitrite. Although no contractions were observed in

/the

the upper parts of the bile ducts, the above suggestion is supported by the fact that changes in the shape of the lower end of the common bile duct were noticed and recorded.

(d) Discussion.

This interpretation of the findings agrees with that of others who have studied the motility of the bile ducts by cholangiography. Indeed, it has been shown that the tonic contractions of the lower end of the bile duct are associated with an increase in the intraductal tension and often with typical biliary colic (25, 26, 27, 52, 71, 228, 349, 353, 354, 356). Moreover, studies of the differential action of various drugs on the duodenum and on the sphincter mechanism have shown that the contractions occur apart from duodenal activity (27, 52, 353, 354).

The present investigation failed to reveal movements of the extraduodenal portion of the common bile duct, but this does not imply that contractions of this portion of the duct do not occur. On the contrary, at least two workers claim that contraction waves do occur, viz:

Mirizzi (261, 262) states that cholangiography has demonstrated that active peristalsis of the common bile duct often occurs when the lower end of the duct

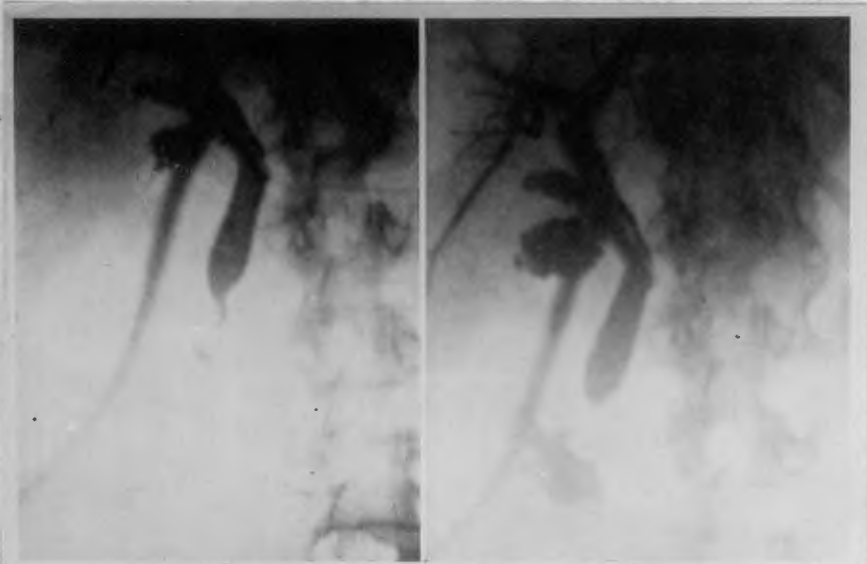
A.

After Mirizzi
(261)



B.

After
MacDonald.
(224)



Cholangiogram made 10 minutes after $\frac{1}{4}$ grain of morphine had been given, and approximately 3 minutes after the injection of 15 cubic centimeters of lipidol. In this figure the dye is observed just beginning to enter the duodenum. The interpretation of this picture by itself would indicate either a ductal or pancreatic pathological condition. This entire narrow channel is not a single constriction. It is longer than the areas seen by fluoroscope.

If it is all constriction it is not the same as intestinal peristalsis, but, judging from the subsequent pictures, only the upper part is involved.

Cholangiogram made 2 minutes after Figure 1, and 5 minutes after the injection of the dye. More dye has entered the duodenum. The outline indicates that the distal end of the duct has completely closed. The hepatic ducts are well filled.

Fig. 93

Cholangiograms showing contraction waves of the common bile duct.

is stenosed. Fig. 93A, page 281, is a reproduction of one of his cholangiographs; It shows irregularity of the common bile duct which Mirizzi correlates with the movements seen on screening.

MacDonald (224) reports on a case in which he accidentally observed peristalsis of the common bile duct during routine cholangiography. Fig. 93B, page 281 is a reproduction of his cholangiographs. This picture demonstrates variations in the diameter of the common bile duct. MacDonald discusses the interpretation of these variations and concludes that they were caused by active contractions of the common bile duct.

SUMMARY AND CONCLUSIONS.

1. Personal studies have shown:
 - (a) that biliary colic is a common symptom of choledocholithiasis. It occurs even after the gall bladder has been removed;
 - (b) that a small number of patients suffer from biliary colic after cholecystectomy. This colic may occur even in the absence of organic lesions of the bile duct and is often precipitated by morphia.
 - (c) That the flow of dye into the duodenum of a patient studied by cholangiography was

/interrupted

interrupted by an injection of morphia.

This interruption was associated with changes in the shape of the lower end of the common bile duct.

2. These findings have been corroborated and supplemented by information obtained from the literature.

3. It has been pointed out that the various observations suggest that the human bile ducts possess contractile muscular tissue in their walls. The tone of this muscle is increased by morphia and diminished by antispasmodics.

4. These findings confirm the observations of the previous sections of this work and serve to illustrate the clinical significance of the musculature of the bile ducts.

GENERAL SUMMARY.

GENERAL SUMMARY.

1. The anatomy of the main bile ducts has been described in detail. The frequency of variations from the normal and the clinical significance of the various anatomical features have been emphasized.
2. It has been demonstrated by histological methods that muscular tissue exists in all parts of the main bile ducts. The muscle is well-developed in the lower third of the common bile duct and the sphincter around the terminal end of the duct is separate from the duodenal muscle.
3. Congenital abnormalities of the bile ducts have been discussed. Data personally collected on examples of congenital absence of the gall bladder, cystic dilatation of the common bile duct, obliteration of the bile ducts and accessory hepatic ducts have been reported.
4. The embryology of the biliary system has been described and it has been shown that muscle differentiates from the mesoderm immediately surrounding the bile ducts. The differentiation commences in the intramural portion of the common bile duct and extends slowly and progressively towards the hepatic duct.

5. The comparative anatomy of the bile ducts has been described and the evolutionary history of the biliary system has been discussed. It has been demonstrated that there is a progressive loss of form, structure and function of the biliary system from the lower to the higher vertebrates.

The relation of the findings to the form and structure of the human biliary system have been discussed. It has been pointed out that comparative studies support the view that the human common bile duct possesses muscular tissue in its walls and a special intrinsic sphincter at its lower end.

6. Experimental and clinical investigations have shown that the bile ducts of man and of examples of several vertebrate orders are contractile and that the sphincter of Oddi can contract independently of duodenal activity.

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ACKNOWLEDGMENTS.

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