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Author(s)	TOO, Kimehiko; KANAGAWA, Hiroshi; KAWATA, Keiichiro
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Instructions for use

FETAL ELECTROCARDIOGRAM IN DAIRY CATTLE[*1]

I FUNDAMENTAL STUDIES

Kimehiko Too[*2], Hiroshi Kanagawa
and Keiichiro Kawata

Department of Veterinary Obstetrics
Faculty of Veterinary Medicine
Hokkaido University, Sapporo, Japan

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With Cremer's first demonstration of a fetal electrocardiogram (F-ECG) in human cases, this technique has been employed in obstetrics mainly to determine evidence of fetal life, presumption of fetal presentation, diagnosis of number of fetus or fetal heart disorders[2,3,10,12,14]. In the veterinary field, on the other hand, there are a few reports on F-ECG: Nörr and Glazier & Nicholson in mares; Larks et al.[12] in cows, mares and sheep; Amada & Senda in race horses. In the case of F-ECG in dairy cattle, however, there is the only work done by Larks et al.[12] who were successful in conducted F-ECG with 100 per cent of positive recording after 5 months of pregnancy.

Early pregnancy diagnosis in the cow with F-ECG may obviously be inadequate as Larks et al.[12] have previously suggested. F-ECG is, however, expected to provide us with new information as to fetal physiology which is undetectable by any conventional methods.

In this connection, the present authors attempted to carry out a series of fetal electrocardiographic studies in dairy cattle. This report deals with some fundamental problems such as recording technique, positivity of F-ECG recording in various gestational stages, changes in fetal heart rate during pregnancy, etc. The possibility of clinical application of F-ECG will also be discussed.

MATERIALS

Ten pregnant Holstein cows, age between 2 and 11 years, were used as materials for this experiment. These animals were raised at the dairy farms of the Hokkaido University and the Obihiro Zootechnical College. Some of the data on the histories and observation periods of animals are shown in table 1. The animals were selected at random from both dairy farms. The fetal ages were calculated from the day of insemination, which ranged from 105 to 288 days.

[*1] A part of this work was released at the 59th Meeting of the Japanese Society of Veterinary Science on April 7, 1965 in Tokyo.

[*2] Department of Veterinary Internal Medicine

TABLE 1 *History of animals and thier experimental periods*

CASE NO.	ANIMAL NUMBER	AGE*	NO. OF PARTUS	F-ECG RECORDING			REMARKS
				Days of pregnancy	Interval	Times	
		yr. mo.			days		
1	H–595	9.5	6	105~231	14	9	Parturition (♀)
2	H–131	9.3	5	119~172	53	2	Parturition (♀)
3	H–198	4.3	2	120~172	53	2	Parturition (♀)
4	H–576	11.2	8	154~266	14	8	Parturition (♀)
5	H–185	3.1	1	159~211	52	2	Abortion (♂, ♀)
6	H–206	4.0	2	199~252	53	2	Parturition (♂)
7	H–199	4.3	2	202~254	52	2	Parturition (♂)
8	H–645	3.3	2	206~276	14	5	Parturition (♂)
9	H–218	5.3	3	219~271	52	2	Parturition (♂, ♂)
10	H–653	2.2	1	232~288	14	4	Parturition (♂)

* At the age of beginning the experiment

METHODS

1) F–ECG recording site A normal consultation room of a large animal clinic was used without any special installations (fig. 7).

2) Noise reduction A troublesome problem which may disturb recording of F-ECG is electrical noise caused mainly by alternate current. In order to prevent such disturbances, a special rubber sheet devised by AMADA & SENDA with a copper net sandwiched between two rubber plates with a thickness of 5 mm each was used. The animals were placed on the sheet in a normal standing position (fig. 7). The copper net was grounded. The wires used in this experiment were entirely shielded. Under these circumstances, electrical noise was almost nil and a satisfactorily noiseless F–ECG was able to be recorded.

3) Electrodes Some special electrodes for skin and rectal applications were devised by the authors in order to obtain a constant contact condition on applied regions. For the skin, an electrode of silver plate with a diameter of 2 cm embedded with chemical cement in a round polyethylene capsule was used. The capsule had a round visor with a width of 5 mm. The depth from the surface plane of the visor to the silver plate was 2 mm. As a rectal or vaginal electrode, a polyethylene column covered by silver plate with a diameter of 2.5 cm was prepared. In this column 100 g of mercury was sealed tightly to prevent removal of the electrode from the rectal or vaginal walls. These electrodes are shown in figure 8.

4) Application of skin electrodes For setting electrodes on the skin surface, the hair was cut off in a diameter of 3 cm wide and the skin surface was cleaned with acetone. A chemical cement was then mounted on the surface of the visor of the capsule and the visor was stamped on the cleaned skin. After natural drying of the cement, an electrode jelly for ECG was filled in the space on the silver plate and also a small quantity of the jelly was rubbed on the skin by hand. Finally, the capsule was placed on the skin by the stamped

ring and capsule's visor (fig. 9). Thus, the electrode had good contact with the skin and also could keep a constant distance between the skin and the electrode surface even though the animal moved or skin muscles trembled during recording. At any portion of the skin surface of the body, the electrode could be easily adhered without injury to the skin. After recording the electrodes could be removed from the skin by hand and the binding agent and jelly were easily cleaned off with acetone and water.

5) Application of rectal or vaginal electrode No difficulty was experienced in placing the electrode in the rectum or vagina because usual rectal or vaginal examination techniques can readily be applied. The electrode did not give any untoward effect to the animal as a foreign body.

6) Lead methods For obtaining fundamental data of some suitable lead methods, 12 points were selected for electrode positions as shown in figure 1. The points on the right side flank or abdomen were numbered as 1~4. The other points on the left were numbered 11~14. These on the ventral abdomen on the middle line were 21 and 22. The numbers, 31 and 32, were on the rectum and the vagina respectively. The recording was always made using a bipolar lead connecting two indicated points. For example, lead 1-2 means a bipolar lead between the right flank and a frontal part of the right side abdomen. The point No. 1 was then connected to the negative (R) as well as in the standard limb lead and point No. 2 to the positive (L). The body earth point was selected at the right hind leg without any special meaning. The electrodes were connected to several or all referenced points before recording, and selection of each lead method was made through a lead selector as well as in an electroencephalographic system (fig. 7).

FIGURE 1 *Applied position of electrode*
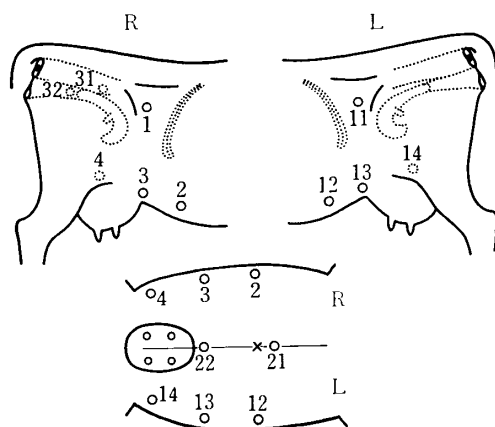
Notes R : right side L : left side

7) Recording equipment In this experiment, an electrocardiograph, type TOF-1000*, was used. This instrument has one channel recording system with a heat stylus and two paper speeds (2.5 & 5 cm/sec). The time constant was always set at 0.01 second (fig. 7).

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* Manufactured by the Fukuda Electro Co. Ltd., Tokyo, Japan

8) Interpretation of the tracings   The following criteria for detecting F-ECG were adopted.   (1) The QRS complex must be followed throughout tracing from at least two different leads or more, and (2) it must occur with fairly regular time intervals.   From the instrumental capacity, recording of fetal heart activity was limited mainly to the tracing of QRS complex.   In some cases, however, at later pregnant stages, there could be observed some waves which seemed to be T or P pattern, although these tracings were not clear. Therefore, in this study, the QRS complex alone could be considered as F-ECG.

RESULTS

1)   Distribution of decisive F-ECG

The outline of the results is given in table 2.   Trials in a total of 5 cases during 105~ 133 days of pregnancy which was ascertained by rectal palpation failed to show F-ECG. Whereas, in a total of 33 cases during the period from 146 days to termination, F-ECG could be recorded without exception, though there existed some variations on F-ECG pattern and QRS amplitude probably caused by the lead position or the fetal age.

TABLE 2   *Distribution of decisive F-ECG*

DAYS OF PREGNANCY	NO. OF CASES	F-ECG	
		−	+
101~120	4	4	0
121~140	1	1	0
141~160	3	0	3[*1]
161~180	5	0	5
181~200	2	0	2
201~220	9	0	9
221~240	4	0	4
241~260	7	0	7
261~288	3	0	3[*2]
Total	38	5	33

Notes :   [*1]   Observed at 146, 154 and 159 days
           [*2]   Including one case observed at the day of parturition

2)   F-ECG pattern in various fetal stages

As shown in figure 10 (133-day fetus), a train of spikes with irregular intervals, except maternal QRS, was recorded from certain limited leads.   These should be considered as an electromyogram of the dam (EMG).   No fetal QRS was observable.

The earliest stage obtained for the recording of a decisive F-ECG was at 146 days pregnant throughout this study (fig. 11).   In this case, on a record from lead 1-2, small negative spikes with regular intervals could be followed.   These spikes, slightly over the noise or base-line level in amplitude, indicated by signs of "f" and black points represent F-ECG.   In order to identify the spikes as F-ECG, it must further be required that the

rhythmic spikes must be shown in recording of other leads. In figure 11-b, lead 2-31 could demonstrate a similar spike rhythm as in lead 1-2 (fig. 11-a), showing small positive and higher amplitude. Furthermore, the analysis of the separated traces of maternal and fetal QRS (figs. 11-c & d) extracted from the original (fig. 11-b), clearly manifested the existence of the fetal QRS with a fairly regular interval and a uniform pattern throughout the segment.

In a case of 203-day pregnancy, F-ECG with the initial negative deflection of high amplitude on lead 1-22 (fig. 12-a) was recorded. In this figure, the polarity of the F-ECG coincided with the direction of maternal QRS (figs. 12-b & c). On the other lead (fig. 12-d), maternal QRS was not clearly recorded while fetal QRS had the initial positive deflection of high amplitude and a similar rhythm of that from lead 1-22. In this case, in most of the leads tested was demonstrated a fairly high amplitude of fetal QRS.

In a case of 274-day pregnancy (fig. 13), F-ECG was recorded with a high amplitude from leads of the right side and with less higher in the left side ones. On leads 21-2 and 21-3 (figs. 13-a & b), F-ECG was shown with higher amplitude, whereas no F-ECG was recorded on the corresponding leads of the left side—leads 12-21 and 13-21 (figs. 13-e & f). Such superiority in appearance of F-ECG in the right side was also observed on the recordings from dorso-ventral leads. In leads 22-2 and 22-3 (figs. 13-c & d), the recording was shown with the manifestation of fetal QRS without maternal QRS. Similar recordings were also obtained on leads 12-22 and 13-22 (figs. 13-g & h).

Over 146 days of fetal age, F-ECG pattern highly varied in polarity of the initial deflection and amplitude depending on lead positions. According to the basic electrocardiographical theory, it is generally believed that a relationship between fetal heart position (electrical heart axis) and electrode position could be a main causal factor which effects the QRS pattern. However, there is little information about the reciprocal fetal heart position to the maternal body at each stage of gestation. Therefore, a definite interpretation of F-ECG changes caused

FIGURE 2 *Fetal QRS patterns from various leads in a case at 259th day of gestation (No. 4)*
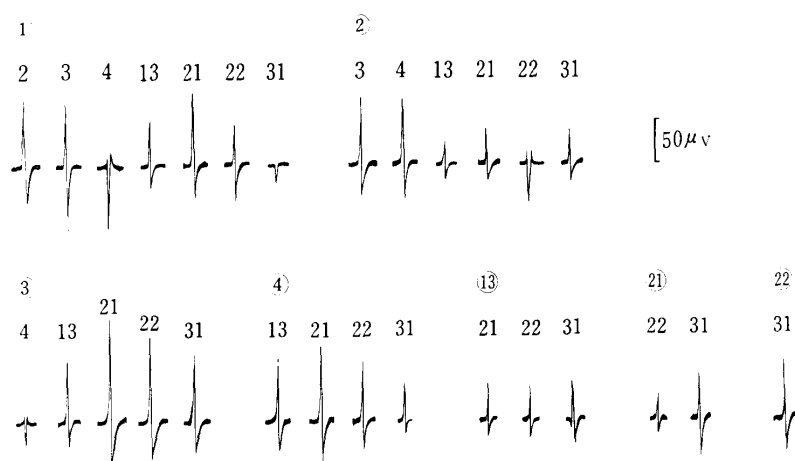

Notes : Each number indicates the lead position.
Determination of polarity of initial deflection of fetal QRS was based on positive polarity of maternal QRS, because the maternal heart position usually indicates the dorso-ventral direction.

by the variety of the lead method is somewhat difficult to be made at this stage. Some examples of F-ECG patterns from various leads in a case of 259-day pregnancy are shown in figure 2.

Changes in F-ECG pattern with the progress in fetal development during gestation were also observed in this experiment. In a pregnant cow which was electrocardiographically examined 7 times during the period from 133 to 231 days in gestation by three different lead methods, an interesting phenomenon was noticed. That is, the fetal spike polarity determined by positive maternal QRS deflection was inverted at the 203rd day of pregnancy (fig. 3). Although such a complete inversion may chiefly be due to the changes in the direction of the electrical heart axis of the fetus probably caused by the changes in fetal presentation and position in the uterus, its detailed mechanism is still unknown.

FIGURE 3   *Fetal electrocardiographic changes with fetal growth from three different leads (Case No. 1)*
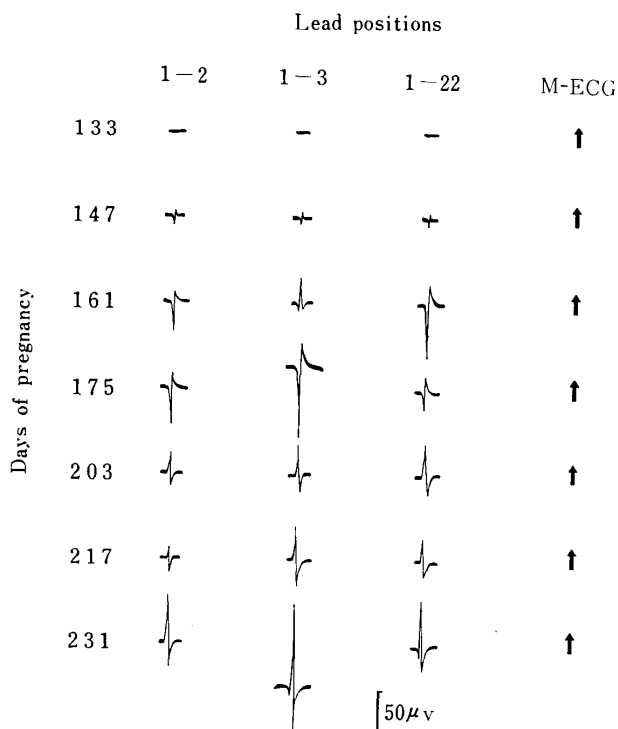
Notes : At 133rd day, no F-ECG was obtained.
Fetal spike polarity is determined by positive maternal polarity.

3) Changes of fetal heart rate (F-HR) during gestation

The F-HR was calculated from visible spike numbers appeared in F-ECG. The heart rate per minute was actually counted from the numbers for a segment of 10 seconds. In order to facilitate statistical analysis of changes in F-HR during gestation, the observed periods were divided into 4 stages; stage I: 161~190 days, stage II: 191~220 days, stage

III: 221~250 days and stage IV: 251~280 days of pregnancy. The F–HR variations in the above four stages in 8 animals are shown in table 3 and figure 4. Differences in reciprocal F–HR in each stage for 8 animals were statistically analyzed (tab. 4-a). Between stages I vs.

TABLE 3 *Fetal heart rate (F-HR)*

STAGE	CASE NO.	DAY OF PREGNANCY	F–HR	S. D.
I	1	161	/min 139.8	6.5
	4	168*	140.0	7.5
	2	171	148.8	2.6
	3	172	143.4	8.9
	1	175	135.4	7.4
II	6	199	139.2	4.8
	7	202	145.2	8.1
	4	203*	138.0	6.4
	1	203	141.6	7.2
	4	217	140.4	3.1
III	4	231*	132.6	8.9
	8	234	135.0	5.2
	4	245	123.6	5.9
	10	246	118.2	6.5
	8	248	130.8	13.5
IV	6	251	127.8	5.8
	7	254	118.8	3.9
	4	259*	113.4	3.5
	10	260	115.8	2.9
	10	274	126.4	4.6

Notes: Data are given as mean values.
* This case was presented for statistical analysis as seen in table 4-b.

III, I vs. IV, II vs. III and II vs. IV, there existed a highly significant differences in F–HR (P<0.01). Some tendencies in F–HR variation with progress of pregnancy in 6 animals are shown in figure 5. Out of these 6, only one (case No. 4) was examined throughout the whole stages. In the statistical analysis for F–HR variation in each stage of case No. 4, significant differences (P<0.01) were obtained between stages I vs. III, I vs. IV, II vs. IV, and III vs. IV, respectively (tab. 4-b). From these results, it may be concluded that the F–HR has a tendency to decrease together with the fetal growth.

In several cases, a long time recording of F–ECG of more than 10 minutes was made.
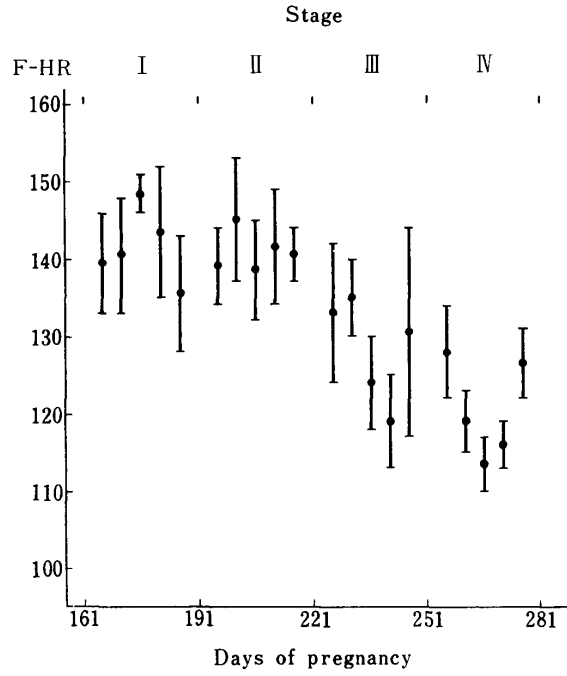
FIGURE 4   *Fetal heart rate (F-HR)*

Stage

Days of pregnancy

FIGURE 5   *Fetal heart rate (F-HR) changes*

Days of pregnancy

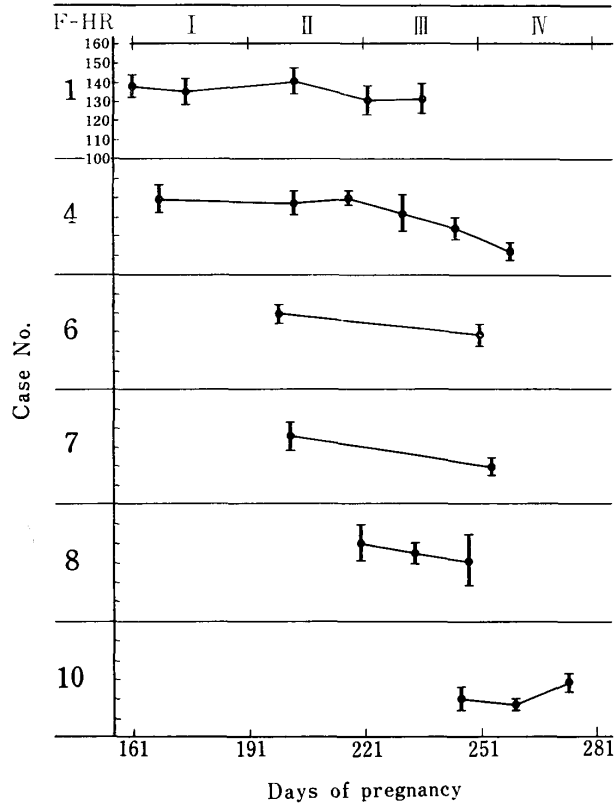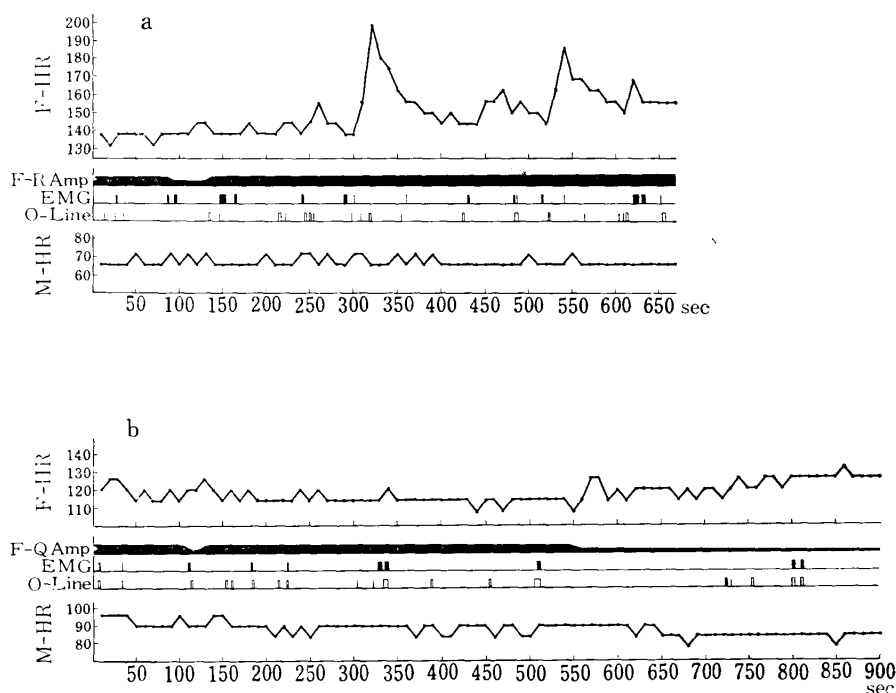TABLE 4 *Significance of difference among reciprocal*
values in four stages of gestation

a Fetal heart rate (8 animals)

* *	* *	I 142$^\Delta$
* *	* *	II 141
	III 128	
IV 120		

b Fetal heart rate (case No. 4)

* *	* *	I 140
* *		II 138
* *	III 133	
IV 113		

Notes　* * : P<0.01　△ : Mean value

FIGURE 6　*Long time recordings*

Notes　a : Observation at 203rd day of gestation
　　　b : Observation at 245th day of gestation
　　F-HR : Fetal heart rate per minute
　F-R Amp : Amplitude of fetal R spike
　F-Q Amp : Amplitude of fetal Q spike
　　　EMG : Occurrence of maternal electromyogram
　　O-line : Movement of ECG O-line
　　M-HR : Maternal heart rate per minute

From such continuous strips, some observations on F-HR, F-ECG amplitude, ECG-O-line movement, EMG (unexpectedly appeared on ECG tracing) and maternal heart rate were made. In a case of 245-day pregnancy, F-HR was almost constantly counted as about 120 per minute without much deviation in a 15 minutes recording (fig. 6-b), whereas in another case of 203-day F-HR varied from 130 to 150 with paroxysmal tachycardia at a late half of the recording (fig. 6-a). Thus, a rhythm of fetal heart beat tended to show paroxysmal tachycardia. In other cases, a similar type of variation with tachycardia was also observed but fetal bradycardia was less recorded. However, the relationships between F-HR change and maternal heart rate, O-line movement or EMG recording were not confirmed from this study.

DISCUSSION

Emphasis should be laid on more perfect electrode attachment to the skin in order to obtain a clear F-ECG than routine ECG recording of adult animals. To resolve this problem, LARKS et al.[12] have tried a technique of holding the electrode by hand to the hair-cut skin in dairy cattle, and AMADA & SENDA was successful in recording F-ECG in race horses by using a round electrode attached to the skin surface with special jelly. Such a technique is convenient for clinical application. However, it is inadequate for long time recording under constant conditions of electrode attachment, because the electrode attachment is likely to be disturbed by maternal somatic movement. On the contrary, the present authors' technique can provide perfect contact of the electrode to the skin even though maternal movement takes place. During the course of a recording as long as 2~3 hours, it was unnecessary to adjust or retouch the electrode.

Another important point for recording F-ECG is to reduce the electrical noise. For this purpose, the use of a special rubber sheet in which a copper net is sandwiched is recommended. At the same time, the electrical source of the instrument should be taken from a distant place using shielded wires. More careful application should be adopted in field cases. For controlling the animal, no sedative drugs were needed. The animal was controlled only by routine restraint.

For deciding lead methods and electrode positions, reports of LARKS et al.[12] and AMADA & SENDA were more useful for the authors than those involving human medicine[3,9,10,15]. According to such investigators, careful attention should be paid to the selection of the electrode positions to obtain a successful F-ECG at the middle gestational stages such as 150 days or so in cows or mares. In such stages, the amplitude of fetal QRS is so small and only a little higher than noise level so that a clear F-ECG may be obtained only by certain limited leads such as from the right side flank, rectum or right abdomen, whereas it may be difficult to record by other bipolar leads. Furthermore, from 150 days of pregnancy onward, F-ECG can easily be detected by most leads. These findings were

ascertained by this study. Undoubtedly, the QRS spike in F–ECG from right side leads was more predominant than from left side ones. The rectal lead was also excellent throughout the recording periods. Therefore, it is recommended that F–ECG recording be accomplished first by right side leads or the rectal lead, and then by other leads.

In this experiment, the authors failed to demonstrate F–ECG in cattle before 146th day of gestation. Likewise, some other investigators (LARKS et al.[12] in cattle; AMADA & SENDA in horses) have not succeeded before about 5 months of pregnancy. The reasons are still unknown, but some workers in human medicine[3,11,16] suggest that there are many factors which give affection to possible recording F–ECG in early pregnancy. In human subjects[4], it is generally recognized that the positivity of F–ECG decreases during 27~34 weeks of gestation, despite higher positivity of F–ECG before such stages. The causal factors of this phenomenon are still obscure. In this experiment, however, no temporary decrease in positivity of F–ECG was observed throughout the recording periods. In addition, a decline of decrease in fetal QRS amplitude at limited periods as shown in human subjects was also never noticed.

According to LARKS et al.[12], the F–HR calculated from F–ECG in two pregnant cows was 144 in 5 months of pregnancy and 132 in 6.5 months, respectively. In the present study, the variation of F–HR was not so great, but a gradual decrease of F–HR was noted with the progress in fetal development in cattle. Similar decline in F–HR was also reported in race horses[1] and in humans[16]. From the results of long time recording, it seems that the fetal heart rhythm is not usually stable but is variable with a type of paroxysmal tachycardia which may be caused by unknown factors. In order to make clear the cause, much more work will be required on fetal physiology.

At present, F–ECG pattern can give less aid for diagnosis of myocardial conditions of the fetal heart, although rhythmical abnormality can be checked by the appearance of fetal QRS. Except for differences in polarity of the initial deflection of fetal QRS and in its amplitude, there is no crucial difference in F–ECG pattern depending on different leads or different stages in pregnancy. Therefore, the feature of F–HR and rhythmical abnormality is very interesting in F–ECG.

Clinical application of the F–ECG technique in the cow will probably become most helpful for giving an accurate diagnosis of fetal death after middle stage of gestation, when fetal mummification or maceration frequently occurs in cattle. The technique, however, may be useless for the diagnosis of early pregnancy of cows at present. Another hopeful use of this may be an application for the diagnosis of multiple pregnancies. Two cases of twin pregnancy were accurately diagnosed electrocardiographically by the authors during the course of the present

study. The details concerning F–ECG in twin pregnancy will be reported in the next paper of this series[8]. Undoubtedly, future advance in fetal electrocardiography may contribute to the progress in physiological or pharmacological studies of fetal life and parturition, as has been suggested by several authors both in the human medicine[2,7] and the veterinary field[1,12].

SUMMARY

Some fundamental problems on fetal electrocardiogram (F–ECG) were studied with 10 pregnant Holstein cows at various gestational stages.

The results obtained will be summarized as follows:

1) It is possible to obtain a satisfactory F–ECG without electrical noise by the application of special electrodes and some suitable lead methods in dairy cattle under experimental or field conditions.

2) The positivity in F–ECG is 100 per cent during the period from 146 days of pregnancy to termination, whereas, at more early stages, F–ECG cannot be recorded by the procedures taken by the present authors.

3) The fetal heart rate has a tendency to decrease with the progress in fetal growth, averaging about 142 per minute at 161~190 days in gestation (I), 141 at 191~220 days (II), 128 at 221~250 days (III) and 120 at 251~280 days (IV), respectively. The differences between stages I vs. III, I vs. IV, II vs. III, and II vs. IV are statistically significant (P<0.01).

4) The pattern of fetal QRS complex varies depending on the different lead methods applied or gestational stages, particularly with its amplitude and polarity of initial deflection. Throughout the whole recordable period, the detection of F–ECG is usually superior when utilizing leads from the right side abdomen or rectum to other leads.

5) The clinical application of the F–ECG technique will be effective toward an accurate diagnosis of fetal death at the later half of gestation or multiple pregnancies.

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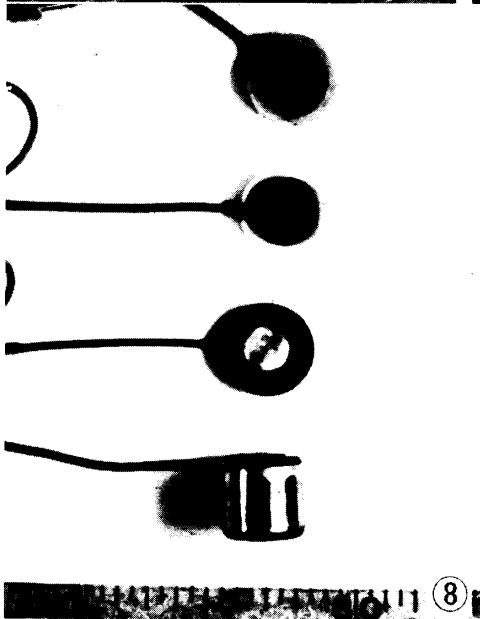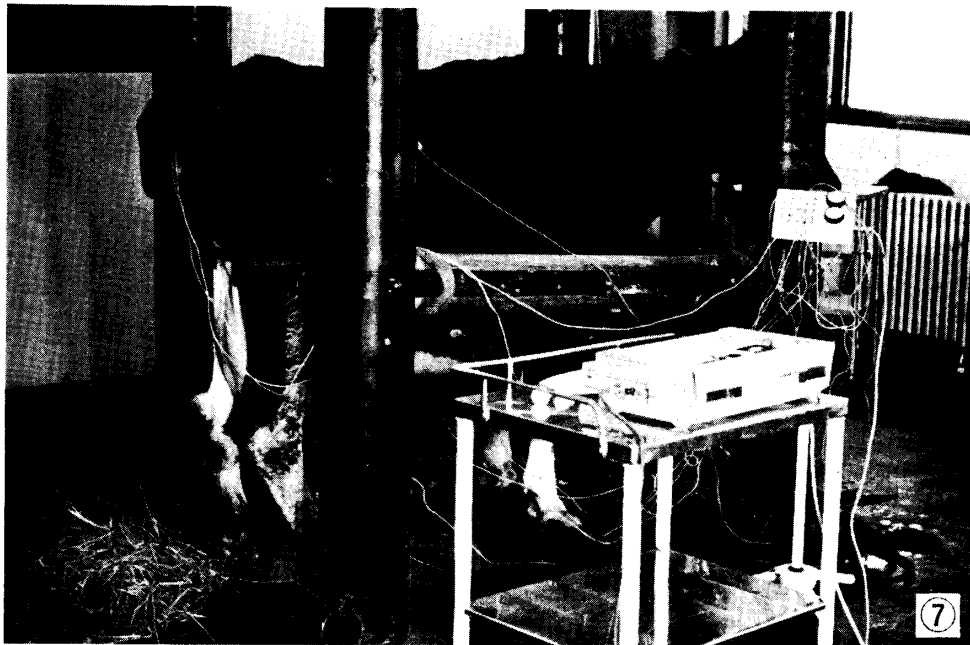
EXPLANATION OF PLATES

PLATE   I

Fig. 10   Electrocardiograms at 133rd day of gestation

No fetal spikes are seen in this stage.

a : Lead 2-3

Spikes indicated as "M" mean maternal QRS and spikes with irregular intervals indicated as black spots are maternal electromyogram

b : Lead 22-2

A group of irregular spikes (right) is electromyogram.

c : Lead 2-1

Only maternal QRS is observed.

Fig. 11   Fetal electrocardiograms at 146th day of gestation, which are the earliest decisive F-ECG.

a : Lead 1-2

Fetal spikes are indicated by signs of "f" and black spots.

b : Lead 2-31

Fetal spikes with regular intervals can be seen.

c & d : Isolated traces copied from b

"M" is matenal ECG and "F" is fetal one.

2 - 3   50μv 1 sec
M   M   M   M   M   ⑩ ⓐ

22 - 2
M   M   M   M   M   ⓑ

2 - 1
M   M   M   M   M   ⓒ

1 - 2
f f f f f f f f f f f f f
M   M   M   M   M   ⑪ ⓐ

2 - 31
f f f f f f f f f f f
M   M   M   M   ⓑ

M   ⓒ
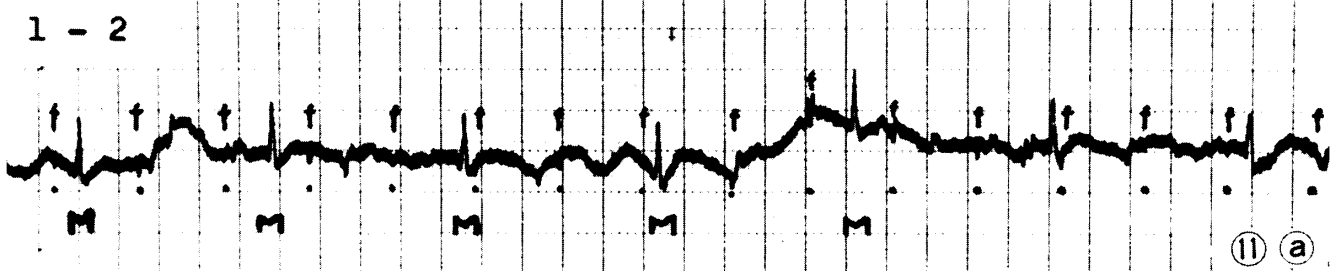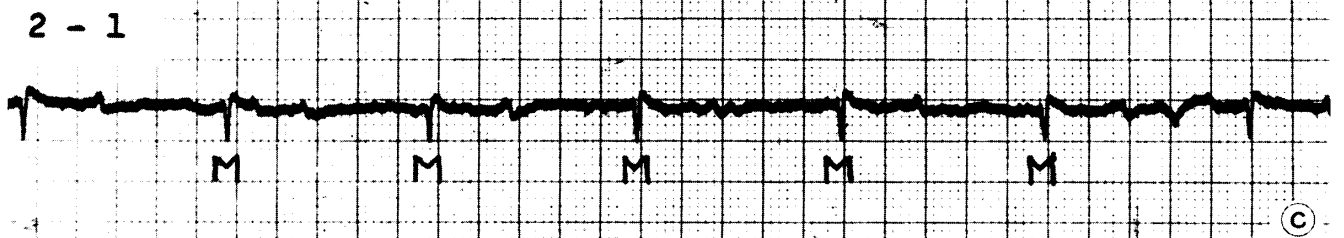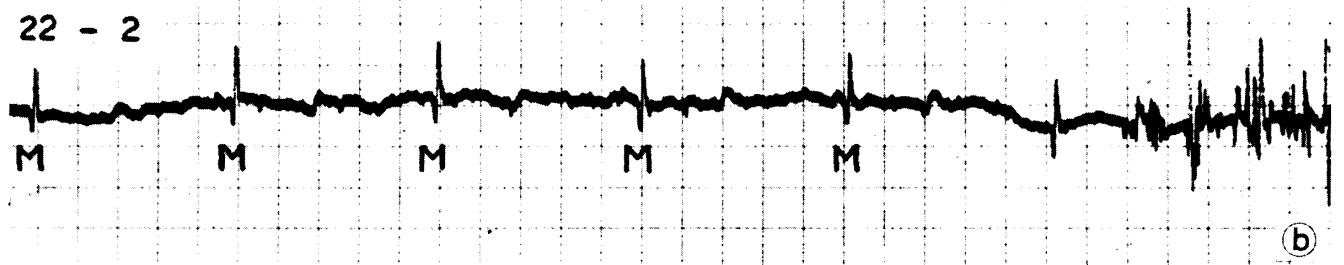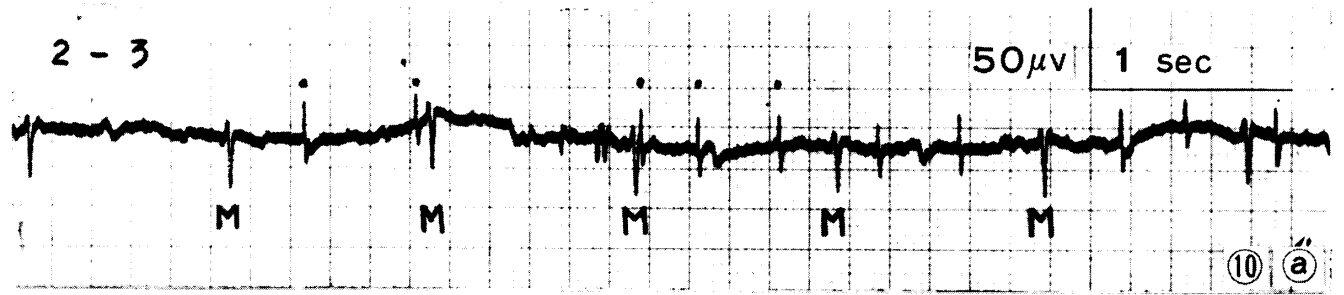
f   ⓓ
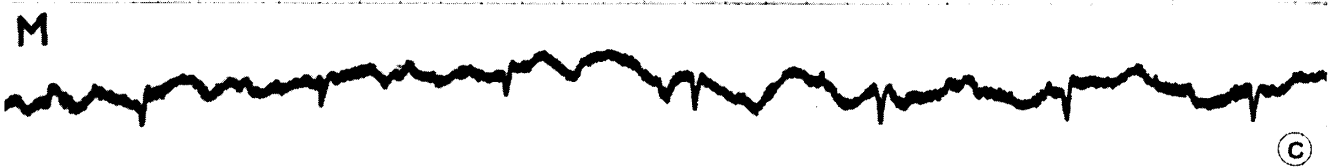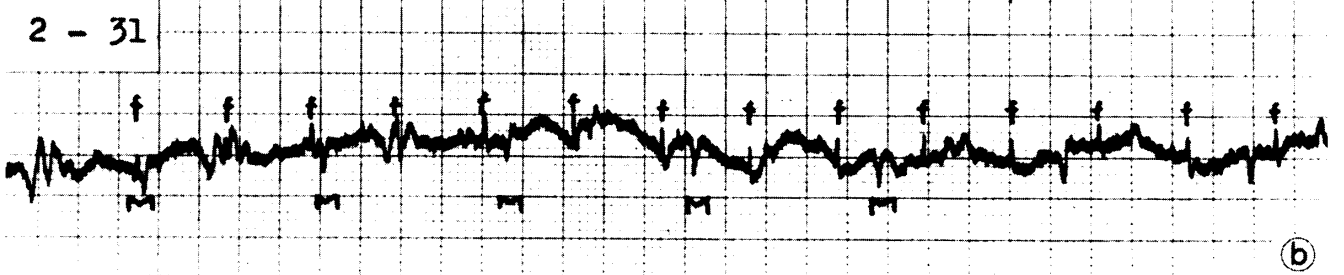
PLATE III

Fig. 12 Fetal electrocardiograms at 203rd day of gestation

a : Lead 1-22

Fetal and maternal spikes can be clearly identified.

b & c : Isolated traces of maternal and fetal ECG copied from a

d : Lead 3-31

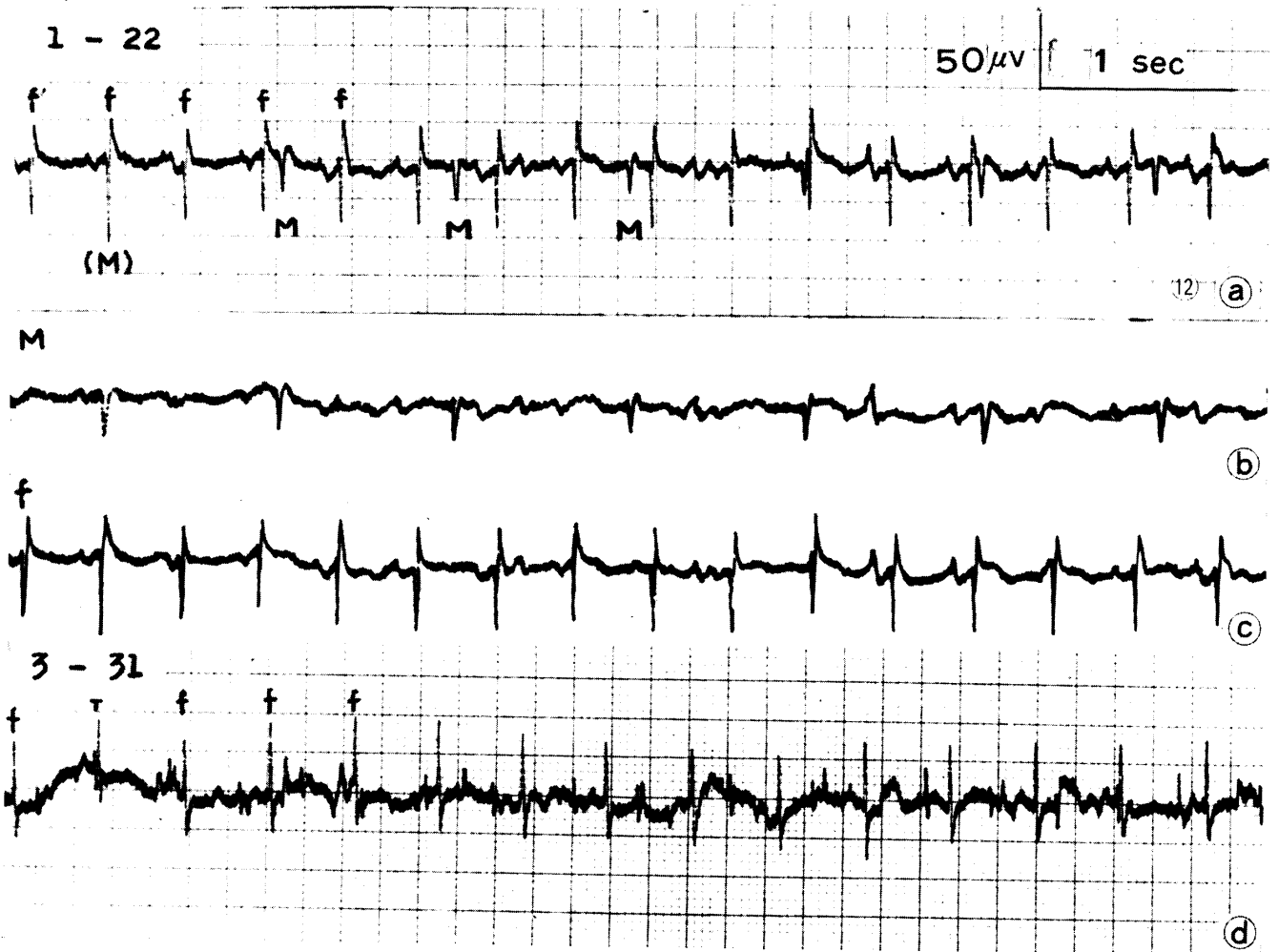Fetal spikes with high amplitude are observed, whereas maternal QRS are lacking.

Fig. 13   Fetal electrocardiograms at 274th day of gestation

a : Lead 21- 2 ⎫
b : Lead 21- 3 ⎭   Both fetal and maternal QRS are obvious.

c : Lead 22- 2 ⎫
d : Lead 22- 3 ⎭   Only fetal spikes are seen.

e : Lead 12-21 ⎫
f : Lead 13-21 ⎭   Maternal QRS is evident, but fetal one is not recorded.

g : Lead 12-22 ⎫   Fetal QRS is clearly seen, whereas maternal one is
h : Lead 13-22 ⎭   not observed.

PLATE IV