J. W. KONTUREK, G. W. SCOTT, Y. J. KINGMA

ELECTRICAL ACTIVITY OF CANINE GALLBLADDER

Surgical-Medical Research Institute University of Alberta Edmonton, Alberta, Canada, T6G 2N8

Our aims were to describe the myoelectrical activity in the single very thin layer of muscle of the canine gallbladder. The study was performed on 22 freshly removed canine gallbladders. Electrical activity was studied by the single sucrose-gap method and contractility of the tissue was measured simultaneously using a force transducer. The strips (15×1 mm) from different regions of gallbladder (fundus, corpus, neck) were cut in longitudinal, circular and oblique axes. The sucrose-gap apparatus together with connecting tubes, solutions and electrodes were kept at 37°C and the initial tension applied to the tissue was set to 1 g. In 82.7% of recordings, spontaneous myoelectrical activity consisted of regular rhythmic changes in membrane potential similar to slow waves recorded in intestinal tissue. The overall mean frequency was 11.4 ± 5.2 (mean $\pm SD$) cycles per min: 11.1 ± 4.4 cycles per min in fundus, 11.9 ± 6.2 cycles per min in corpus and 10.8 ± 3.8 cycles per min in the neck of the gallbladder. In 84.2% of cases electrical activity correlated with mechanical activity and preceded it. No significant differences were seen between the electrical patterns in strips with different orientations or from the different regions of the gallbladder.

INTRODUCTION

The gallbladder performs two distinct but physiologically related functions. Firstly, it absorbs most of the water and electrolytes from dilute hepatic bile, thereby producing a similar volume of dark viscid bile. Secondly, during meals it contracts and delivers its contents into the small intestine to aid optimal fat absorption (1, 2, 3, 4). It has been shown also that during the interdigestive period the gallbladder contracts periodically and the contractions are always coincident with the end of phase II and the beginning of phase III of the migrating motor complex (5). In recent years gallbladder motion has been studied by several investigators using in vitro and in vivo methods such as radiography, measurements of bile flow, manometry, ultrasonography and the application of different types of force transducers (6, 7). Although the motility patterns themselves have been well investigated, knowledge about

intrinsic electromyographic activity that controls gallbladder contractions is still emerging. Relatively few studies have attempted to elucidate these mechanisms and the results remain inconsistent among different species (5, 6). Gallbladder musculature consists of a single layer of smooth muscle cells which form a mesh network which is not oriented in any particular direction. The muscle layer is very thin and in the case of canine gallbladder ranges from approximately 100 μ in the fundus 40 μ in its neck (8). Our aims were to determine if there was an electrical equivalent of the rhythmical contractions which can be recorded from gallbladder muscle strips in vitro. Our interest was also concerned with whether or not there were differences in the electrical activity in different regions of gallbladder or whether the gallbladder muscle operated as a coupled single unit.

METHODS

The study was performed on gallbladder strips obtained from 22 anesthetized (sodium pentobarbital 30 mg/kg) mongrel male and female dogs. The tissue was placed immediately in oxygenated Krebs' solution. The superficial connective tissue was removed and full-thickness wall strips (15×1 mm) from the fundus, corpus and neck were cut in longitudinal, circular and both oblique axes. Simultaneous measurements of electrical and mechanical activities of the strips were
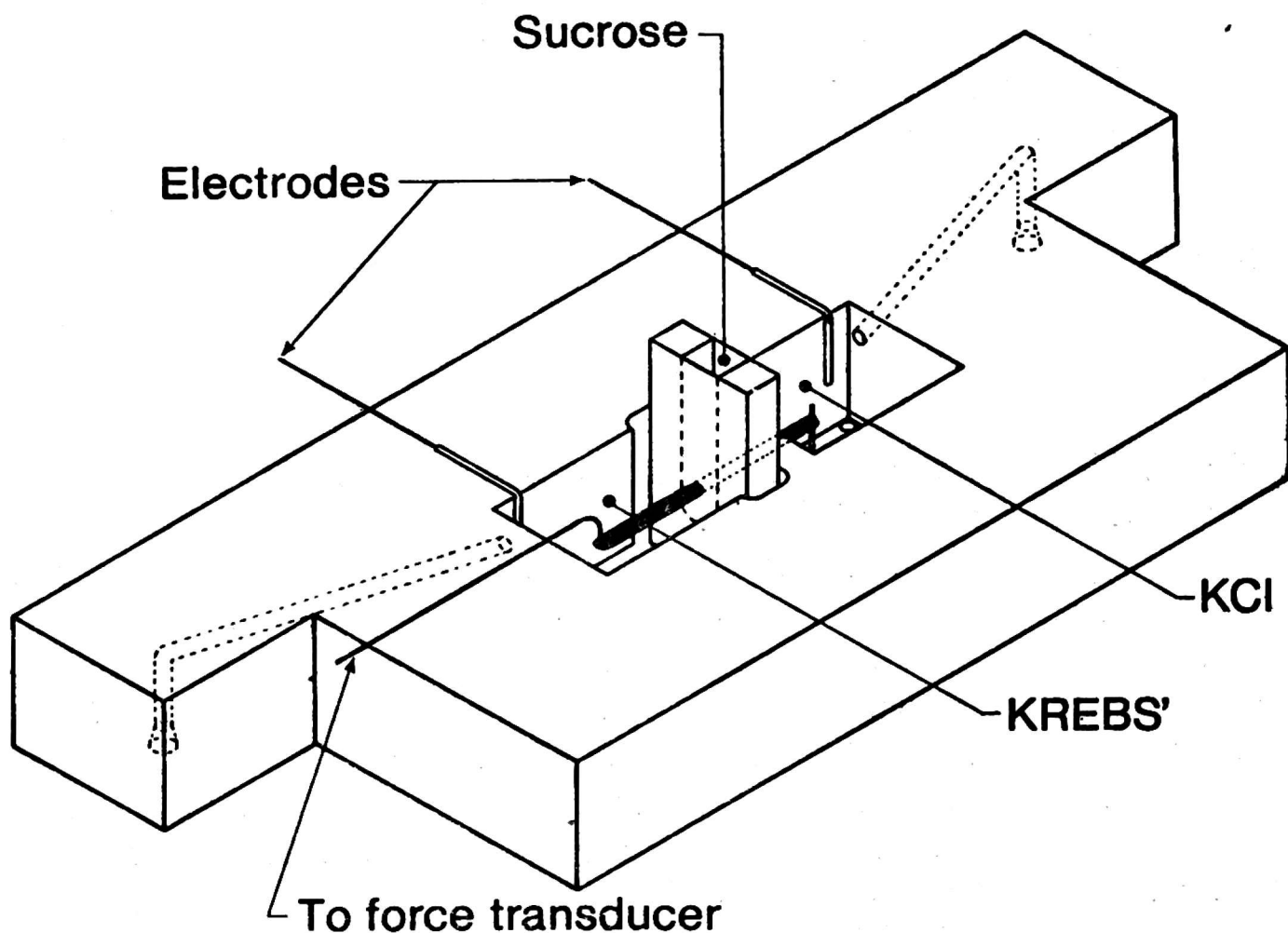

Fig. 1. Diagramatic representation of the sucrose-gap unit.

made using the sucrose-gap method (9, 10, 11) as shown in *Fig. 1*. The apparatus, together with connecting tubes and solutions, were kept at 37°C. Electrical signals recorded with Ag-AgCl. electrodes were amplified with a high input impedance amplifier (constructed at the Department of Electrical Engineering, University of Alberta). Contractility of the tissue was measured with a Grass force transducer type FTO3D (Grass Instrument Co, Quincy, Mass.) and the initial tension of the strips was set to 1 g. If was expessed in millivolts (mV) and 10 mV was equivalent of 1.0 g. Mechanical and electrical signals were recorded on a Beckman RM Dynograph recorder (Beckman Instruments Inc., Shiller Park, Ill.)

Solutions used: Krebs' solution (in milimolar); glucose 10.1; NaCl 116; KCl 5.4; $CaCl_2$ 2.5; $MgCl_2$ 1.2; NaH_2PO_4 1.2; $NaHCO_3$ 22.0; sucrose 234; KCl 117. The solutions were constantly equilibrated with 95% O_2 — 5% CO_2.

RESULTS

Spontaneous electrical and mechanical activities were recorded in 43 preparations from 22 gallbladders. The time of the recording periods ranged from 15 min up to 75 min (mean 38.9 min). The electrical activity consisted of ascillatory activity at quite variable frequencies (*Fig. 2*). At irregular intervals single spikes were superimposed on the oscillations (*Fig. 3*). The amplitude of the oscillations varied between 0.5 mV to 20 mV (mean 4.2 mV) in different preparations and was of the same value during the recording time. In 82.7% of recordings oscillations were rhythmic and regular. The overall mean frequency was 11.4 ± 5.2 (mean $\pm$ SD) cycles per min and mostly ranged between 6 and 14 cycles per min. On a few occasions the frequency was as low as 3 cycles per min or as high as 29 cycles per min (*Fig. 4*). In the remaining 17.3% cases electrical activity showed an increase in frequency during the
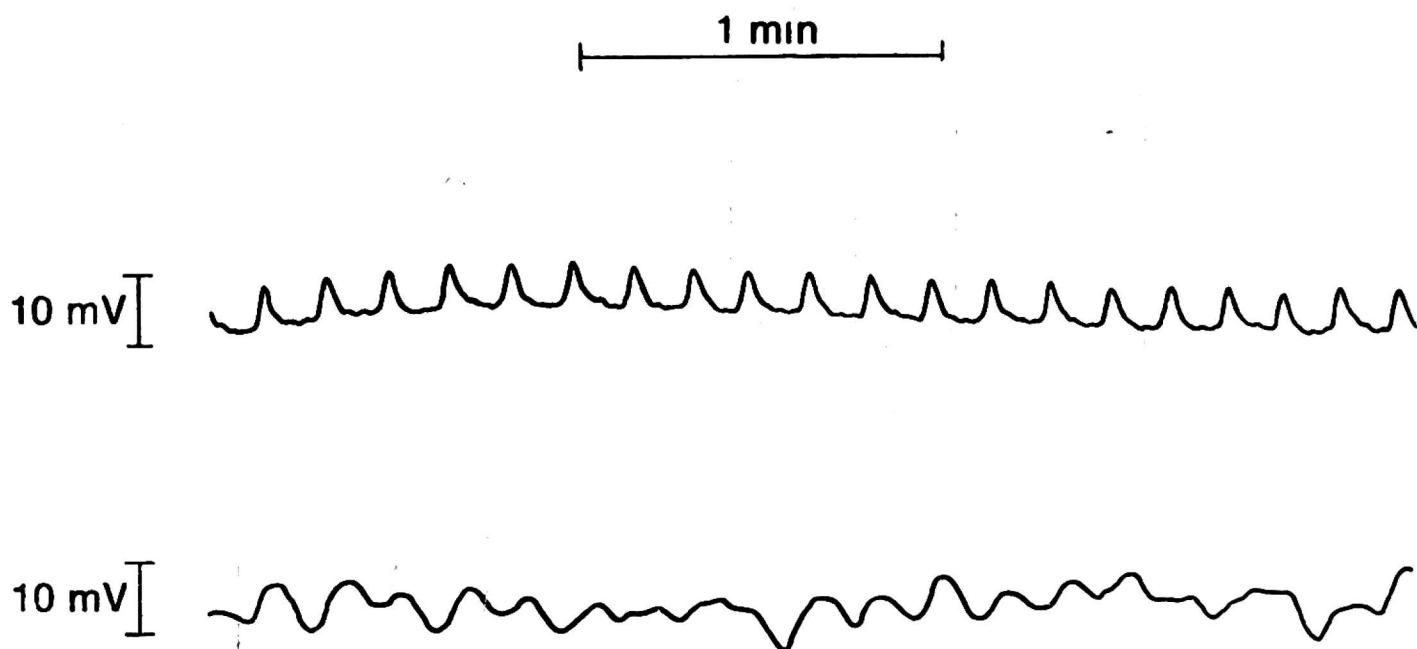

Fig. 2. Typical patterns of electrical activity (upper tracing) and contractility (lower tracing) in canine gallbladder.
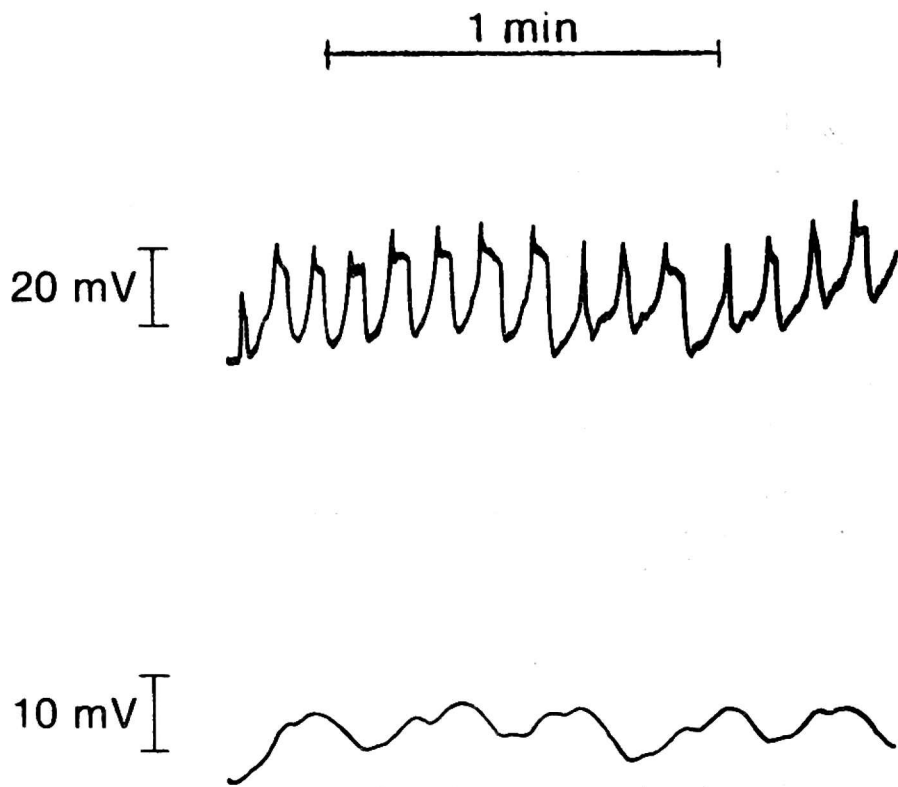
Fig. 3. Gallbladder neck; electrical oscillations with superimposed spikes.
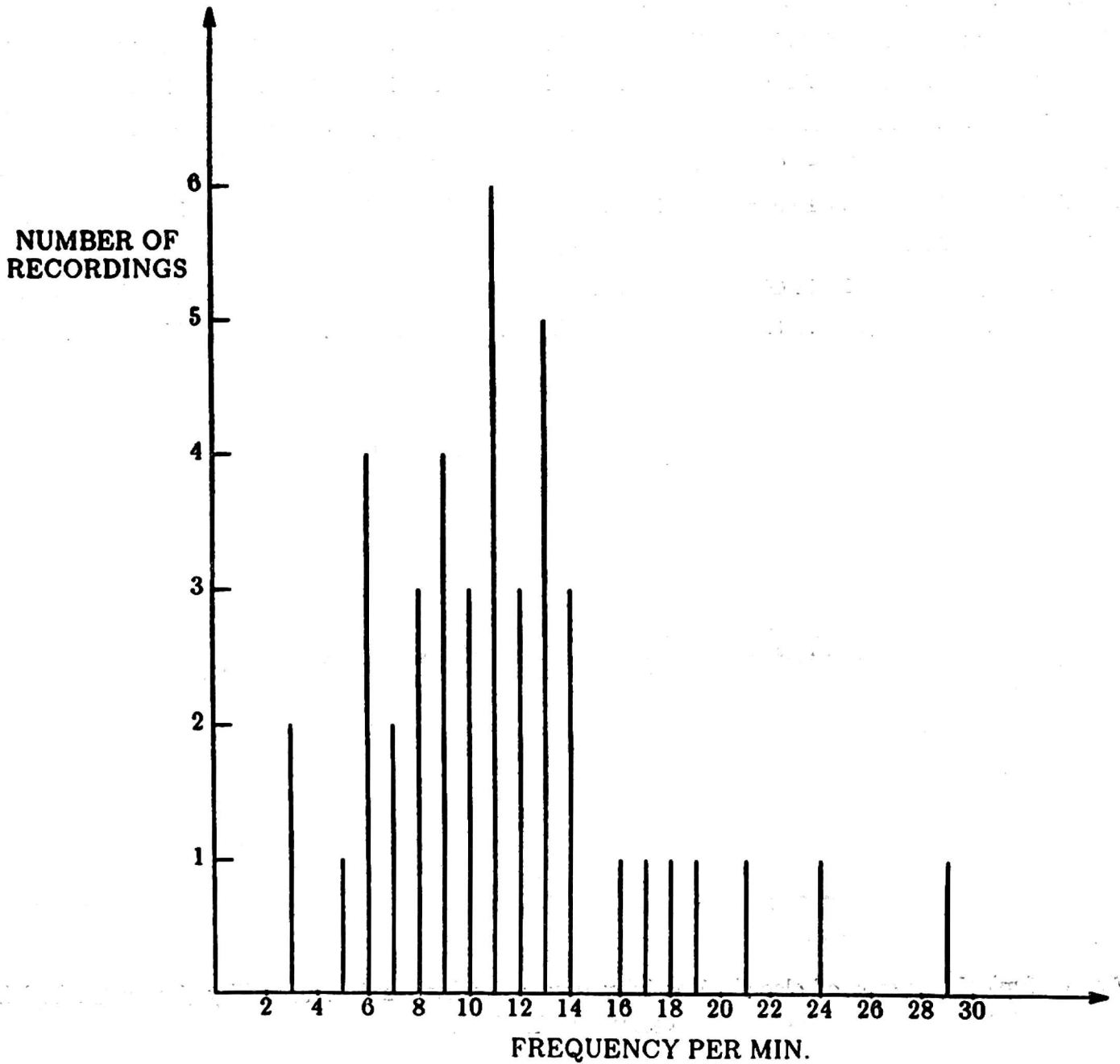

Fig. 4. Diagram representing distribution of the frequencies of electrical oscillations.
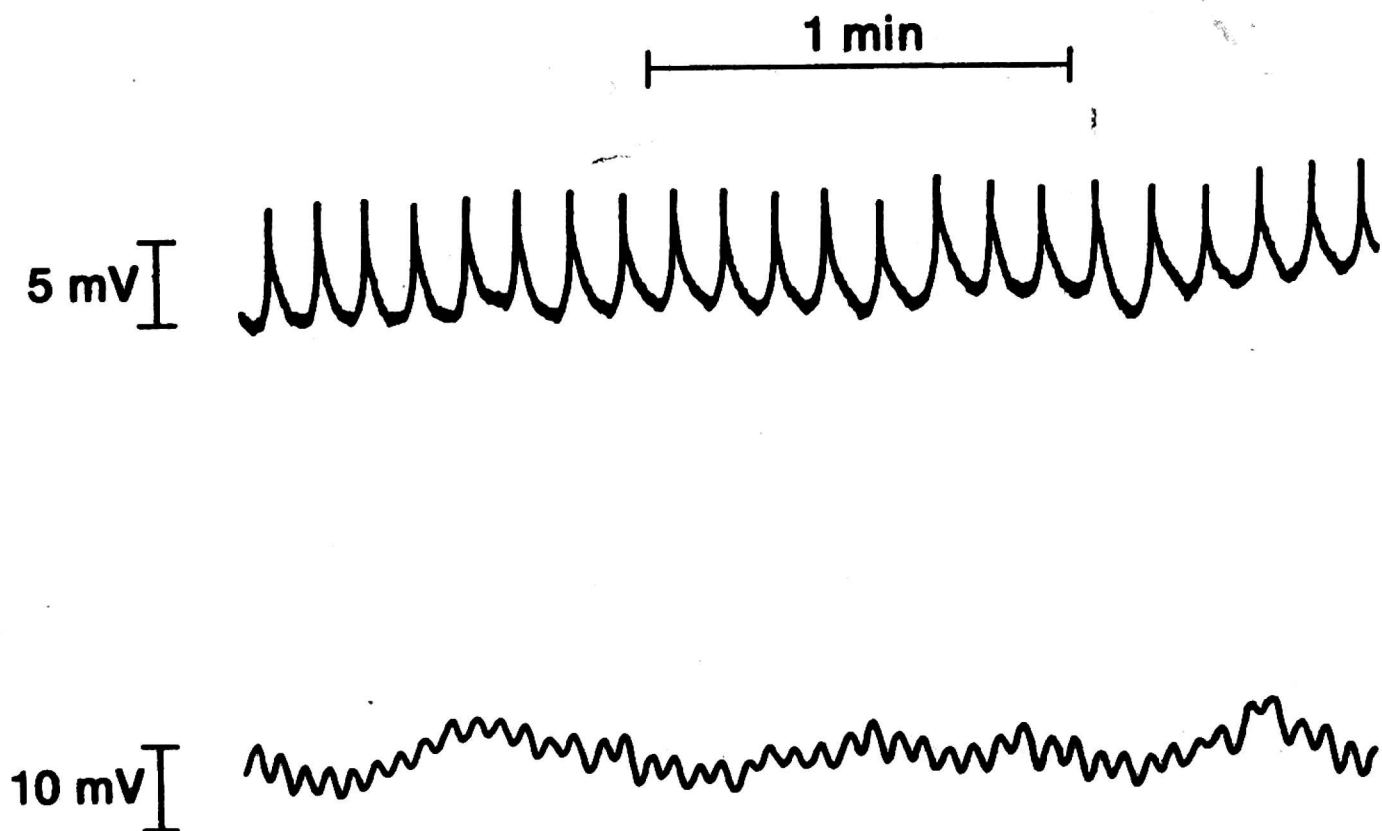
Fig. 5. Gallbladder corpus; electrical oscillations not in phase with the contractile activity

recording time. This increase in frequency correlated with increases in the frequency of phasic contractions.

Simultaneously recorded contractile activity consisted of regular phasic contractions usually of low amplitude (mean 0.2 g). In 84.2% of the recordings the contractile activity consisted of repetitive contractions which correlated with and were preceded by electrical oscillations. In the remaining 15.8% the contractile pattern was not in phase with the electrical activity (*Fig. 5*).

There were no significant differences in frequencies of electrical waves in different regions of the gallbladders. The mean values of the frequency of oscillations were 11.9 ± 6.2 (mean $\pm$ SD) cycles per min in corpus, 11.1 ± 4.4 cycles per min in fundus and 10.8 ± 3.8 cycles per min in the neck of the gallbladder. In the gallbladders, in which it was possible to get recordings from multiple sites, there were no significant differences in frequencies in the different regions of the gallbladders. Also no such differences occurred between electrical patterns in strips cut in different orientations (longitudinal, circular and oblique axes).

DISCUSSION

Although the rate of gallbladder emptying may be affected by the resistance to flow through the cystic duct and/or the sphincter of Oddi, a major determinant of emptying is contraction of gallbladder muscle (6). Emptying elicited by meal or exogenous CCK is a slow steady process that usually

requires 30—60 min. The sustained contraction delivers bile into the duodenum for 20 min or more while it raises intraluminal pressure only a few cm H_2O above that in the common duct. During the postprandial period low magnitude tonic contractions have been recorded in canine gallbladder by a serosal transducer and intraluminal manometry (5). During filling intraluminal pressure in the gallbladder is little less than common duct pressure.

The understanding of the electrophysiologic basis of motility in the gallbladder awaits the characterization of the electrical activities of the smooth muscle cells of this organ. Relatively few studies have attempted to provide such a characterization and the results have not been consistent. The gallbladder usually shows little myoelectrical activity during emptying (12). With extracellular recording techniques no slow wave or spike activity was found in the gallbladder of dog and monkey (12, 13). Undoubtedly, this reflects primarily the insensitivity of extracellular readings in a viscus with little smooth muscle. Intermittent rhythmic bursts of spike activity have been recorded in vivo from sheep gallbladder in association with slow changes in pressure (14). The gallbladder of the opossum shows an irregular slow wave pattern but no spike activity (13). In vitro studies on the gallbladder of guinea-pig demonstrated the presence of irregular spike bursts or just single spikes (15, 16).

Our results show that the electrical activity of canine gallbladder measured by the sucrose-gap method consists of oscillatory activity. The amplitude of the oscillations varied between 0.5 mV to 20 mV (mean 4.2 mV) in different preparations. The usual low amplitude of the contractile activity in our results was probably due to the size of the strips. In many regions of the gut, tonic contractions may not be associated with characteristic electromyographic signals (6, 17). In the gallbladder electrical activity (84.2% of recording periods) correlated only with phasic contractions.

On a few occasions the electrical activity was not in phase with the mechanical activity. This was presumably because electrical and mechanical activities were recorded from different groups of smooth muscle cells. Gallbladder muscle seems to undergo both phasic and tonic contractions, but the tonic contractions dominate (2, 5). Tonic contractions could be responsible for gallbladder emptying whereas phasic contractions might promote mixing of gallbladder contents.

This study confirms that there is myogenic electrical activity in the canine gallbladder. A prerequisite for the sucrose-gap method is that there must be cell-to-cell coupling (9, 18); we can therefore presume that electrical coupling occurs in the gallbladder muscle layer. However, the usual absence of the spiking activity superimposed on the oscillations suggests that there might be some differences in the excitation-coupling in the gallbladder smooth muscle compared with that in the rest of the gastrointestinal tract (19).

As shown in recent years, motility of the biliary tree remains closely integrated with that of the duodenum (5). The electrophysiological basis of this phenomenon remains obscure and there is an obvious need to record the electromyographic pattern of the two systems simultaneously.

REFERENCES

1. Banfield WJ. Physiology of the gallbladder. Gastroenterology 1975; 69: 770—7.
2. Ryan JP Motility of the gallbladder and the biliary tree. In: Johnson L.R., ed. Physiology of the gastrointestinal tract. New York: Raven Press, 1981: 473—94.
3. Torsoli A, Romorino ML, Alessandrini A. Motility of the biliary tract. Rendic R Gastroenterol 1970; 2: 67—80.
4. Ivy AC. The physiology of gallbladder. Physiol Rev 1934; 14: 1—102.
5. Itoh Z, Takahashi I. Periodic contractions of canine gallbladder during the interdigestive state. Am J. Physiol 1981: 240: G183—G9.
6. Hogan WJ, Dodds WJ, Geenen JE. The biliary tract. In: Christensen J., Wingate D.L., ed. A guide to gastrointestinal motility. Bristol, England: John Wright & Sons, 1983: 157—97.
7. Schoetz DJ, La Morte WW, Wise WE. Mechanical properties of primate gallbladder: description by a dymanic method. Am J Physiol 1981; 241: G376—G81.
8. MacPherson BR, Scott GW, Chansouria JPN, Fisher AWF. The muscle layer of the canine gallbladder and cystic duct. Acta Anat 1984; 120: 117—22.
9. Abe Y, Tomita T. Cable properties of smooth muscle. J Physiol 1968; 196: 87—100.
10. Bulbring E. Correlation between membrane potential spike discharge and tension in smooth muscle. J Physiol 1955; 128: 200—21.
11. Coburn RF, Ohba M, Tomita T. Recording of electrical activity with the sucrose-gap meethod. In: Daniel EE, Paton DM, eds. Methods in pharmacology, Vol. 3: Smooth muscle. New York: Plenum, 1975: 231—45.
12. Ludwick JR, Bass P. Contractile and electric activity of the extrahepatic biliary tract and the duodenum. Surg Gynecol Obstet 1967; 124: 536—46.
13. Becker JM, Duff W, Moody FG. Myoelectrical control of gastrointestinal and biliary motility: a review. Surgery 1981; 89: 466—77.
14. Bueno L, Praddaude F. Electrical activity of the gallbladder and biliary tract in sheep and its relatiosnship with doudenal motility. Ann Biol Anim Biochim Biophys 1979; 19: 1109—21.
15. Creed K. E., Kuriyama H. Electrophysiological properties of the smooth muscle cells of the biliary system of the guinea-pig. Jap J Physiol 1971; 21: 333—48.
16. Kamata M. Electrical and mechanical properties of smooth muscel cells of the guinea-pig biliary system. Jap J Physiol 1980; 30: 179—204.
17. Bortoff A. Amooth muscle of the gastrointestinal tract. In: Christensen J, Wingate DL, eds. A guide to gastrointestinal motility. Bristol, England: John Wright & Sons, 1983: 48—74.
18. Tomita T. Electical properties of mammalian smooth muscle. In: Bulbring E, Brading A, Jones A, Tomita T, eds. Smooth muscle. London: Arnold, 1970: 197—243.
19. Matsumoto T, Sarna SK, Condon RE. Gallbladder electrical activity in vivo (Abstract). Dig Dis Sci 1985; 30: 782.

Author's address: Dr. Jan Konturek, Medizinische Klinik und Poliklinik B, Der Universitat Münster, Albert-Schweitzer Str 33, 4400 Münster, FRG.