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ELECTROCHOLEDOCHOGRAM: A STUDY OF THE ELECTROMECHANICAL ACTIVITY OF THE COMMON BILE DUCT IN THE DOG

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1. ABSTRACT

The electromechanical activity of the common bile duct (CBD) was studied in 11 dogs aiming at elucidating the mechanism of bile transport through the CBD as well as at characterizing a normal electrocholedochogram that could act as a standard for the pathologic conditions. After opening the abdomen under anesthesia and exposing the CBD, the electric activity of the CBD was recorded by 2 electrodes sutured to its serosa and the pressure registered by a perfused catheter introduced into the CBD. The effect of CBD distention and myotomy on its EMG activity was tested. Slow waves or pacesetter potentials (PPs) were recorded exhibiting the same frequency, amplitude, and velocity of conduction from the 2 electrodes of each dog on all test days. They were followed by action potentials (APs) which were inconsistent and associated with a rise in the CBD pressure. These variables were higher postcibally than in the fasting state ($p < 0.05$). They increased on balloon-produced distention of the CBD. The caudad direction of PPs and APs was evident when, following the CBD myotomies, the signals appeared from the segment proximal but not distal to the cut. The study demonstrated that the CBD possesses an electric activity which seems to be responsible for the motile activity of the duct. Furthermore a normal "electrocholedochogram" was characterized which is expected to exhibit changes in pathologic conditions of the CBD. It is proposed that the electrocholedochogram could act as an investigative tool in the diagnosis of CBD disorders, provided it could be performed transcutaneously.

2. INTRODUCTION

The common bile duct (CBD) transmits the bile from the gall bladder (GB) to the duodenum through the sphincter of Oddi (SO). It is lined by a mucous membrane that consists of simple columnar epithelium. The lamina propria is thin and surrounded by a smooth muscle layer that becomes thicker near the duodenum and, in the intramural portion, forms the sphincter of Oddi (1,2).

Like the rest of the gut (3-12), the CBD is assumed to have electromechanical activity which might share in its motility. Electrograms could be recorded for the different parts of the gut. Percutaneous electrograms have been registered for the stomach (13), the rectum (14) and sigmoid colon (15, 16) in normal and pathologic conditions. They have been used as investigative tools for the diagnosis of various pathologic lesions.

The purpose of the current communication was to study the electromechanical activity of the CBD aiming at a better understanding of the mechanism of bile transport through the CBD as well as the characterization of a normal electrocholedochographic pattern. The latter might act as a standard for the diagnosis of the different pathologic conditions of the CBD, especially those affecting its motility. The study was approved by our Faculty Review Board.

3. MATERIAL AND METHODS

3.1 Materials

The study comprised 11 mongrel dogs (7 male and 4 female) with a mean weight of 13.6 ± 3.2 SD kg

3.2 Methods

The animals were fasting during the night. They were premedicated with subcutaneously injected acepromazine (0.15 mg/kg) and anesthetized with

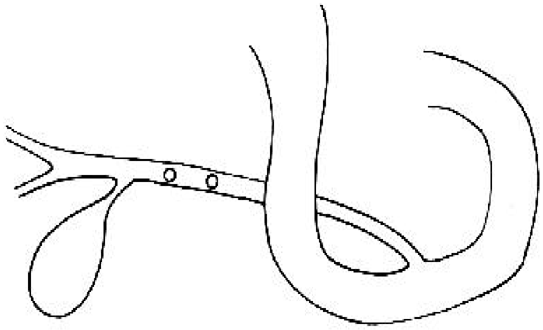

Figure 1: Diagram illustrating the site of the electrodes applied to the common bile duct.

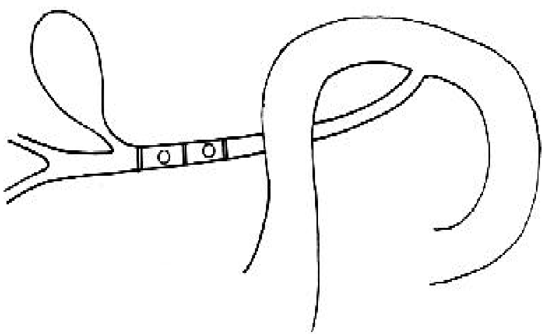

Figure 2: Location of the common bile duct myotomies.

intravenous sodium pentobarbital (35 mg/kg) given as a bolus injection at 20-25 mg/hour to maintain adequate anesthesia with spontaneous respiration. All dogs were intubated to assist ventilation.(range 11-16). The animals were selected from a population with normal liver functions and a normal CBD on sonographic examination. The dogs were put into cages one week prior to the study to get accustomed to the facilities. They were treated in compliance with the "Guide for the Care and Use of Laboratory Animals" (17).

The abdomen was opened through an upper midline incision, and the GB, CBD, and duodenum were exposed. The canine CBD has a free and an intramural portion (18). The free portion, approximately 5 cm long and 2.5 mm in diameter, courses through the lesser omentum. The intramural portion measuring 1.5-2.0 cm in length, extends obliquely through the duodenal wall and is surrounded by the sphincter of Oddi (SO).

The electric activity of the CBD was recorded by means of monopolar silver-silver chloride electrodes of a diameter of 0.8 mm each and covered with an insulating vinyl sheath sparing its tip (Smith-Kline Beckman, Los Angeles, CA, USA). Two electrodes were sutured, 1.5 - 2 cm apart, to the serosa of the free portion of the CBD, using a 5/0 vicryl stitch for each electrode (figure. 1). A metal cannula containing a 2-pin socket to which the electrodes were attached, was sutured to the anterior abdominal wall.

The pressure within the CBD was measured by means of a 2F catheter which was introduced into the CBD through a puncture in its wall approximately 1 cm below the distal electrode. The catheter was fixed to the CBD by a 5/0 vicryl stitch. It had multiple side ports and a closed distal end to which a metallic clip was applied for fluoroscopic control. The catheter was connected to a pneumohydraulic capillary infusion system (Arndorfer Medical Specialities Greendale, WI, USA). The pump delivered saline continually via the capillary tube at a rate of 0.6 ml/min. The transducer outputs were registered on a rectilinear recorder (RS 3400 Gould Inc, OH, USA). Occlusion of the recording orifice produced a rate of rising pressure greater than 250 cm H_2O/s. Finally, the abdominal wound was closed and the dogs were allowed to awaken from anesthesia. The animals were given a 2-week resting period for wound healing prior to the start of the recordings.

Insulated wire leads were attached to the pins in the cannula and connected to a Brush Mark 200 rectilinear pen recorder. The electric activity including frequency, amplitude and velocity of conduction, was recorded from the 2 electrodes in each dog for periods of 30 minutes daily on 15 different days.

3.2.1 Balloon distention of the CBD

The effect of balloon-produced distention of the CBD on its electromechanical activity was tested in 4/11 dogs. The CBD was exposed as aforementioned. A 4F catheter tipped with a latex balloon of 2 mm in diameter (London Rubber Industries Ltd., London, UK), was introduced into the CBD through a puncture located 0.5-1 cm below the electrodes and was fixed to the duct by a 4/0 vicryl suture. The abdomen was closed. After 15 days to allow for wound healing, the balloon was inflated with 1 ml of carbon dioxide (CO_2). The controlled CO_2 source was the Heyer-Schulte CO_2 cystometer (Heyer-Schulte Corp, Goleta, CA, USA) which has a self-contained CO_2 system using disposable CO_2 cartridges. The CO_2 balloon filling was increased in increments of 0.25 ml to a total of 2 ml while the EMG activity was recorded.

3.2.2. CBD myotomy

The direction of propagation of the electric waves was examined by means of multiple CBD myotomies. Myotomy comprised division of the adventitia and muscle layer of the CBD down to, but not including the mucosa. This was performed with the aid of fine surgical instruments, bright light and a magnifying loupe. The CBD wall was so thin that caution was required to avoid injury to the mucosa. In 6 dogs, the CBD was exposed as aforementioned. An annular myotomy was performed proximally to electrode 1 in two dogs, between electrodes 1 and 2 in two dogs and distally to electrode 2 in two dogs (figure. 2). After a free period of two weeks to allow for abdominal wound healing, the electric activity was recorded in each dog for periods of 30 minutes daily for 10 days.

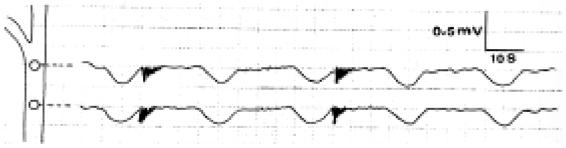

Figure 3: Electrocholedochogram in the fasting dog showing the pacesetter and action potentials recorded by the 2 electrodes applied to the common bile duct.

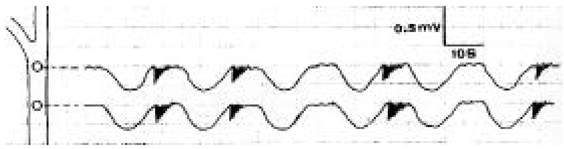

Figure 4: Postcibal electrocholedochogram of the dog of figure 3 showing increase in the frequency, amplitude and velocity of the pacesetter and action potentials.

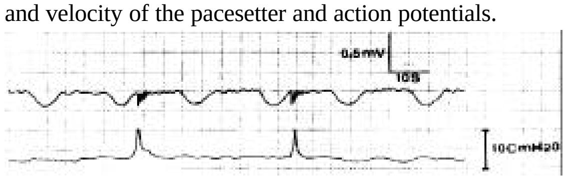

Figure 5: Fasting electrocholedochogram showing rise of the common bile duct pressure (lower tracing) synchronous with the action potentials (upper tracing). The pacesetter potentials were not associated with pressure rise.

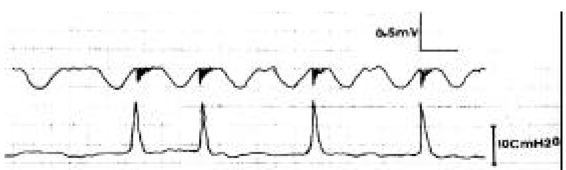

Figure 6: Postcibal electrocholedochogram of the dog of figure 5 showing that the pressure rise (lower tracing) associated with the action potentials (upper tracing) was higher than in the fasting animal.

3.2.3. Statistical analysis

The results were analysed statistically using the Student's t test. Differences assumed significance at $p < 0.05$, and values were given as mean ± standard deviation (SD).

4- RESULTS AND DISCUSSION

No adverse effects were encountered during or after operation. There was no electrode break or migration nor manometric or balloon catheter slip from the wound during the tests. All the animals were evaluated.

Electric activity. Slow waves or pacesetter potentials (PPs) were recorded from the 2 electrodes. The configuration of the wave was constant in all recordings from the same site. The wave was monophasic and consisted of a large negative deflection (figure 3). The PPs transmitted from the 2 electrodes in each dog had the same frequency, amplitude and velocity of conduction.

In the fasting dog, the PPs recorded a mean frequency of 3.1 ± 0.9 cycle/min (cpm), an amplitude of 0.32 ± 0.04 mV and a velocity of conduction of 2.8 ± 0.9 cm/s. (table 1, figure 3) Postcibal recordings showed a significant increase of these variables ($p < 0.05$, table 1, figure 4).

Bursts of fast activity spikes representing action potentials (APs) were recorded (figures 3,4). They consisted of negative deflections and followed the PPs. They did, however, not follow every PP and their frequency was inconsistent in each individual dog.

4.1 Manometric study

The basal CBD pressure recorded a mean of 5.8 ± 1.2 cm H_2O (range 4-8). Simultaneous recordings of electric activity and CBD pressure in the fasting state showed that the APs were associated with a significant rise in CBD pressure which recorded a mean of 8.6 ± 1.9 cm H_2O ($p < 0.05$, range 6-11, figure 5). The CBD pressure did not increase with the PPs.

Postcibally, the CBD pressure increased during the bursts of APs. The pressure rise was greater than the one recorded in the fasting state (figure 6). The CBD pressure registered a mean of 18.8 ± 4.2 cm H_2O ($p < 0.01$, range 14-26). A pressure rise in association with PPs did not occur.

4.2 Electromechanical activity and balloon distention

Balloon distention of the CBD led to increase in frequency, amplitude and velocity of conduction of the PPs and APs. The levels of these variables increased with the increase of the distending volume (table 2). Although frequency, amplitude, and velocity of conduction of the APs increased, yet they were inconsistent and the variables varied when the recording in the individual animal was repeated. We did not distend the balloon with more than 2 ml for fear of injury or rupture of the CBD.

4.3 CBD myotomy

Owing to the aforementioned precautions during the performance of the CBD myotomy, the mucosa was not torn in any of the operated animals. The electric activity was recorded from the electrodes proximally but not distally to the myotomy (figure 7). When the myotomy had been performed proximally to the two electrodes, no electric activity was recorded. Electric waves were registered from electrode 1 when the myotomy was done between the two electrodes, and from both electrodes when it had been performed distally to the two electrodes.

During the study no abnormal waves or retrograde electric activity were recorded. The aforementioned results were obtained from all of the studied animals. They were reproducible with no significant difference ($p > 0.05$) when the tests were repeated in the same dog. Furthermore, the effects were permanent during the period of the study.

The current study demonstrates the presence of electric activity of the CBD in the form of PPs and APs. The waves were transmitted along the duct from the first electrode to the second as evidenced by the similarity of the waves obtained from the 2 electrodes of each dog. The APs, and not the PPs, were associated with CBD pressure rise, denoting that they probably have a motile activity. This agrees

Table 1: The frequency, amplitude and velocity of conduction in the fasting animal and postcibally+.

Status	Frequency (cpm)		Amplitude (mV)		Velocity (cm/s)	
	Mean	Range	Mean	Range	Mean	Range
Fasting	3.1±0.9	2-4	0.32±0.04	0.15-0.46	2.8±0.9	1.5-3.5
Postcibal	5.4±1.6*	3-7	0.53±0.07*	0.4-0.7	4.4±1.1*	3-8

+ Values are given as mean ± standard deviation. *p* values of 'postcibal' were compared to the 'fasting'. values * $p < 0.05$

Table 2: The frequency, amplitude and velocity of conduction of the pacesetter potentials at different volumes of common bile duct distention+.

Distending volume (ml)	Frequency (cpm)		Amplitude (mV)		Velocity (cm/s)	
	Mean	Range	Mean	Range	Mean	Range
Basal	3.1±0.9	2-4	0.32±0.04	0.15-0.46	2.8±0.9	1.5-3.5
1	4.6±1.1*	3-6	0.42±0.08*	0.25-0.55	3.6±1.1*	2.0-4.2
1.25	5.8±1.3*	4-8	0.51±0.08*	0.36-0.68	4.8±1.3*	3.7-6
1.5	6.2±1.6*	4.5-11	0.53±0.1*	0.42-0.75	5.6±1.2*	4.4-6.8
1.75	7.3±1.5**	6-12	0.86±0.11**	0.58-0.95	6.3±1.6**	5.1-7.3
2.0	7.6±1.4**	7-12	0.91±0.12**	0.60-0.98	6.5±1.8**	5.8-8

+Values are given as mean±standard deviation. *p* values were compared to the 'fasting'. values * $p < 0.05$**. $p < 0.01$

with the observation of CBD motile activity by cineradiography which was attributed by some investigators to the contractions and milking effect of the duodenal peristalsis (1,19).

The waves spread caudad towards the duodenum as is evident from the myotomies which interrupt the distal propagation of the PPs and APs beyond the cut. These waves probably direct the bile flow from the liver towards the duodenum. During our study we did not encounter abnormal or retrograde waves that might interfere with the bile drainage to the duodenum.

The increased frequency, amplitude and velocity of conduction of the electric waves upon CBD distention seem to designate an increase in its motile activity and consequently an increased bile transport through the CBD. Thus CBD distention presumably occurs when the GB contracts to evacuate its bile content into the CBD; it is associated with increased AP activity with a resulting rise of CBD pressure and motility and consequently of bile drainage.

The inconsistent occurrence of the APs points to irregular or non-rhythmic segmental CBD contractions. However, once they occurred, they were conducted caudally in a regular fashion like the PPs. Thus, the APs seem to cause a contractile sweep along the CBD. However, this contractile activity induces a small CBD pressure rise which is not clinically perceivable as pain. The basal inconsistent contractile waves induced by APs need to be activated when the GB tonically contracts releasing its contents into the CBD. It seems that this activation is effected by the CBD distention resulting from the tonic GB contraction. CBD distention appears to not only stimulate CBD contracile activity but to reflexly open the SO. A recent study has demonstrated that CBD distention effects SO dilatation, and this was mediated through the "choledocho-sphincter inhibitory reflex" (unpublished data).

4.4 Suggested mechanism of bile flow through the CBD

At basal conditions, the CBD electric activity effects a slight pressure rise within the CBD which appears to keep its contents in a minimal but continuous motion to avoid the complications of stagnation. The GB receives and stores bile from the liver until it becomes distended or, upon food ingestion, undergoes tonic contraction. The tonic GB contraction presumably distends the CBD which evokes the choledocho-sphincter inhibitory reflex with a resulting SO relaxation and bile passage to the duodenum. The SO relaxes only momentarily and closes again, although the CBD is still distended (unpublished data). More bile accumulation in the CBD evokes the reflex SO opening and the passage of bile to the duodenum. Thus bile is delivered to the duodenum in jets until the contents of the contracted GB has been completely drained to the duodenum. At this point the SO closes, leaving the bile coming in from the liver to accumulate in the empty GB. This cycle is then repeated.

4.5 The role of PPs and APs in the CBD motile activity

While the appearance of APs was associated with pressure elevation upon CBD distention and thereby defined their role in CBD motility, the exact role of PPs could not be determined from the results of the current study. The regular rhythm and caudad propagation of the PPs along the CBD suggest that they pace the CBD motile activity in terms of direction and frequency. With this concept, we postulate that the PPs initiate the APs as is evident from the fact that the APs invariably followed the PPs and have not been recorded separately.

4.6 Common bile duct pacemaker

The origin of the electric waves in the CBD might be neurogenic or myogenic. They may arise from the intra- or extramural nerves; yet the latter can be excluded as in the present study the CBD myotomy has interrupted the electric waves and blocked their propagation distally past the cut. Retrograde or abnormal electric waves did not occur and this indicates that the electric activity starts in the proximal part of the CBD where a "pacemaker" initiating this activity is suggested to exist. The myogenic origin of the waves cannot be excluded either, especially because the APs were associated with motile activity and the smooth musculature is known to have an electric activity. However, the origin of the CBD electric waves needs to be studied.

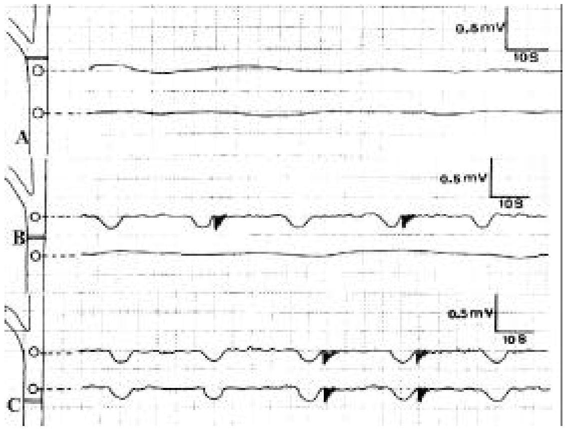

Figure 7: Electrocholedochogram after common bile duct myotomy, a. myotomy proximal to the 2 electrodes: no electric waves recorded, b. myotomy between the 2 electrodes: electric waves recorded from the proximal but not the distal electrode, c.myotomy distal to the 2 electrodes: waves recorded by the 2 electrodes.

In conclusion, the study has demonstrated that the CBD possesses an electric activity which is suggested to be responsible for the motile activity of the duct. The study, furthermore, could characterize a normal "electrocholedochogram" which is anticipated to reveal changes in the pathologic conditions of the CBD, in particular motility disorders. The electrocholedochogram is proposed to act as an investigative tool in the diagnosis of such disorders provided it could be performed transcutaneously.

5- ACKNOWLEDGMENT

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