ANALYSIS OF THE FETAL ELECTROCARDIOGRAM

SATOKI NINOMIJA, HAJIME MUROOKA
AND KOETSU ISHIKAWA

(Received Nov. 30, 1966)

The fetal EKG is generally easy to intermix with murmurs and the amplitude of fetal waves (vibration) is diminutive in many instances, so that it is often indecipherable. Clinically, we would like to confirm the existence of the embryo by the fetal EKG, for example, bleeding during the period of pregnancy. We endeavored to settle the indecipherable recording by statistical transaction; its problem is the affirmation of periodic weak signs of fetal waves which are comprehended in various murmurs.

1. Fetal electrocardiogram (EKG)

The fetal EKG is the electric potential charge of the embryo which is inducted from the abdominal wall (in some occasion from the vaginal wall) of a pregnant woman and it is a method of acquiring informations from the fetal heart. The factors which cause lucidity of the fetal EKG are the murmurs such as impedance between maternal abdominal wall skin and electrode, electromyogram of maternal rectus abdominis, maternal EKG, etc. In addition, the amplitude of the fetal vibrations is very small especially in the beginning of gravidity. Fortunately, however, it shows periodical appearance. Owing to the living body, of course, its cycle has a few variations. Up to today, in inspecting fetal waves, it has been considered to eliminate murmurs and make the amplitude of fetal waves as big as possible by electro-technology and by other various methods.

2. Inspection method of the simple fetal EKG

From fetal electrocardiometers in ordinary hospitals, only the data shown in Fig. 2.1 were obtained. From this data it was not possible to decide whether or not there were any fetal waves. Accordingly, the existence of periodic signs was deduced by using the formulated pro-

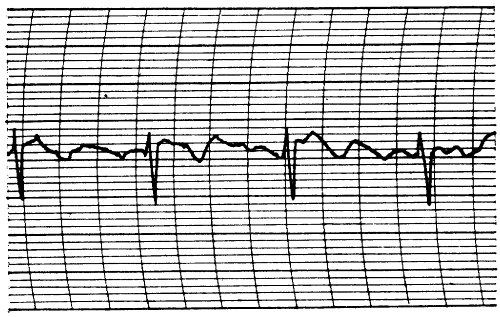

Fig. 2.1 Fetal EKG (pregnancy *v*)

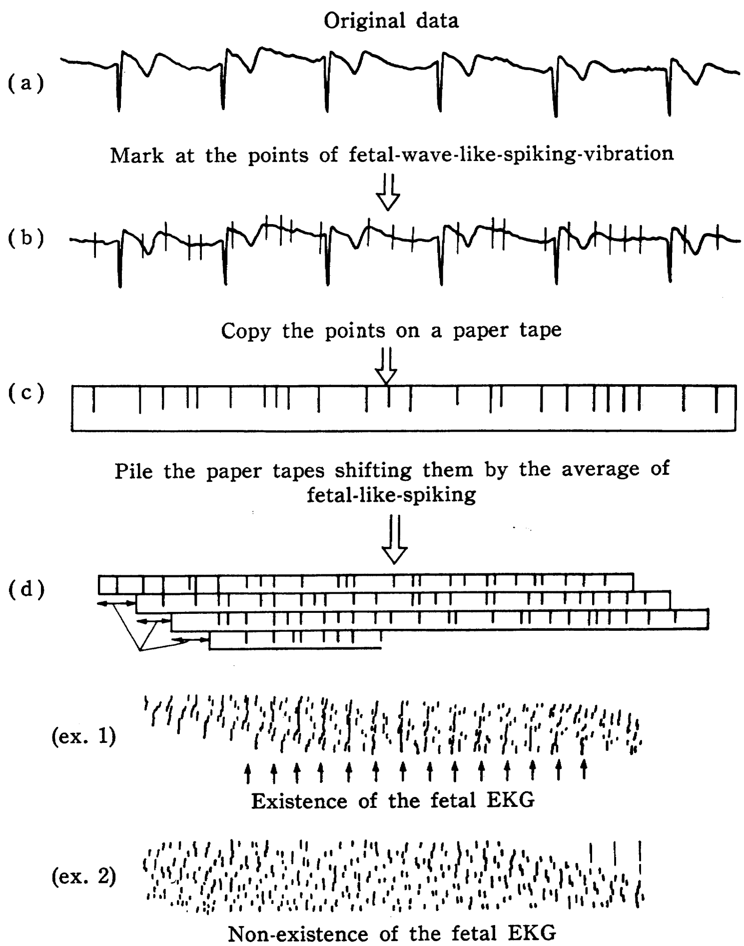

Fig. 2.2

cedure as shown in Fig. 2.2 and then the artificial auto-correlation was simply acquired.

We announced this method for the first time in 1965 together with clinical records at the Japanese medical conference. At present, this method is used practically and its merit is widely accepted.

A characteristic feature of this method is that if an electrocardiometer is used, anyone can easily operate it without other special machines. If the physician has various experience in skillful discrimination of fetal spiking waves, he will be able to work accurately at the point of fetal-wave-like-spiking-vibration as shown in Fig. 2.2 b). On the other hand, if he has little experience, he will misinterpret the fetal waves at the point b), or he may unnecessarily mark at the points which there are no fetal waves and may cause many errors in the following step.

The defect of this method is that when a long recording is taken, poor results occur owing to the jolting of fetal periodic heart beats. This result will always arise as long as one deals with an auto-correlation. In order to prevent this, two paper tapes of c) inductions should be separately prepared from the electrocardiogram with one placed upon the other, from which a cross-correlation can be obtained. If there are only a few inductive numbers, the mixed auto-correlation and cross-correlation should be used. If there are three leads, for example, one should prepare four c) from each lead, and search for their auto-correlation separately. From these three pairs of auto-correlations, an investigation on the existence of cross-correlation should be made. In the d) operation, the numbers of points were added, but they may be multiplied.

This method has its limit; it is impossible to decide the existence of the fetal EKG when there are too much noise, or too much disperse of the fetal periodic heart beats or when the data is too short.

3. Automatic examination method

The methods stated hereafter are all digitalized wave types of the fetal electrocardiogram; and, in order to transact with the digital computer, the data were digitalized at the ratio of 400 samples per second.

In the examination of fetal waves, the maternal EKG and myogram will affect as murmurs; therefore, the following test was tried in order to debar these effects.

a) Method of removing the average maternal EKG

Choose as data one which contains about six cycles of maternal electrocardiograms $x(t)$, and then make the average pattern of maternal EKG $y(t)$. Namely, by using the Ninomija-Kimura method, move the beginning of each QRS complex in maternal EKG so that one lies on the top of the other. After piling up the average maternal EKG, subtract $y(t)$ from original data as shown in Fig. 3.1: $z(t)=x(t)-y(t-g_i)$. Here g_i is the beginning point of each QRS complex in maternal EKG. Obtain the auto-correlation of $z(t)$. Or by such a method, from some other leads, make $z^1(t), z^2(t), \cdots$. Then search for cross-correlations.

------- average of maternal EKG

——— original data

Z(t) is the difference of two curves.

Fig. 3.1

b) Method to make 0 at the area of maternal EKG

Change to 0 the part (QRS complex to T) which is clearly indicated in the maternal EKG, and make $z(t)$ as given in a). Although the fetal waves disappear from the portion of maternal QRS to T with such a change, there is no hindrance since there is a long period of search for the auto-correlation.

c) Method of using two filters

In the methods of a) and b), murmurs of the maternal electromyogram and an alternating current (50 c/sec in Tokyo) were ignored. Therefore, the following method should be adopted for the recording which has many murmurs. The formulated procedure shown in the flow-chart of Fig. 3.2 was prepared. In this method, we used a small-sized electronic computer OKITAC-5090, but if one makes exclusive use of a hybrid computer, one would be able to manage at a moderately low cost.

(1) Original data: The data of the fetal EKG is recorded with various murmurs. This data is digitalized at 400 samples per second.

(2) 1st filter: A moving average was compiled from N samples taken from original data X_i and was named X_{1i}. $N=8$ in this operation.

$$X_{1i}=\frac{1}{N}(X_i+X_{i+1}+\cdots+X_{i+N-1})\ .$$

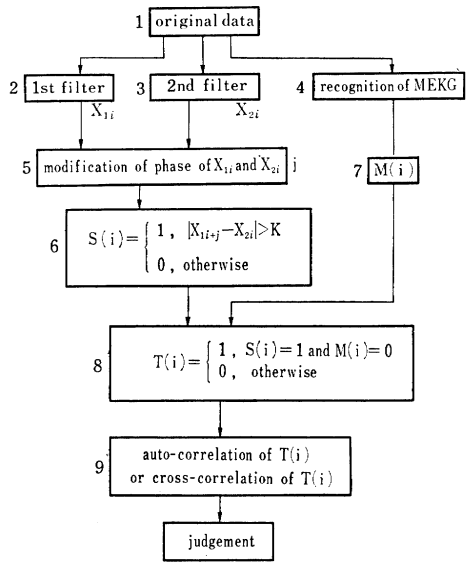

Fig. 3.2

(3) 2nd filter: The same procedure as (2) was carried out and a moving average was named X_{2i}, but $N=32$.

By the (2) transaction, the murmurs which have higher vibrations than the fetal waves are eliminated, and by the (3) operation, the murmurs which have same vibrations as and higher vibration than the fetal waves are excluded.

(4) Recognition of the maternal EKG:

By the Ninomija-Kimura method, the beginning and end of QRS complex of the maternal EKG should be recognized.

(5) X_{1i} and X_{2i} have a different phase. The correction of the phase should be made by the method shown in Fig. 3.3. This revision of the shift value is named j.

(6) $S(i)$:

$$S(i)=\begin{cases} 1, & |X_{1i+j}-X_{2i}|>K, \\ 0, & \text{otherwise}. \end{cases} \quad \left(\begin{array}{l} K \text{ is a constant but must} \\ \text{be changed at the murmur} \\ \text{level of original data} \end{array}\right)$$

Videlicet, let the parts with a bigger difference between X_{1i} and X_{2i} be 1, and other parts be 0.

(7) $M(i)$: Refer to the maternal EKG which is confirmed at (4), and make $M(i)$ in the following manner.

$$M(i)=\begin{cases} 1, & \text{when maternal QRS spike exists,} \\ 0, & \text{otherwise.} \end{cases}$$

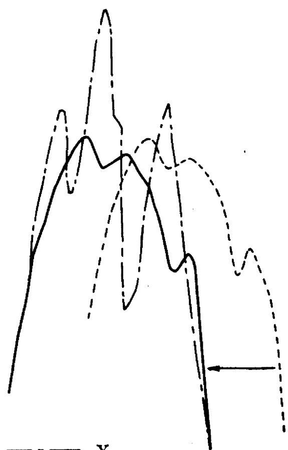

Fig. 3.3

(8) $T(i)$:

$$T(i)=\begin{cases} 1, & S(i)=1 \quad \text{and} \quad M(i)=0\ , \\ 0, & \text{otherwise.} \end{cases}$$

Namely, $T(i)=1$, if $S(i)=1$ (the area which seems to be the fetal QRS complex) and $M(i)=0$ (which is not the maternal QRS complex). If the data is long, there is no inconvenience even though one takes $S(i)$ as $T(i)$ without taking the above procedures.

(9) Auto-correlation of $T(i)$: Obtain the auto-correlation of $T(i)$. If there are high peaks in the curves of the auto-correlation of $T(i)$, the existence of the fetus can be affirmed. If there are no high peaks, then the result is negative.

In the method c) we replace the data with 0 and 1; however there is no difference in making $T(i)=X_{1i+j}-X_{2i}$ when the effect of the maternal EKG is low. And only one lead recording was calculated here, but if the complicated leads $T_1(i)$, $T_2(i)$ are made, then cross-correlations should be calculated so that the good result can be obtained even in the case of vibration in the fetal periodic heart beats. This method is becoming more valid.

4. Statistical problem

The methods stated in sections 2 and 3 apply to the recordings which do not easily conclude the existence of fetal waves owing to a large variety of murmurs. When this method is used, the existence of fetal waves are easily determined and affirmed without errors. In short, as many spikes as possible similar to the fetal QRS complex were selected from the recordings and as many spikes as possible not similar to the fetal QRS complex were disposed of. This was done by the medical doctor in section 2, and done by the automatic machine in section 3 from which auto-correlations or cross-correlations were obtained. This is the spontaneous result in the medical field when data shows various differences and uncertainties. It can be recognized from the results as shown by dotted lines in Fig. 4.1, whether or not this method of disposition is pertinent. When the procedures of transactions (1) and (2) were reversed, the management method was all together in vain. We consider it of great importance in respect to statistical problems to compile a meaningful disposal formula of data in a broad sense of information theory.

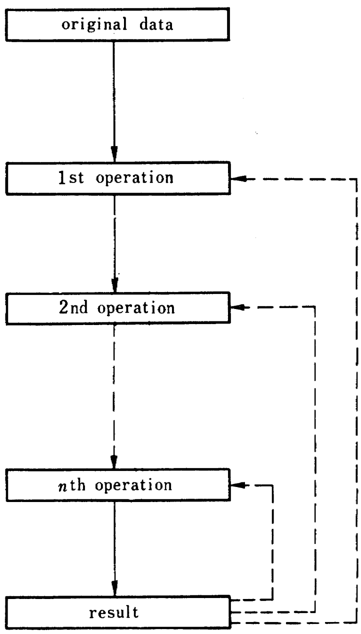

Fig. 4.1

5. Medical problems

In heightening the ratio of fetal EKG inspection, we consider it extremely desirable not only to widen the area of application of the fetal EKG in the clinical field, but also to determine the cases of bleeding pregnants. In this aspect, this manipulation is an essential problem.

Dept. of Science and Engineering, Aoyama Gakuin University
Dept. of Obstet. and Gynec., Nippon Medical School
Dept. of Obstet. and Gynec., Nippon Medical School