PROCEEDINGS OF THE SOCIETY FOR EXPERIMENTAL BIOLOGY AND MEDICINE 173, 344–348 (1983)

Compliance of the Extramural Portion of the Canine Common Bile Duct (41654)

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Abstract. The physiologic characteristics of the biliary tract cannot be adequately evaluated without analyzing both the resistive and compliant characteristics of the common bile duct. We studied the compliance of the common bile duct in six anesthetized dogs. Saline was infused continuously while pressure was monitored with the sphincter of Oddi intact and tied off. The mean opening pressure of the sphincter was 8.45 cm H_2O. In the obstructed duct, compliance was found to decrease with increasing pressure. The mean compliance for all five dogs at low pressures (below opening pressure) was 11.0×10^{-2} μl/cm H_2O/mm^2, and at high pressures was 1.7×10^{-2} μl/cm H_2O/mm^2. Changes in flow rate did not affect the compliance of the duct. Although the compliance of the duct was found to be nonlinear overall, it was nearly linear in both the high- and low-pressure ranges.

To evaluate the physiologic characteristics of the biliary tract system, both the resistive and compliant properties of the common bile duct must be analyzed. Although there have been many studies on the pressure relationships in the common bile duct (1–6) as well as on the resistance to flow through the sphincter of Oddi, (7–9) the compliance, or the ability of the duct to store fluid (bile), has received little attention.

Anatomic studies of the canine common duct (at a distance away from the sphincter of Oddi) have revealed a significant amount of elastic tissue throughout the duct intermingled with collagenous connective tissue (10–12). This histological description of the duct, with a predominance of fibroelastic tissue, allows for a significant storage capacity (or compliance) of the duct.

In this study we analyzed the compliance of the common duct under various physiological conditions. Using continuous infusions, the compliance of the duct was measured with the sphincter of Oddi obstructed by proximal ligation.

Material and Methods. The experiments were performed on six healthy mongrel dogs with an average weight of 25 kg. Under pentobarbital anesthesia, the cystic duct and all hepatic ducts except for two were ligated. One hepatic duct was cannulated with a polyethylene catheter and connected to a Harvard pump for the purpose of continuous infusion of saline. The other hepatic duct was also cannulated and attached to a Statham (P231a) pressure transducer which was connected to a Beckman type RP Dynograph recorder. Both catheters were filled with saline and introduced into the intact duct system in a way that would minimize the entrance of air. Prior to taking any pressure measurements the system was flushed with saline and all air bubbles were removed. A ligature was loosely placed around the distal common duct immediately proximal to the sphincter of Oddi but not tied until the

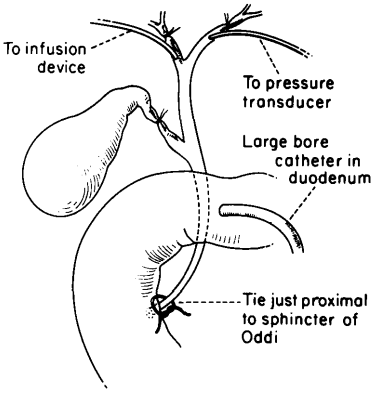

FIG. 1. Diagramatic representations of the experimental model used.

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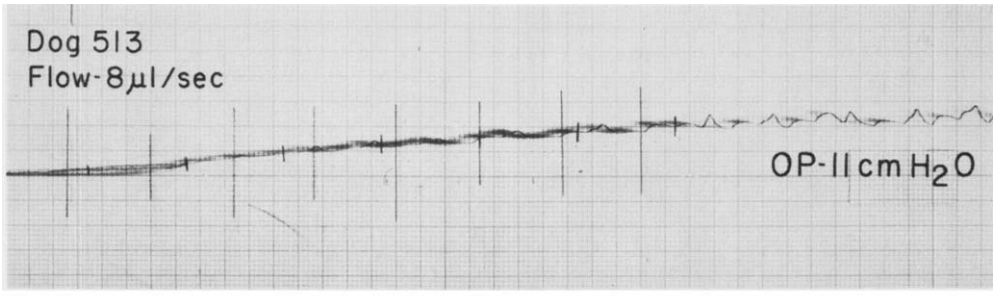

FIG. 2. Photograph of a pressure recording in dog 513 with the sphincter of Oddi intact.

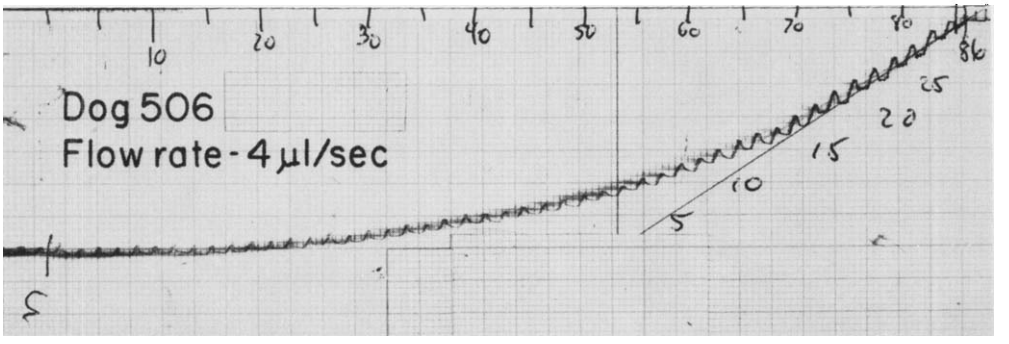

FIG. 3. Photograph of a pressure recording in dog 506 with the sphincter obstructed by a ligature.

latter part of the experiment. A large-bore catheter in the duodenum allowed for decompression (Fig. 1). The zero pressure reference was level with the common bile duct of the supine dog.

Two groups of experiments were performed. In the first group, which included five dogs, the sphincter of Oddi was intact and saline was infused at various constant rates from 4–22 μl/sec while pressure was monitored. Opening pressures (OP) were recorded as the constant pressure that occurred after the pressure stopped rising. This OP was always accompanied by small oscillations (Fig. 2). In

TABLE I. REPRESENTATIVE PRESSURE–VOLUME DATA FOR FIVE DOGS WITH THE SPHINCTER INTACT

304[a] Flow = 22.2 OP = 8.0		311[a] Flow = 11.5 OP = 10.0		422[a] Flow = 4.0 OP = 5.0		506[a] Flow = 4.0 OP = 7.0		513[a] Flow = 8.0 OP = 10.0	
V	P	V	P	V	P	V	P	V	P
0	0	0	0	0	0	0	0	0	0
44	2.0	58	0	40	0	40	0	80	0
88	2.8	115	1.0	80	1.0	80	0.8	160	0.5
132	3.8	173	2.2	120	1.5	120	1.5	240	3.0
176	4.2	230	3.0	160	2.0	160	2.5	320	4.0
222	5.2	288	3.4	200	3.0	200	3.6	400	5.0
262	6.0	345	5.2	240	3.8	240	4.5	480	6.0
306	6.8	403	6.0	280	4.2	280	5.2	560	7.3
		460	7.8			320	6.0	640	8.1

Note. Flow = flow rate (μl/sec); OP = open pressure (cm H_2O); V = volume (μl); P = pressure (cm H_2O).
[a] Number of dog.

TABLE II. OPENING PRESSURE OF THE SPHINCTER OF ODDI AT EACH FLOW

Dog No.	Flow (μl/sec ± 1 SE)	OP (cm H_2O ± 1 SE)	OP (cm H_2O ± 1 SE)
304	22.22	10.5 ± 1.85	10.0 ± 1.02
	11.50	9.33 ± 0.33	
311	22.22	9.8 ± 0.2	8.64 ± 0.65
	11.5	10.0 ± 0	
	5.88	5.5 ± 0.5	
	2.33	5.0 ± 0	
422	15	10.0 ± 0.0	6.88 ± 0.63
	8	6.0 ± 0.5	
	4	6.75 ± 0.85	
506	8	6.33 ± 0.67	6.17 ± 0.4
	4	6.0 ± 0.58	
513	15	10.33 ± 0.33	10.13 ± 0.23
	8	10.5 ± 0.50	
	4	9.67 ± 0.33	

the second part of the experiment, the ligature that had been placed around the common duct just proximal to the sphincter of Oddi was tied. Saline was infused again at similar constant rates as in the previous experiment and pressure was monitored in six dogs (Fig. 3). Compliances were calculated for the duct only when the sphincter was excluded by proximal ligature.

The pressure measured in response to various volumes infused was recorded during each experiment. Compliances were calculated for the low- and high-pressure segments of the pressure–volume curves obtained since those were the parts that were nearly linear. The method of least squares was used to obtain "best fit" straight lines from the pressure–volume data. The compliance was then calculated as one over the slope of the "best fit" straight line in which pressure is plotted on the ordinate and volume is plotted on the abscissa. After completing each experiment, the animals were sacrificed and the common duct was removed. The length and diameter of the duct were measured in five dogs so that compliances could be reported per unit of surface area, and thus each dog could be compared.

Results. *Opening pressure of the sphincter.* A representative set of pressure–volume data for a specific flow rate for each dog studied is shown in Table I. The OP of the sphincter, at each flow, in all dogs is shown in Table II. The mean OP for all five dogs was 8.45 ± 0.37 (SE) cm H_2O.

Compliance with the sphincter excluded. Typical pressure–volume data obtained at specific flow rates after ligating the duct proximal to the sphincter of Oddi is shown in Table III. Compliance was then calculated for both

TABLE III. REPRESENTATIVE PRESSURE–VOLUME DATA FOR FIVE DOGS WITH THE SPHINCTER TIED OFF

304[a] Flow—11.5 μl/sec		311[a]		422[a]		506[a]		513[a]	
V	P	V	P	V	P	V	P	V	P
0	0	0	0	0	0	0	0	0	0
11.5	0.5	115	3.0	40	1.0	40	1.0	75	1.0
23.0	1.0	230	6.0	80	2.0	80	3.0	150	3.0
46.0	2.0	345	8.0	120	3.0	120	5.0	255	4.0
69.0	2.3	460	12.0	160	5.0	160	7.0	300	5.0
92.0	3.1	575	18.0	200	6.0	200	10.0	375	7.0
115.0	4.0	690	31.0	240	7.0	240	15.0	450	8.0
138.0	7.0	713	35.0	280	9.0	280	21.0	525	10.0
161.0	7.5			320	12.0	320	32.0	600	12.0
184.0	10.4			360	17.0	324	35.0	675	15.0
207.0	14.5			400	26.0			750	18.0
230.0	19.5			432	35.0			825	23.0
253.0	27.5							900	31.0
264.0	30.5							915	35.0
276.0	35.0								

Note. V = volume (μl); P = pressure (cm H_2O).
[a] Number of dog.

TABLE IV. COMPLIANCE OF THE COMMON DUCT WITH THE DISTAL DUCT LIGATED

Dog	Flow (μl/sec)	Compliance (μl/cm H_2O) Early (low pressure)	Late (high pressure)
212	2.33		5.48
	5.88		4.62
	11.5		5.26
	22.22		3.37
304	5.88	20.53	3.36
	11.5	22.00	3.61
	22.22	23.69	4.67
311	5.88	35.64	5.54
	11.5	46.30	6.57
	22.55	46.25	7.07
422	4	35.85	3.37
	8	36.67	3.73
	15	43.22	3.64
506	4	25.07	3.64
	8	34.70	3.24
	15	32.27	2.95
513	4	43.74	8.53
	15	59.45	8.25
	8	46.97	9.68

the high- and low- (below previously measured OP with the sphincter intact) pressure ranges (Table IV). The compliance was consistently higher at lower pressures at all flow rates. There was no consistant relationship between compliance and flow rate.

Analysis of compliance in all dogs. The various compliances for each experimental condition at different flows were averaged together for each dog and the results are shown in Table V. The highest compliances measured were at low pressures for each dog. In Table VI, the compliances recorded in Table V were changed to compliance per unit surface area so that the data for all dogs could be combined.

TABLE V. COMPLIANCE OF EACH DOG WITH THE SPHINCTER TIED OFF

Dog No.	Compliance (μl/cm H_2O) Low pressure	High pressure
212		4.45
304	22.01	3.93
311	44.5	6.57
422	38.6	3.58
506	30.84	3.19
513	46.47	8.20

TABLE VI. COMPLIANCE PER UNIT AREA FOR FIVE DOGS WITH SPHINCTER TIED OFF

Compliance[a] (μl/cm H_2O/mm^2) Low pressure	High pressure
$11.0 \pm 1.4 \times 10^{-2}$	$1.7 \pm 3 \times 10^{-2}$

[a] Plus or minus 1 SE.

Discussion. Although many investigators have studied pressure and flow characteristics of the common duct as well as a resistance across the sphincter of Oddi, the compliance or storage capacity of the duct has not been taken into account. The common duct is not merely a conduit for the passage of bile from the liver or gallbladder to the duodenum; it has a capacity to store a variable amount of bile itself. Physiologically the common bile duct is never empty of bile and knowledge of its compliance is important in understanding how it functions.

In the nonobstructed duct, with an intact sphincter of Oddi, we found opening pressures that were consistent with reports of other investigators. (13–16). The compliance of the obstructed duct was found to be highly dependent on the pressure range studied. At physiologically low pressures that are normally found in the common duct, compliance was high, whereas at high pressures the compliance was quite low. The low compliance at these high pressures is probably due to the fact that the tissue of the duct wall is at maximum stretch and thus has an increased elasticity.

The compliance of the obstructed duct was found to be nonlinear over the whole range of pressures measured. At physiologic pressures below OP and at high pressures, the compliance was linear. No relationship between compliance and rate of flow was demonstrated in the obstructed duct. Since the compliance is mostly a function of the properties of the duct wall itself, this finding is not surprising.

This study has characterized some of the compliant characteristics of the obstructed canine common duct. We feel that the storage capacity of the duct is an important physio-

logic property and must be taken into account in pressure and flow studies.

1. Crispin JS, Chin YE, Dau TK, Wiseman GH, Gillespie DJ, Lind JF. A direct manometric study of the canine choledochoduodenal junction. Arch Surg **101**:215–218, 1970.
2. Hallenbeck GA. Biliary and pancreatic intraductal pressures. In: Code CF, ed. Alimentary Canal. Baltimore, Williams & Wilkins, Vol II:pp1007–1025, 1967.
3. Hauge CW, Mark JBD. Common bile duct motility and sphincter mechanism. I. Pressure measurements with multiple-lumen catheter in dogs. Ann Surg **162**:1028–1038, 1965.
4. Menguy RB. On the physiology of the pancreatic and biliary ducts in the dog. (Thesis). University of Minnesota, Minneapolis, 1957.
5. Murphy JJ, Tansy MF. Motor function of the extramural portion of the canine common bile duct. Surg Gynecol Obstet **153**:19–27, 1981.
6. Parry EW, Hallenbeck GA, Grindlay JH. Pressures in the pancreatic and common ducts. Arch Surg **70**:757–765, 1965.
7. Liedberg G, Halabi M. The effect of vagotomy on flow resistance at the choledochoduodenal junctions. Acta Chir Scand **136**:208–212, 1970.
8. Scott GW, Smallwood RE, Rowlands S. Flow through the bile duct after cholecystectomy. Surg Gynecol Obstet **140**:912–918, 1975.
9. Wlodzimierz JO, Scott GW, Rodkiewicz CM. A comparison of resistance to flow through the cystic duct and the sphincter of Oddi. J Surg Res **27**:68–72, 1979.
10. Berci G. The behavior of foreign bodies (imitated "Gallstones") in the extrahepatic biliary system. Amer J Surg **108**:250, 1964.
11. Hendrickson WF. A study of the musculature of the entire extrahepatic biliary system, including that of the duodenal portion of the common bile duct and of the sphincter. Johns Hopkins Hosp Bull **9**:221, 1898.
12. Ludwick JR. Observations on the smooth muscle and contractile activity of the common bile duct. Ann Surg **164**:1041–1050, 1966.
13. Beneventano TC, Rosen R, Schein CJ. The physiological effect of acute vagal sectionon canine biliary dynamics. J Surg Res **9**:332–334, 1969.
14. Dardik H, Gliedman M, Christ R, Koslow A. Neuroendocrine influences on the dynamics of the choledochal sphincter. Surg Gynecol Obstet **131**:675–678, 1970.
15. Ivy AC. The physiology of the gallbladder. Physiol Rev **14**:1–102, 1934.
16. Tansy MF, Innes DL, Martin JS, Kendall FM. An evaluation of neural influences on the sphincter of Oddi in the dog. Dig Dis **19**:423–437, 1974.

Received July 26, 1982. P.S.E.B.M. 1983, Vol. 173.