Study on the Ventricular Activation of the Heart of Cattle and Goat

Hiroshi SUGENO, M.D., Satoru MURAO, M.D.,
and Hideo UEDA, M.D.*

In cattle and goat, the mode of ventricular activation was pursued by the multiple chest leads, esophageal leads, direct epicardial leads and intracardiac leads in both right and left heart. The area showing QS pattern was invariably found on direct epicardial leads, and the tracings from both ventricles showed several different patterns such as QS, rS and RS. In the tracings of the part cephalad from atrioventricular groove, qR pattern was revealed. From these findings, the ventricular activation is considered to be directed toward apicobasal as well as endocardial-epicardial. This assumption is consistent with the recent knowledges on the special distribution of the Purkinje fibers in ungulates.

IT has been pointed out by some authors that the electrocardiogram of ungulates show some peculiar patterns in extremity leads as well as in precordial leads.^{1), 2)} The QRS complexes are fairly similar among cattle, horse, goat, sheep and camel, and are distinctly different from those of man and dog though the cause of the difference has not been conclusively studied by analytical methods.

Kisch,¹⁾ in 1948, observed upright QRS complex by intraventricular leads and downward QRS complex in direct epicardial leads in calves, and concluded that the direction of ventricular excitation was from the epicardium toward the endocardium, which was quite opposite to that of normal man and dog, but was somewhat alike to the mode of ventricular excitation in WPW syndrome.⁴⁾

The purposes of this paper are to clarify whether Kisch's opinion is valid or not in adult cattle and goat, and to analyse the genesis of the peculiar electrocardiographic patterns of ungulates.

MATERIALS AND METHOD

Nine cattles and 12 goats were used in this experimental study. The age, sex and body weight are tabulated in Table I. Multiple chest leads, intracardiac leads, esophageal leads, and direct epicardial leads were taken, using an ink-writing, one-channel electrocardiograph.

1. Chest leads. Multiple chest leads were recorded in a lateral recumbent

From the Veterinary Hospital, Faculty of Agriculture, Iwate University, Morioka and the Second Department of Internal Medicine, Faculty of Medicine, University of Tokyo, Tokyo.

* Professor of Internal Medicine.

Table I. The Experimental Animals and the Kinds of the Special Leads Used

	No.	Age	Sex	Body weight (Kg.)	Leads
Cattle	1	3	M	230	R.L.
	2	3	M	265	C.R.L.D.
	3	7	F	450	R.
	4	6	F	380	R.
	5	30 days	M	40	C.E.R.
	6	30 days	M	30	C.E.R.
	7	4	F	430	C.R.L.D.
	8	3	M	333	R.L.E.D.
	9	4	F	450	C.E.L.D.
Goat	1	5 Mon.	M	12.0	C.E.R.L.D.
	2	5 Mon.	M	12.6	C.E.R.
	3	5 Mon.	M	11.1	C.E.R.L.D.
	4	3	F	32.0	C.R.L.D.
	5	3	F	33.0	C.
	6	3	F	38.0	C.E.R.L.D.
	7	4	F	40.0	C.E.R.L.D.
	8	3	M	35.0	L.
	9	2	M	26.5	R.L.
	10	2	M	28.8	R.
	11	2	F	11.8	R.
	12	3	F	28.6	C.R.L.D.

M: male, F: female.

C: chest lead, D: direct epicardial lead, E: esophageal lead,

L: left intracardiac lead, R: right intracardiac lead.

position in most instances and in standing position in rare cases, without anesthesia. Fig. 1 shows the positions of the reference electrode, and the lines A, B, C, D and E represent the circumferential lines on the body surface, cut by perpendicular planes. The anal region was selected as a point for an indifferent electrode.

2. Esophageal leads. Recording was made at every 1–5 cm. interval successively by pulling out the electrode which had been inserted in the stomach.

3. Intracardiac leads. Right and left heart catheterization were performed through left jugular vein and through carotid artery respectively in a lateral recumbent position under local anesthesia, when needed.

Though catheterization was not always carried out under the control of fluoroscopy because of a thick trunk of the animals, it could be differentiated mainly by the E.C.G. patterns of intracardiac leads whether the tip of the catheter was actually within the ventricle or not, as discussed later.

4. Direct epicardial leads. Chest was opened under local anesthesia and artificial respiration when needed, and recordings from epicardium were made. The anal region was selected for the site of indifferent electrode in all cases.

Fig. 1, A. Exploring points of multiple chest leads in cattle.

Fig. 1, B. Exploring points of multiple chest leads in goat.

RESULTS

1. Ventricular complexes in chest leads

All cases of cattle and goats, with one exception of goat, showed a quite similar pattern of ventricular complex in the chest leads, typical cases of which were represented in Fig. 2.

The remarkable findings on the ventricular complexes are the following:

(1) Every explored point on the neck, shoulder and back of the forward half of the trunk revealed qR or R pattern.

(2) Relatively circumscribed region adjacent to the heart apex showed QS or rS pattern.

Fig. 2, A. Ventricular complexes in chest leads in cattle.

Fig. 2, B. Ventricular complexes in chest leads in goat.

(3) The ventricular complex recorded in the leads from the reference points along the lines D and E usually showed low voltage QRS complex.

One exceptional case (Goat No.6) showed rS or QS pattern of ventricular complex in the leads from the backward points on A and B lines.

2. Ventricular complexes in epicardial direct leads

Cattle No. 9

Cattle No. 7

Fig. 3, A. Ventricular complexes in epicardial direct leads in cattle.

Fig. 3, B. Ventricular complexes in epicardial direct leads in goat.

Tracings obtained from the surface of atria or great vessels cephalad from the atrioventricular groove, showed qR or R pattern invariably. From the ventricular surface in the majority of instances, qR or R pattern was restricted on the basal, relatively small area of both ventricular surfaces. On the other parts RS, rS and QS patterns were revealed, and the distribution of ventricular surface exhibiting each pattern was puzzlingly intermingled, and the width for each pattern was unexpectedly different in each case.

The most remarkable finding was QS pattern at the apex in many cases which should be R or RS in man and dog (Fig. 3).

Fig. 4. Esophageal leads and ventricular complexes in these leads in cattle.

In some cases, the area revealing QS pattern extended further to antero-lateral part of both ventricles. In other cases, an isolated region on right ventricle also showed QS pattern. In some cases, almost all ventricular surface exhibited QS or rS pattern except for the basal part.

In 5 experiments in goat, diaphragmatic semidirect leads were taken to explore the postero-apical region of the heart. On the region which showed marked pulsation due to cardiac beat, in all 5 cases, QS pattern was revealed.

3. Ventricular complexes in esophageal leads

The configuration of ventricular electrogram was quite similar on every esophageal exploring point, that is, qR in both cattle and goat, as illustrated in Fig. 4.

4. Ventricular complexes in intracardiac leads

Though the position of the catheter tip was confirmed by X-ray or autopsy in some cases, it was presumed by the features of electrographic patterns in majority of the experiments.

The electrographic criteria for the actual exist of the catheter tip within the ventricle were: (1) Small P-wave in magnitude and showing neither intrinsic deflection nor predominantly negative deflection, (2) RS-T segment elevation caused by the catheter tip against the ventricular endocardium.

By these criteria, the possibility of catheter tip being in the atrial cavity, in the great vessels cephalad from atrioventricular groove, or in the circumflex branch of coronary vessels could be excluded though the possibility of the catheter tip being in inferior vena cava or pulmonary artery could not be ruled out completely. A set of serial electrograms was recorded by withdrawing the catheter from the point which seemed to be in ventricular cavity by the above criteria to the point showing intraatrial or juxtaatrial pattern, which had large and peaked or diphasic P-wave.

In the both right and left intraventricular leads, several patterns, such as RS, rS and QS, were obtained.

Fig. 5, A. Intracardiac tracings by right heart catheterization in cattle.

Fig. 5, B. Intracardiac tracings by right and left heart catheterization in cattle No. 8.

It was impressive that QS pattern was obtained in deeper level near the cardiac apex, and RS pattern in the higher level near the base, though the exact positional correspondence could not be confirmed. At any rate, it was to be noted that the predominantly downward deflection was observed and no R or qR pattern was present in apparently intraventricular tracings.

There was no essential difference in the tracing from right and left ventricle in this study to suggest the existence of asynchronism of the activation of both sides of the ventricular septum in cattle and goat as normally found in man and dog.⁶⁾

The typical examples of intracardiac tracings were reproduced in Figg. 5 and 6.

DISCUSSION

It may be desirable to summarize some of the anatomic features of the heart of cattle and goat concerning the electrical phenomenon before the discussion on the findings observed in this study.

The heart of these ruminants lies in the more ventral part of the thorax than in man and dog, and its longitudinal axis is almost parallel to the sagittal plane of the trunk, and the angle formed by the longitudinal axis of the heart and the trunk is likewise as illustrated in Fig. 7. The position of the heart

Fig. 6, A. Intracardiac tracings by right heart catheterization in goat.

Fig. 6, B. Intracardiac tracings by right and left heart catheterization in goat No. 7.

to the sagittal plane shifts somewhat toward the left as a whole. Both right atrium and ventricle occupy the ventro-cranial part of the heart, and the left atrium and ventricle occupy dorso-caudal part.

Fig. 7. The position of the heart of cattle in the thorax, illustrated by X-ray. Lateral view.

Difference in the thickness of right and left ventricular wall is essentially the same as in dogs.

The esophagus passes above the basal part of the heart throughout its

course, and does not contact with the posterior wall of the heart.

There is no gross difference in the macroscopic composition of the heart itself among cattle, goat, dog, and man, except for the positional specificity in the thorax.

As described in the introduction of this paper, it has been noted that the electrocardiogram of some kinds of ungulates is apparently different from that of man or dog in conventional leads. Some of the peculiar patterns are reproduced in Fig. 8. It has been a problem to be solved that how much

Fig. 8. Several patterns of the limb leads on cattle.

these patterns are due to the positional specificity of the heart of the animals, or due to the mode of ventricular excitation specific for these animals. Ueda, one of the authors, and associates⁵⁾ have studied this problem in horse by multiple precordial leads, and suspected that the ventricular excitation is directed apico-basal as well as endocardial-epicardial. Kisch,³⁾ applying the technique of cardiac catheterization and multiple direct epicardial leads to this problem on young calves, has concluded that ventricular excitation of the animal was rather directed toward epicardial-endocardial, contrarily to that of normal man and dog. Though his speculation is very attractive as described in the introduction of this paper, it cannot persuade us completely because the signification of the intraventricular tracings obtained by his method seems to be unsettled to the authors. His conclusion has been derived from the facts that the predominantly negative deflection in the direct epicardial leads and largely upright deflection in the intraventricular leads have been obtained.

In the present experiment on cattle and goat, however, QS, rS and RS patterns were obtained both in left and right ventricle, and predominantly upright QRS was not seen in apparently intraventricular leads. This discrepancy may be due to the difference in the age of the experimental animals, but close examination of the reproduced tracings of Kisch's paper discloses that rS pattern has also been obtained in the intraventricular leads, and some of his records of "intraventricular leads" may be considered to show that the catheter tip was outside of the ventricular cavity judging from the shape of the P-wave.

The authors' findings on direct epicardial leads are essentially consistent

with those of Kisch. Though there are some differences in each case, QS or rS pattern is recorded on more or less wide area of the ventricular surface. The area in which these peculiar patterns are recorded, in most cases of this experiment, occupies the apical region, and in some cases it extends to more basal, lateral or posterior in the left ventricle, and further anterobasal or posteroapical portion in the right ventricle, isolated or continuous to the area of left ventricle.

The fact that the QS pattern can be recorded on the normal epicardium of cattle and goat, is consistent with the recently ascertained anatomical and physiological knowledges. Ter Berg⁷⁾ and Meyling⁸⁾ have found that the Purkinje fibers in some species of ruminants form a network not only in the septum but also throughout the whole parietal wall of both ventricles. From these findings, it may be possible that the transmural excitation is almost synchronous. This deduction has been verified in the study of Durrer and associates⁹⁾ on sheep by the technique of multiple intramural electrodes.

Furthermore, Ter Berg and Meyling have found that the density of the network of Purkinje fibers diminishes in the basal region of the ventricular wall and the septum, and that the fibers at the basal part of the septum do not originate from the main bundle, but from points situated in more apical portion. From these findings, it is expected that activation of the basal part of ventricle, as a whole, is later than that of the apical part. In this experiment, ventricular complex showing R or qR pattern is recorded in the direct epicardial leads at the basal part of ventricle near-by atrioventricular groove, in the direct atrial epicardial leads, in the intraatrial leads, and intravascular leads cephalad from atrioventricular groove.

Ventricular complex in the intraventricular leads, on the other hand, shows QS, rS and RS patterns. The positions in the ventricular cavity from which these 3 patterns are recorded tend to be arranged successively in an apicobasal direction, though it is not exactly confirmed.

It may be postulated that the activation of the ventricle, in cattle and goat, is conducted in an apicobasal as well as transmural direction as a whole, though much more complexed activation must be considered in the more precise discussion according to puzzling distribution of various patterns on epicardial surface.

From these considerations on the mode of ventricular activation and the anatomical position of the heart relative to the trunk, it is considerably easy to understand the cause of QS or rS pattern in precordial part of the chest, qR pattern in esophageal leads and in the leads taken from the craniodorsal parts of the trunk, and further the apparently peculiar patterns in limb leads of these animals.

It is concluded that the ventricular activation in the heart of ungulates is quite different from that in man or dog because of the difference in the distribution of the Purkinje net work. However this discrepancy may be due to rather slight difference in the distribution of Purkinje fibers in the parietal

wall, because some recent studies⁹⁾⁻¹¹⁾ by intramural leads have suggested that the deeper penetration of Purkinje fibers into the ventricular wall in dogs than hitherto assumed.

SUMMARY

(1) Multiple chest, esophageal, intracardiac leads and direct epicardial leads were taken in cattle and goats to study the mode of ventricular activation of ungulates.

(2) There was little difference between cattle and goat in these special leads.

(3) In direct epicardial leads the area showing QS pattern was invariably observed, and in the intraventricular tracings, QS, rS and RS patterns were noted.

(4) From the findings in direct epicardial leads and intraventricular leads, it was assumed that the ventricular activation, as a whole, was directed from apex to base, though transmural activation might play a role at least in some regions of ventricular wall. This assumption could explain well the findings of multiple chest leads and esophageal leads.

ADDENDUM

This study was reported in divided parts before the proceedings of the 47th (April, 1959) and the 49th (April, 1960) Meeting of the Japanese Society of Veterinary Science, and the 13th Meeting of Kanto Branch of the Japanese Circulation Society (May, 1959). Publications in Japanese are in Jap. Circulation J. 23: 1193, 1959,¹²⁾ and Journal of Faculty of Agriculture Iwate University 4:4, 1960.¹³⁾

While this paper was in press our attention was called to the studies by R.L. Hamlin, C. R. Smith and R. W. Redding,¹⁴⁾¹⁵⁾ closely related to the present study. Our conclusions agree in general with theirs.

ACKNOWLEDGEMENT

We wish to thank Dr. Y. Yasuda, the chief of the Veterinary Hospital, Faculty of Agriculture, Iwate University, without whose help the present study would not have been accomplished.

REFERENCES

1. Lepeschkin, E.: Modern Electrocardiography Vol. I, pp. 133-136, 1951.
2. Braun, K., Rosenberg, S. Z., and Bellin, L.: Am. Heart J. **55**: 754, 1958.
3. Kisch, B., Groedel, F. M., and Borchart, P. R.: Exper. Med. & Surg. **6**: 125, 1948.
4. Kisch, B.: Am. Heart J. **40**: 466, 1950.
5. Ueda, H., Kashida, R., Kimura, E., Nagata, T., and Watanabe, S.: Jap. Circulation J. **11**: 108, 1947 (In Japanese).

6. Kossman, C. E., Berger, A. R., Rader, B., Blumlik, J., Briller, A. S., and Donnelly, J. H. : *Circulation* **2** : 10, 1950.
7. Ter Berg, H. : *Acta Neerl. Morphol.* **4** : 97, 1941 (cited by Durrer).
8. Meyling, H. A. : cited by Durrer.
9. Durrer, D., and Van der Tweel, L. H. : *Ann. New York Acad. Sci.* **65** : 779, 1957.
10. Prinzmetal, M., Shaw, C. M., Maxwell, M. H., Flamm, E. J., Goldman, A., Kimura, N., Rakita, L., Borduas, J. L., Rattman, S., and Kennamer, R. : *Am. J. Med.* **16** : 469, 1954.
11. Scher, A. M., Young, A. C., Malgren, A. L., and Danton, R. R. : *Circulation Res.* **1** : 539, 1953.
12. Sugeno, H. : *Jap. Circulation J.* **23** : 75, 1959 (In Japanese).
13. Sugeno, H., Yasuda, Y., and Nishikawa, H. : *Journal of Faculty of Agriculture Iwate University* **4** : 4, 1960 (In Japanese).
14. Hamlin, R. L., Smith, C. R., and Redding, R. W. : *Circulation* **20** : 709, 1959.
15. Redding, R. W., Smith, C. R., and Hamlin, R. L. : *Circulation* **20** : 755, 1959.