Gastroenterologia Japonica
Vol. 12, No. 3

Printed in Japan

—Original Article—

INTRAOPERATIVE MEASUREMENT OF THE BILE FLOW RESISTANCE IN THE TERMINAL PORTION OF THE COMMON BILE DUCT AND ITS CLINICAL SIGNIFICANCE IN BILIARY SURGERY

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Summary

A practical method, safe and relatively simple to perform, which we have developed for the intra-operative measurement of the resistance to bile flow in the terminal portion of the common bile duct is described. This method performed routinely in conjunction with the operative cholangiography in the operating room, proved to be a powerful diagnostic aid for detecting abnormalities in the terminal portion of the common bile duct. In gallstone disease, the results by this method were compared with the operative results. It was found that minimal organic changes or functional disturbances in the terminal portion of the common bile duct, even those without jaundice, can be detected, and unnecessary choledochotomy or sphincteroplasty avoided. This method has a further advantage in that it gives universality to the resistance R and the residual pressure P as quantitative discriptive indices for the qualitative state of bile flow in the terminal portion of the common bile duct, and, if adopted as a standard and routine method, should make the comparison of works by different investigators easier and more significant.

Key Words: *bile flow resistance, cholangiomanometry, sphincteroplasty, choledochotomy, sphincter of Oddi.*

The terminal portion of the common bile duct plays an important role in the bile flow into the duodenum. In order to improve the results of biliary surgery, particularly for gallstones, it is necessary to recognize the abnormalities of the biliary system, especially those in the terminal portion of the common bile duct[1]. These deficiencies have led to numerous failures in biliary surgery. Although the operative cholangiography has been widely used for this purpose, the estimation of the functional status as well as the pathologic changes in the terminal portion of the common bile duct still seems to be unsatisfactory. The methods for measuring the intraductal pressure during surgery to cover the disadvantage of the operative cholangiography have been developed. These methods, however, vary with the investigators and are not always simple to perform. In addition, it is difficult to evaluate or compare the results, because the values obtained are not universal nor standardized numerical values. The fact that the relationship between changes of the intraductal pressure and changes of the volume of physiological saline solution irrigated into the bile duct is linear, led us to attempt the evaluation of the functional and organic condition of the terminal portion of the common bile duct by calculating the resistance

against bile flow in the terminal portion as numerical values.

Apparatus and Method of Measurement

A pump for irrigating the bile duct, a manometric tube mounted along a ruler for the measurement of the intraductal pressure, and an adjoining tube are connected via a three-way stopcock as shown in **Fig. 1**, then set up on the perfusion apparatus (**Fig. 2**). The core of the measuring apparatus is the infusion pump (Holter 911 Roller pump*) which is small and light weighted, with an adjustable flow volume change of as much as ten times or over and the small flow vibration is set symmetrically with a pair of silicone pumping chambers. By connecting these chambers in parallel, the pulsative change of flow can be more or less completely eradicated. The flow rate is changed by turning the knob of the pump, and indicated by an ammeter with scaling from one to six (**Fig. 3**). The relationship between the flow and the calibration using the chamber PC-7025 of this apparatus is shown in **Fig. 1**. The first step in operating the pump is to fill the apparatus with sterile physiological saline, and to expell

Fig. 2. Picture of the apparatus. The zero point is adjusted by the pedals marked UP and DOWN.

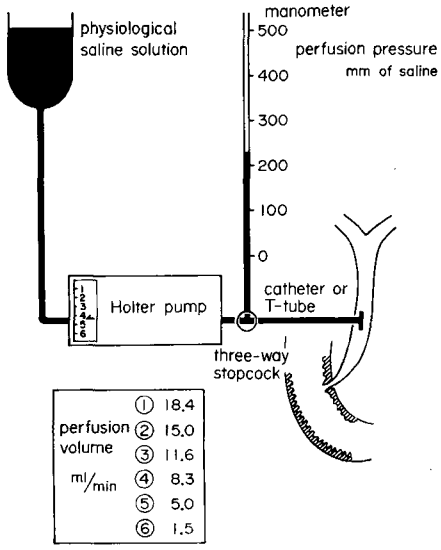

Fig. 1. Schematic drawing showing arrangement of the apparatus.

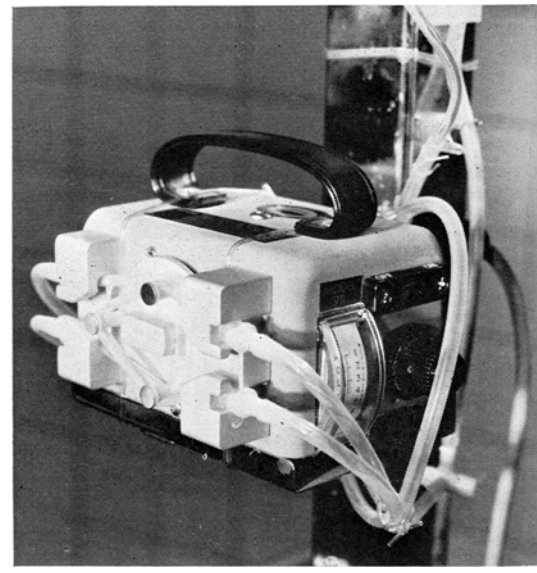

Fig. 3. Illustration of the infusion pump (Holter pump) with a pair of silicone pumping chambers (PC-7025) set symmetrically, and tubes connected parallelly.

*Extracorporeal Medical Specialties, Inc. Royal & Ross Rds. King of Russia, Pa, 19406 U.S.A.

air bubbles. The next step is to decrease the pump speed, and to drip the physiological saline continuously from the tip of the connecting tube. Then the advanced tip of the connecting tube is kept at the height of the papilla of the duodenum of the patient under laparotomy. By stepping on the pedals of the apparatus, the zero point of the manometer scale is adjusted to O level. The error at the zero point can be avoided by keeping the irrigating volume minimal and by keeping the dripping of saline from the tip of the connecting tube continuous.

Operative cholangiography is done before performing the intraductal pressure measurement via a catheter inserted into the common bile duct through the cystic duct after cholecystectomy, or via a T-tube after choledochotomy. Subsequently the connecting tube is joined to the catheter or the T-tube, and the biliary tree is filled with saline by increasing the flow volume (by turning the pump), waiting until a stable manometric pressure level of not exceeding 500 mm plysiological saline is obtained. Unless there is a marked dilatation of the bile duct, the surface level of manometer becomes stable within a minute and fluctuates only with respiration. Then the reading of manometer pressure is done by decreasing the flow volume in a stepwise fashion with each scaling of the pump, and the values so taken are plotted on a graph as shown in **Fig. 4**. These plots more or less lie on a straight line. If the tip of the catheter or the tube is in contact with the wall of the bile duct, or if contraction of the duodenum occurs, the line joining the plots will not be a straight line. In such cases it is necessary to repeat the measurement. The measurement described above should be carried out within several minutes while waiting for the developed films of the operative cholangiography to be returned.

The straight line plotted on the chart crosses the zero line of the flow volume at a certain pressure level. This crossing point is named as P. P is equivalent to the residual pressure by the conventional method, and shows the capacity of the terminal portion of the common bile duct for maintaining the intraductal pressure. The slope of this straight line expresses the magnitude of resistance in the terminal portion of the common bile duct against the flow. Therefore, the resistance can be expressed as a numerical value by dividing changes of the perfusion pressure by changes of the flow volume just as the electric resistance is calculated by dividing the voltage by the current. The resistance so obtained includes the resistances of the connecting tube of the apparatus and of the radiographic catheter or the T-tube added in series, therefore, the resistance value R in the terminal portion of the common bile duct of the patient is obtained by subtracting these resistance values measured beforehand by the same method, as shown in **Fig. 4**. Unlike electric resistance, the pressure

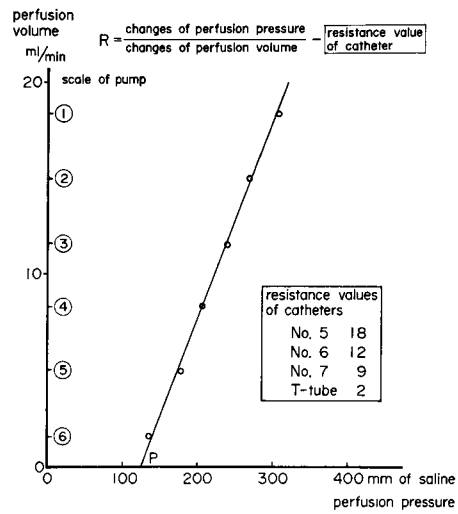

Fig. 4. Calculation of the resistance value of the terminal portion of the common bile duct.

reading indicates P mm of saline instead of O mm at the level of O flow volume. Thus with this method, we can evaluate the state of the terminal portion of the bile duct against bile flow by the slope R and the location P of the straight line. We take these two indices as one and designate it as R (P mm).

Results

The method described above was performed routinely in the operating room and the resistance of the terminal portion of the common bile duct was calculated and compared with the operative results in 329 patients who underwent biliary surgery at Keio University Hospital and National Tochigi Hospital, over a period of five years from 1970 to 1974 including 174 cholecystolithiasis, 123 choledocholithiasis and 32 non-calculous cholecystitis. R (P mm) of these cases was plotted as shown in **Fig. 5, 6, 8** and **9**. All of non-calculous cholecystitis except one (**Fig. 5**) and most cases of cholecystolithiasis (**Fig. 6**) remained below R 20 and P 200 mm, therefore, we defined the area bounded by R 20 and P 200 mm as normal. In cases of cholecystolithiasis, only eight cases showed R exceeding 20 and all remained below 100 except one case with a maximum rise of 177. For this exceptional case, the transduodenal sphincteroplasty was performed, because the stenosis of the duodenal papilla was seen in the operative cholangiography. Pathohistologically this case presented a marked fibrosis of the duodenal papilla (**Fig. 7**), and

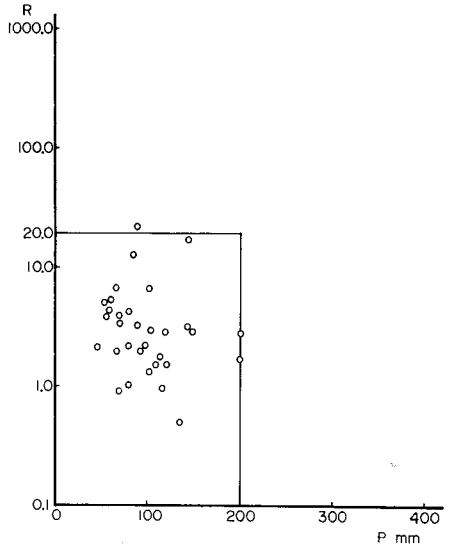

Fig. 5. Cases with non-calculous cholecystitis and cystic duct syndrome.

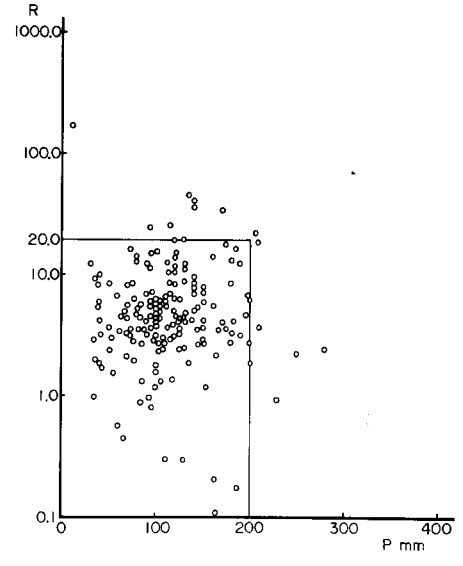

Fig. 6. Cases with cholecystolithiasis.

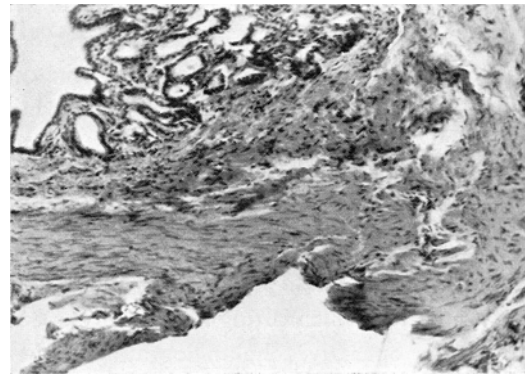

Fig. 7. Duodenal papilla. Marked fibrosis is observed.

its postoperative course was uneventful. About one third of the cases with choledocholithiasis were outside the normal range before the removal of intraductal stones (**Fig. 8**). Strikingly, in all cases with non-impacted ampullar stones R was over 100 and P below 100 mm. Also in the cases with impacted stones in the duodenal papilla resulting in jaundice, the values of R were extremely high and unmeasureable.

There was quite a number of cases with intraductal floating stones in which R exceeded 20, and after their removal only few cases had R exceeding 20. A high P level was found in very few cases (**Fig. 9**).

A functional intraductal hypertensive status was created by pharmaceutically inducing contraction of the sphincter of Oddi and the changes in R and P were observed. For this purpose patients with a T-tube inserted into the common bile duct and with a post surgical period of over two weeks were selected. 10 mg of morphine sulphate was administered intramuscularly in the fasting state. R and P were measured within 7–12 minutes of its administration, and they were compared with the values measured before the administration

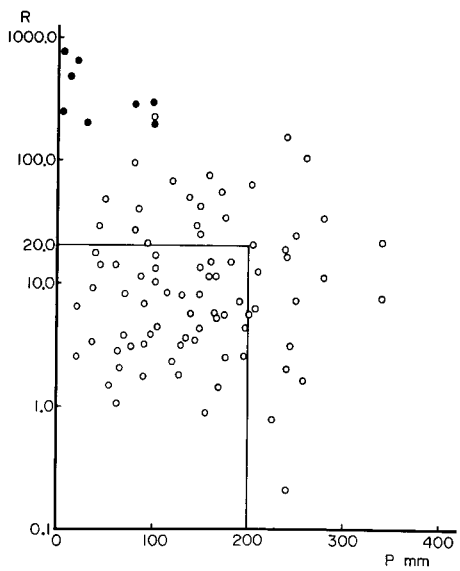

Fig. 8. Cases with choledocholithiasis. Before removal of intracholedochal stones.
● Cases with non-impacted ampullar stones.

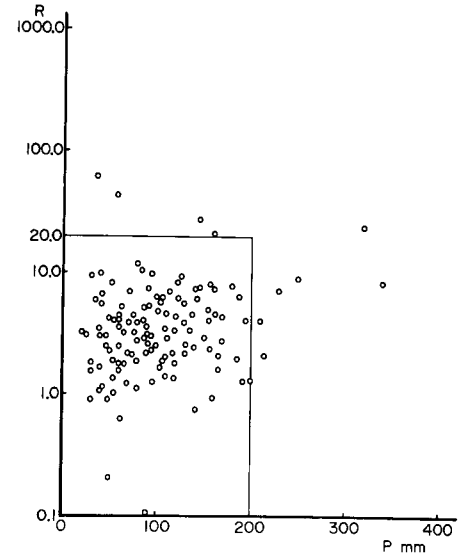

Fig. 9. Cases with choledocholithiasis. After removal of intracholedochal stones.

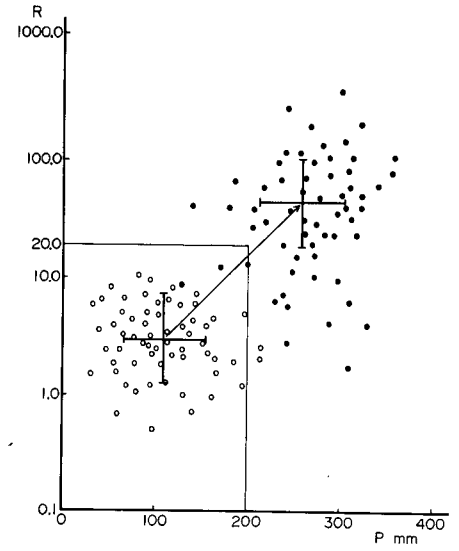

Fig. 10. Changes of R (P mm) by administration of morphine sulfate.
○ Before administration.
● After administration.
⊹ Mean values of R (P mm).

of the drug. Both R and P were elevated after the administration of morphine as shown in **Fig. 10**. Especially the rise of P was striking but the rise of R over 100 was observed in only several cases and there were no cases with R exceeding 400. Although few in number, in cases with sphincteroplasty performed for removing impacted stones, morphine sulfate was administered in the same manner and only a slight elevation of R and P was seen as expected. The rise in P probably reflects the rise in the intraduodenal pressure.

Discussion

The hypothesis that the intraductal pressure is elevated abnormally when the bile flow into the duodenum is disturbed by functional or organic abnormalities in the terminal portion of the common bile duct gave birth to the method for measuring the intraductal pressure in order to evaluate the state of bile flow in the common bile duct. From the experimental study by Judd and Mann[2], the method of measuring the intraductal pressure advanced to the clinical application by McGowan[3] and Doubilet[4]. These methods, however, are various and so far no standardized method has been established, making the evaluation and comparison of works by different investigators confusing and difficult. In order to measure the true intraductal pressure, special care must be paid to avoid the interference by surgical maneuvers and unexpected effect created by the dead space of the measuring apparatus. If the sphincter of Oddi contracts suddenly the elevation of intraductal pressure will be delayed due to the small amount of bile secretion per unit time. Therefore, the real situation of contraction will not be reflected in the measurement. To cover these disadvantages, methods in which the common bile duct is irrigated with physiological saline making a more precise observation of changes in intraductal pressure possible has gained wide acceptance. Two methods are popularly employed: the constant perfusion pressure method[5,6] and the constant perfusion volume method[4,7]. In the first method the state of passage in the terminal portion of the common bile duct is observed by irrigating it with physiological saline under constant pressure. In the latter method the state of passage is observed from the changes in intraductal pressure produced by irrigating the common bile duct under a constant flow volume of 1–3 ml per minute. In the constant perfusion volume method, the intraductal pressure fluctuates from one extreme to another depending on whether the perfusion volume is large or small (e.g. the existence of stenosis). In the constant pressure method the actual intraductal pressure exerted on the terminal portion of the common bile duct changes due to the fact that the resistance to flow will vary with the measuring apparatus or with the size of catheters used; therefore, the intraductal pressure observed will fluctuate accordingly. In addition, these methods can show whether the passage of flow is good or bad, but they cannot show the hardness, the elasticity, or the pressure retaining capacity in the terminal portion of the common bile duct. Thus, one point measurement alone by the constant perfusion pressure method or the constant perfusion volume method, and the mere determination of residual pressure or passage pressure[8] are insufficient for evaluating the functional status or organic changes in the terminal portion of the common bile duct. Therefore, the necessity for a dynamic observation of the changes produced by altering either the perfusion volume or the perfusion pressure is now generally recognized[9,10]. Using a DeBakey pump, Newman and Northup[11] varied the perfusion volume between

0 and 20 ml per minute, and from the changes in intraductal pressure so produced discussed the spasm of the sphincter of Oddi and partial organic obstruction in the terminal portion. Boulter[12] measured the proportional changes in perfusion volume by making stepwise alterations in perfusion pressure, and from the pressure and flow relationship so obtained investigated the difference in the state of flow in the terminal portion of the common bile duct between cases with sphincterotomy and cases with intact sphincter. With our method the relation between the perfusion volume and the intraductal pressure is shown as a straight line on a graph. The slope of this straight line shows whether the passage is good or bad; therefore, it indicates the resistance R in the terminal portion of the common bile duct. The resistance values of catheters or T-tubes including those of the connecting tubes and of the measuring apparatus are calculated beforehand. The true resistance in the terminal portion of the common bile duct is given by subtracting these resistance values. The straight line passes on the point of P mm instead of O mm at the level of zero flow, and this indicates the theoretical residual pressure. The reason that we do not take the actual residual pressure is that the residual pressure is equivalent to the intraduodenal pressure itself (disregarding the capillary phenomenon), if an obstructive insufficiency in the terminal portion of the common bile duct exists even though it is due to a stenosis. There is originally no relationship between P as an expression of the ability for maintaining intraductal pressure in the terminal portion of the common bile duct and R as a qualitative expression of flow. However, according to the usual measurement of the residual pressure alone, they may be confused with each other. Boulter[12] reported that, in normal cases, the relationship between flow and pressure revealed a curved line in the area where the perfusion pressure is low, and we also recognized similar results. This seems to be due to the elasticity of the terminal portion of the common bile duct: therefore, in order to eliminate the error we take P corresponding to the theoretical residual pressure disregarding the part of the line with curving. In our method, we have defined tentatively the normal range as R below 20 and P between 100 mm and 200 mm.

Further, by taking the logarithm of R as the vertical and P as the transverse axis, and from the sites of R and P on the graph, we tried to evalute the state of flow in the terminal portion of the common bile duct and to determine whether the insufficient flow is due to organic changes or functional abnormalities. If stenosis of the terminal portion of the common bile duct with loss of elasticity, which may be referred to as an organic biliary hypertension, exists the flow is inadequate simulating flow through a fine injection needle, and the pressure retaining ability is small. In such cases, R is high and P which is equivalent to intraduodenal pressure is low, and R and P will occupy a point on the left upper portion of the graph. After sphincteroplasty or choledochoduodenostomy with a wide anastomosis, which may be referred to as organic biliary hypotension, R and P will occupy the left lower portion of the graph. The remaining right lower portion of the graph shows cases with a certain condition of biliary hypertension in which bile flows freely into the duodenum if the perfusion pressure exceeds the intraduodenal pressure. Thus, with this method, it is possible to show a comprehensive relationship between the intraductal pressure and the bile flow through the bile duct into the duodenum, substantiating the fact that the intraduodenal pressure greatly affects the intraductal pressure as elaborated by Newman and Northup[11] in

their work.

From the specific location of R and P it is possible to determine if the case is normal or if it belongs to the organic biliary hypertension or hypotension group (**Fig. 11**). To the organic biliary hypertension I belong cases of non-impacted ampullar stones (A condition which cannot be induced by the contraction of the terminal portion alone) or cases of organic stenosis, and is an absolute indication for the common duct exploration or sphincteroplasty. In the area of biliary hypertension II, the organic stenosis occupy the low P area. For these cases, a further operative intervention is determined and indicated on the individual basis referring the findings of the operative cholangiography as a further aid. The cases belonging to the biliary hypertension III are excluded from the indication for choledochotomy and the cases with biliary hypotension are similary treated. The existence of intraductal stones cannot be denied, even if R and P are within normal range; therefore, the operative cholangiography must be performed with each measurement.

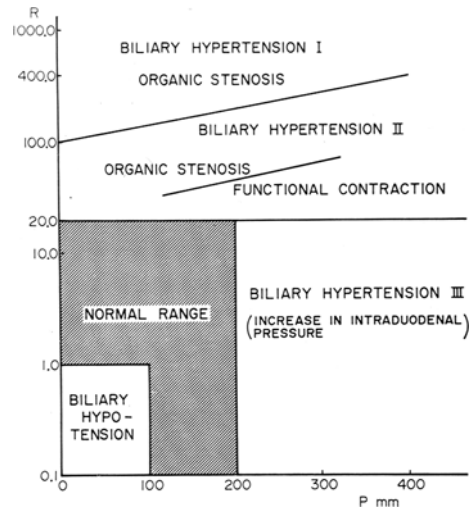

Fig. 11. Evaluation of the status of the terminal portion of the common bile duct by R (P mm).

The organic changes in the terminal portion of the common bile duct are generally considered as an important cause of the post-cholecystectomy syndrome, however, according to our comparative study between the resistance values in the terminal portion of the common bile duct and the over one year post operative results, such cases are fewer than expected. All cases with non-impacted ampullar stones naturally showed the state of organic biliary hypertension. Functional biliary hypertension is observed in a considerable number of cases with floating intraductal stones and in cases immediately after the removal of intraductal stones. It is probably due to the reflex spasm in the terminal portion of the common bile duct caused by the presence of stones or by the manipulation in removing them. There were no cases with the state of organic biliary hypertension once intraductal floating stones have been removed. Accordingly, sphincteroplasty is not indicated merely because the bile duct is dilated or intraductal stones exist. In order to examine the existence of stenosis in the terminal portion of the common bile duct during surgery, a Bakes' dilator is occasionally passed[13]. However, it is well known that spasm of the sphincter of Oddi and ampullary edema are caused by this maneuver[14,8]. We found a marked elevation of both R and P after this procedure; therefore, we consider this maneuver not only useless but also confusing once the operative cholangiography and the measurement of R and P are done.

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Received March 25, 1977
Accepted April 18, 1977
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