THE FETAL ELECTROCARDIOGRAM:
THE SIGNAL AND ITS PROCESSING

A thesis submitted in partial satisfaction of the requirements for the degree of Master of Science in Engineering

by

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ABSTRACT

THE FETAL ELECTROCARDIOGRAM:
THE SIGNAL AND ITS PROCESSING

by

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On the undertaking of studying a biomedical engineering system, it is of value to be aware of the system's total domain; in other words, an examination of its medical, engineering, and biomedical engineering aspects enables a more appreciative and perhaps profitable understanding. It is with this perspective I approached the writing of a paper on the processing of the fetal electrocardiogram. This study is based on papers and laboratory work done under Dr. E. H. Hon.

After a brief description of the electrocardiogram, an examination is made into the importance of the fetal electrocardiogram. Different categories of fetal heart rate variation are defined; these classifications are then shown to be of diagnostic value for different conditions of fetal stress.
The fetal electrocardiogram processing system is then described. After playing the recorded fetal signals on an analog tape unit, the waveforms are then conditioned, digitized, and averaged. The signal processor generates a "sampling window", based on the peak of the waveform, and provides a digital and analog output after every eight samples.

The products of the processing system consists of two different strip chart recordings and a digital computer print-out. The strip chart recordings contain the raw data, time coding, sampling event marking, and analog averaged fetal electrocardiogram. The computer print-out contains the digitized converted fetal electrocardiogram information and various amplitude and duration parameters. A sample of data produced by the FECG processing can be found in the appendix.
I. INTRODUCTION

The fetal electrocardiogram (FECG) is a projection of the cardiac electric potential generated by the fetus. Similar to the adult ECG, where abnormal patterns are of diagnostic value, deviations from normal FECG readings can be used as an aid to determine fetal stress. However, unlike its adult counterpart, an elaborate system is needed to extract the fine details of the FECG waveform.

Awareness of the importance of fetal heart condition dates back to 1893, when von Winckel first made an association between fetal bradycardia, a decrease below normal fetal heart beat rate, and fetal stress (10)*. Since then, however, von Winckel's hypothesis has been proven to be an incorrect generalization (6).

The recording of the FECG, first reported by Cremer in 1906 (2), opened a new dimension in the evaluating of fetal heart condition. With the use of a standard stethoscope, fetal heart activity cannot be detected until the twentieth week of gestation. But using an FECG monitor, a positive indication of a live fetus can be detected as early as the eleventh week and in most cases no later than the sixteenth week (9). Thus the electrical signal

*Parenthetical numbers refer to references in bibliography.
generated by the fetus enables an earlier diagnosis of a newly created life than that possible with the fetus' audible heart sounds.

Present FECG recording techniques are of two types, transabdominal and transcervical. Each of these techniques have certain advantages which makes them suitable for specifically desired information.

The transabdominal method is the taking of the FECG via the mother's abdominal wall and uterus. In this way three main facts about the fetus can be established (8). They are:

1) Fetal life,
2) Multiple pregnancy, and
3) Fetal presentation.

The transcervical method records the FECG while the mother is in labor. The electrodes are placed directly to the fetal presenting area (6). This technique provides a strong, clear FECG that is suitable for an analysis of the waveform. It is this method that is the basis of the FECG processing system to be presented.
II. ECG THEORY

Before examining the details of the FECG, it is necessary to be familiar with some of the characteristics of the ECG. Many of the characteristics of the FECG correspond to those of the ECG; it is generally in the area of wave duration and amplitude that the FECG differs from the ECG.

The different parts of the FECG waveform, generated by the heart's pacemaker and conducting system, correspond to various events in the cardiac pumping cycle (3). The origin of the electrical impulses, which are the basis of the ECG pattern, is a bundle of specialized neuromuscular tissue known as the sinoatrial node. Because of its initial generating capacity, the sinoatrial node is known as the primary pacemaker. The impulse it generates which spreads through both atria, comprise the part of the ECG waveform called the P wave.

After traversing across the internodal atrial pathways, the impulse reaches a bundle of tissue called the atrioventricular node. This node, capable of initiating impulses in the event of a malfunctioning sinoatrial node, is known as the secondary pacemaker.
Traveling past the atrioventricular node, the cardiac impulse is conducted along the bundle of His, the right and left bundle branches, and then the Purkinje system. These various conducting systems are shown in Figure 1.

The ECG waveform provides a record of the impulse as it travels across the different parts of the conduction system. The components of the ECG waveform and the cardiac events which correspond to each of its individual waves are shown in Figure 2.

Synchronized by the action of cardiac bioelectric impulses, the heart is able to fulfill its function as the source of pressure forcing the blood along its pathways throughout the body's vascular system.
Main components of the cardiac conduction system (3).
Figure 2

An ECG record showing the different shapes of the PQRST waves. Above are the cardiac events that coincide with each of the different bioelectric phenomena (1).
III. THE IMPORTANCE OF THE FECG

With the development of equipment capable of monitoring the FECG, it became apparent that deviations from a normal range of FECG readings corresponded to certain conditions of fetal stress. Subsequently, it was necessary to establish guidelines for limits of normality, and the recognition of the conditions that were the cause of the fetal stress.

Dr. E. H. Hon, and others working in his laboratories, have come up with a working classification of different conditions associated with the varying characteristics of the FECG (4), and with measurements of normal and abnormal FECG waveform characteristics (6,7). These studies comprise the basis for the FECG processing system and the subsequent categorizing of the FECG waveform into its specific diagnostic classifications is the end to which the processing system endeavors.

FETAL HEART RATE

A signal closely associated with, and derived from the FECG is the fetal heart rate (FHR). The FHR is a measure of the duration between peaks of the R wave of the FECG. It is this signal, together with a signal from the maternal uterine contractions (UC),
that opens the path for a correlation between differences in fetal heart performance and fetal stress (4).

A record of the UC signal is usually presented alongside the printed FHR as shown in Figure 3. The FHR is measured in beats per minute and the UC in mm. Hg. This continuous record provides a constant monitoring of the instantaneous FHR and allows correlation with the UC for any given instant. Any method that would not provide an indication of instantaneous FHR, such as stethoscopic sampling or an average FHR monitor, bypasses short duration FHR variations that can be of diagnostic value. This situation is illustrated in Figure 4.

There are two major types of variations associated with the FHR (4). Changes that occur which represent a rising or falling of the base FHR level (the quiescent level) are called baseline changes. Changes that occur having specific waveshapes are called periodic changes. Within each of these two categories are subcategories of FHR variations that enable a more accurate classification of any given FHR pattern.

The baseline FHR levels are described over ten minute intervals. If there are baseline changes having less than a ten minute duration, they are described according to the duration of their variation. The two major distinctions, constituting an abnormal baseline FHR level, are a rising or a falling of the baseline above or below limits of normality. The condition where the baseline rises above 160 bpm is called "tachycardia"; the condition where the baseline falls below 120 bpm is called "bradycardia".
Figure 3

A strip chart recorder printing out records of Fetal Heart Rate (FHR) and Uterine Contractions (UC) (4).
Figure 4

An illustration of the loss of important FHR information by using an averaged FHR recording technique (4).
A subcategorization of baseline FHR is the recognition of varying amounts of fluctuation. The different classifications are:

1) No irregularity—no visible fluctuations,
2) Minimal irregularity—less than three per cent of the baseline FHR,
3) Average—four to nine per cent of the baseline FHR,
4) Moderate—ten to fifteen per cent of the baseline FHR,
5) Marked—greater than fifteen per cent of the baseline FHR.

Illustrations of the different classifications of baseline FHR changes are shown in Figure 5 and Figure 6.

Periodic FHR changes are initially classified as either a periodic increase or decrease. The periodic increase is called an "acceleration" and the periodic decrease is called a "deceleration". The periodic FHR deceleration is then classified into three sub-classifications depending on its timing relationship and shape with the UC wave.

The three classifications of the periodic FHR deceleration waveform are called "early", "late", or "variable". The early deceleration waveform is characterized by having a uniform shape and has a timing relationship with a consistent early onset, with respect to the UC waveform. Similarly, the late deceleration waveform has also a uniform shape but differs from the early deceleration waveform by having a consistent late onset with respect to the UC waveform. The variable waveform has neither of the former two
The different categories of baseline FHR (4).
Various degrees of baseline FHR irregularity (4).
waveform's characteristics; rather, it has a variable waveshape and shows no consistent time relationship with the UC. Examples of the above three are shown in Figure 7.

The value of the various schemes of FHR pattern classification becomes apparent with the identification of different types of fetal stress. Corresponding to a specific kind of stress on the fetus, there will be a definite FHR or FHR and UC pattern. Using the previously discussed method of pattern classification, a table of pattern characteristics versus type of fetal stress is compiled (4,5).

FETAL STRESS

A source of fetal stress is attributed to the mechanical energy of the mother's uterine contractions. Possible areas affected by these contractions are diagramatically shown in Figure 8. They are the fetus, umbilical cord, or intervillous space blood flow.

The uterine contractions' stress on the fetus can be the cause of an increased pressure on the vertex of the fetal body. This pressure, called head compression, is thought to be associated with a decelerating FHR, not falling below 100 beats per minute, and of a duration of less than 90 seconds. The baseline FHR is usually in the normal range. However, the main characteristics of this condition are an early deceleration pattern, with respect to each of the uterine contraction waveforms, and the FHR deceleration being of a uniform shape reflecting the UC curve. This condition is illustrated in Figure 9.
Figure 7

Three different types of periodic FHR (4).

Top—early deceleration, uniform waveshape,
Middle—late deceleration, uniform waveshape,
Bottom—variable onset, variable shape.
Figure 8

Different possible areas that can be placed under stress from uterine contractions (4).
Figure 9

The response of the fetal heart rate to a uterine stress placed on the vertex of the fetus. Note the uniform shape and early onset with respect to the uterine contraction signal (4).
The umbilical cord stress, which can be brought on by the uterine contractions, shows a most marked response on the FHR record. Known as umbilical cord compression, it produces a variable periodic FHR. The duration is variable from a few seconds to a few minutes and is associated with a baseline FHR in the normal to low normal range. The main characteristics are of variable shape and onset with respect to the UC signal. An umbilical cord compression record is shown in Figure 10.

The third type of stress associated with uterine contractions is that causing an interference with interfillous space blood flow. The effects of an increased pressure from a uterine contraction can cause a closing of the venous outflow from the intervillous space. This is followed by a decrease in arterial inflow. What this causes, in essence, is a physiological isolation of the fetus from the mother. The FHR pattern associated with this type of fetal stress is a late, uniform periodic FHR. Called uteroplacental insufficiency, this pressure may cause an FHR in the range of 120-60 beats per minute under severe conditions. The baseline FHR is usually within the high normal or tachycardia range. The main characteristics of this pattern being an FHR pattern reflecting uniform shape in comparison with the associated uterine contraction curve and a late onset relative to the UC wave. Figure 11 illustrates the waveforms associated with an uteroplacental insufficiency condition.

Therefore, given the FHR and UC records of a fetus, it is possible to diagnose the type of fetal stress present. The FECG is
UMBILICAL CORD COMPRESSION

VARIABLE SHAPE

FHR

VARIABLE onset

180

VARIABLE onset

100

50

0

UMBILICAL CORD

Figure 10

The response of fetal heart rate to a uterine stress on the umbilical cord. Note the variable shape and onset with respect to the uterine contraction signal (4).
The response of the fetal heart rate to a uterine stress from a pressure placed on the intervillous space. Note the uniform shape and late onset with respect to the uterine signal (4).
the source of this information, and the FHR is a record of only one piece of FECG data—clearly, then, a greater insight into the fetus' condition can be obtained from a complete analysis of the FECG. This is the goal of the FECG processing system.
IV. THE FECG PROCESSING SYSTEM

The FECG processing system extracts all useful information from the fetus' electrocardiogram. It also processes two other signals which are closely allied to the FECG, the FHR, and the UC patterns.

BASIC COMPONENTS

The FECG signal is obtained from vaginal electrodes (4). The signal is then routed through a preamplifier and a filter. The signal coming out of the filter is in the form of a spike (due to the presence of the QRS complex) which enables each FECG "pulse" to trigger an instrument known as a cardiotachometer (4).

The cardiotachometer provides a constant indication of fetal heart rate (FHR). This is accomplished by providing a voltage which is inversely proportional to the duration between two successive FECG peaks. This voltage is then scaled to a specific heart rate to which it is directly proportional. In this manner an instantaneous fetal heart rate record is produced.

The UC signal is detected using a strain gauge connected to a catheter placed within the uterus. This signal is then sent through a preamplifier in preparation for the processing.
The above three signals, the FECG, UC, and FHR, are recorded on tape. Along with these, a time code is recorded which references the recorded signals with specific events in time. Also recorded is a signal known as the filtered FECG (FFECG) which is obtained from the output of the forementioned filter. The FECG, FHR, UC, and time code are also recorded on paper with an ink recorder, along with certain calibration pulses as a means of maintaining a printed record of the original data.

Once the FECG is ready to be processed, the desired tape is chosen and placed on the analog tape unit. After calibrating the processing system (described later), processing is ready to begin. A schematic of the various components of the processing system is shown in Figure 12.

The five signals coming off the tape each go through a signal conditioner called a normalizer. These normalizers amplify the various signals to the levels appropriate for the instruments to which the signals are feeding. There are seven normalizers. Normalizer one is for the FECG feeding the processor; normalizers five and six are for the FHR feeding the processor and Brush strip chart recorder; normalizers three and four are for the UC feeding the processor and Brush strip chart recorder; normalizer seven is for the time code feeding the Brush strip chart recorder; and normalizer two is for the FFECG feeding a pulse generator. Normalizers three, four, five, and six are adjusted during the calibration procedure and normalizer one is monitored during
Figure 12

The FECG Processing System
processing and adjusted if the FECC signal falls below the required threshold level.

As the signals are being processed, leading up to a final digital output, a constant recording is being made of the pre-processed and processed signals. These recordings are made on an Elema and Brush strip chart recorders.

The Elema strip chart recorder provides a record of the FECC before it is fed into the processor along with a record of the processed FECC, which has gone through an analog to digital and digital to analog converter. Superimposed upon the processed FECC is the average FECC output from the processor, being printed out after every eighth 500 msec. processor sampling period. The averaged FECC is printed out in the form of a code, with the aid of an event marker from the processor, whereby every tenth averaged FECC is printed above the normal line of the processed FECC printout; the other nine averaged FECC's are printed below the normal line of the processed FECC printout. A sample printout of the Elema strip chart recorder is shown in Figure 13.

The Brush strip chart recorder records the FHR and UC signals off the analog tape unit, and two digital signals. One digital signal, the time code, is a binary coded decimal representation of the time the FECC recording took place. The time code, printed out as pulses and blanks, is in hours, minutes, and seconds, and comes off the analog tape unit after being normalized to a level of plus or minus two and a half volts by normalizer seven. The other digital signal, the event marker, comes from the processor and
Figure 13

A sample of the data printed out by the Elema strip recorder. The lower row is the raw FECG data and the upper row contains the averaged FECG in a "one-out-of-eight" sampling printout.
indicates the instant an FECG average is outputted from the processor. The event marking signal, in the same way as that of the FECG average signal code, is printed above the line every tenth sample and below the line for the other nine times. An illustration of a Brush strip chart recorder record is shown in Figure 14.

Three signals are fed into the FECG processor: The FECG, the FHR and the UC. The outputs of the processor are an analog averaged FECG, an event marker signal, and five digital signals which are fed to a digital tape unit for recording. Once on tape, the digital data is processed at a computing facility and an output is obtained with all the important parameters calculated with the aid of a special purpose computer programming language.

THE FECG PROCESSOR

The main product of the FECG processor, given the analog, normalized FECG waveform at its input, is a digitized version of the FECG comprised of 500 words and representing an average of eight successive samples. All the FECG signals are similarly sampled and averaged, until the complete set of analog input signals has been converted to an averaged, digitized output.

After loading the proper programming instructions into the processor control system (a PDP-8/I mini-computer and associated peripheral equipment), the processing is initiated by the typing of instructions on a teletype unit. With a printed out signal signifying the control system is prepared for processing ("ready"),
Figure 14

A Brush strip recorder sample print-out. The digital data on the top row is the time code and on the bottom row (slightly blurred) is the event marker. The second row is FHR data and the third row are UC recordings.
the program name is then typed in ("L, FECG"). The rest of the information typed in is the I.D. number, pattern number, sampling rate, and the threshold level for the peak of the R wave. A teletype input sample is shown in Figure 15.

The main components of the processor, illustrated in block diagram form in Figure 16, performs the function of sampling and averaging. The FECG signal, after being converted to a digital form, is fed into a threshold indicator device. If the signal level falls below a prescribed threshold, the FECG digital data will bypass the comparator circuitry, via AND gate G1, and be processed by the remaining components. However, when the data exceeds the threshold level, the signal is then routed through the comparator logic.

Two sets of flip-flops, termed "new" and "old", provide a word-for-word comparator input storage, allowing a comparison of all incoming data above the threshold level. With a given signal filling the "old" and then the "new", comparison proceeds. If the word in the "new" set of flip-flops is greater than the word in the "old" set of flip-flops, the data from "new" word replaces the "old" word. The "old" word is then shifted into register R1, a 200 word register. Data which comes into register R1 shifts out the data at the end of the register, only allowing 200 words to be stored at a time.

If the "new" word is less than the "old" word, as determined by the comparator, the next set of 300 words is routed to register
READY
L· FEC G

STARTING ID NO. = 1
STARTING PATTERN NO. = 1
SAMPLING RATE (USEC) PER POINT = 500
THRESHOLD FOR "R" PEAK = 100
RC IS CALIBRATED

STARTING ID NO. = 2
STARTING PATTERN NO. = 1
SAMPLING RATE (USEC) PER POINT = 00500
THRESHOLD FOR "R" PEAK = 100
RC IS CALIBRATED

STARTING ID NO. = 3
STARTING PATTERN NO. = 1
SAMPLING RATE (USEC) PER POINT = 500
THRESHOLD FOR "R" PEAK = 100
RC IS CALIBRATED

STARTING ID NO. = 4
STARTING PATTERN NO. = 1
SAMPLING RATE (USEC) PER POINT = 500
THRESHOLD FOR "R" PEAK = 100
RC IS CALIBRATED

STARTING ID NO. = 5
STARTING PATTERN NO. = 1
SAMPLING RATE (USEC) PER POINT = 500
THRESHOLD FOR "R" PEAK = 100
RC IS CALIBRATED

STARTING ID NO. = 6
STARTING PATTERN NO. = 1
SAMPLING RATE (USEC) PER POINT = 500
THRESHOLD FOR "R" PEAK = 100
RC IS CALIBRATED

EDF

Figure 15

The information supplied to the processor's digital control system via teletype input.
The method by which an FECG waveform is digitized, sampled, and averaged.
R2. AND gates G2 and G3, together with an inverter I, enable the routing of words to registers R1 and R2, by means of a control level signal from the comparator.

When register R2 is filled, the data from both registers R1 and R2 are fed into register R3. The process of feeding registers R1 and R2 into register R3 is repeated eight times corresponding to the taking of eight FECG samples; each sample being sequentially added in the adder. When the eighth sample has been taken, as indicated by the step counter and index register, the sample and averaged 500 word FECG is routed out of the adder. Then the data is fed into a digital tape recorder and a digital to analog converter for the Elema strip chart recorder.

The events corresponding to the sampling process is illustrated in Figure 17. Corresponding to the 200 words stored by register R1, is the FECG signal sampled up to the peak of the R wave. Three hundred words past the R wave is the sample taken by register R2. One total sample, stored in register R3, corresponds to a 500 msec sampling of an FECG waveform. In the system, however, the analog input tape is run at twice real time so that a 250 msec sampling period will cover an FECG wave period of 500 msec.

CALIBRATION OF THE FECG PROCESSING SYSTEM

Before any of the FECG data can be processed, it is necessary to insure that the amplitude references and timing standards are accurately adjusted. In between processing tapes, changes could
Figure 17

The "sampling window" of the processor interrogates the FECG waveform before and after the peak of the R wave. For fetal heart rates other than 120 bpm, certain points on the waveform will be overlooked as illustrated above.
have been made in equipment set-up and drift in signal modifying
circuitry could have taken place. The adjustment of amplitude
and timing circuitry comprises the system's calibration.

After loading the program into the minicomputer, the first
step in calibration is the checking of equipment interconnection.
The means by which most of the instruments are interconnected is
through the use of a patchboard. The patchboard consists of three
separate panels which are interconnected via wire jumpers. The
different patchboard interconnections are shown in Figure 18.

Next, the tape to be processed is chosen and placed on the
analog tape unit. Before threading, the heads are cleaned with
xylene preventing interference from collected dust. The tapes are
then threaded, power applied, and the specific tape location is
searched for with the tape's search unit.

When the beginning of the data to be processed is reached,
amplitude calibration is done. Before each recording are calibration
pulses which are taken as a basis for amplitude standards. While
the calibration pulses are being played through the analog tape unit,
adjustments on the normalizers are made. Normalizers 3 and 5 are
adjusted corresponding to a minimum level of -1.0 volt, a maximum
level of +1.0 volt and a 0.0 volt level. These normalizer adjust-
ments are made with the fine gain and zero level controls to an
accuracy of plus or minus 5 mv. Similarly, normalizers 4 and 6 are
adjusted to -2.5 volt, 0.0 volt, and +2.5 volt levels. The monitoring
INPUT OUTPUT PANELS:
(FECG) tape 1 o/p ch 1 to norm 1 i/p
(FECG) tape 2 o/p ch 2 to norm 1 i/p
(UC) tape 1 o/p ch 3 to norm 3 i/p
(FHR) tape 1 o/p ch 5 to norm 5 i/p
  norm 2 o/p to trigger 1 i/p
  norm 3 o/p to norm 4 i/p
  norm 5 o/p to norm 6 i/p

BLACK PATCH PANEL:
  slow code to norm 7 i/p
  norm 1 o/p to bnc 10
  norm 5 o/p to bnc 9
  norm 3 o/p to bnc 8
  bnc 5 to norm 8 i/p

ANALOG PRINT OUT PANEL:
  norm 1 o/p to Elema 2+
  norm 4 o/p to b200 2+
  norm 6 o/p to b200 1+
  norm 7 o/p to markers + (b200+ col.)
  norm 8 o/p to Elema 1+
  b200 (1-7) to b200 (1-7) -
  markers 2+ (b200+ col.) to Elema 2-
  markers 2+ (b200- col.) to Elema 1-
  cat 1 to cat 1-

Figure 18

Patchboard interconnecting jumpers.
of the amplitude calibration is done with two scopes and a digital voltmeter (DVM) as shown in Figure 19.

For purposes of establishing an accurate "sampling window" for the processor, a processor scope monitor is used in conjunction with a triangular wave generator. The generator is set to put out a 4 Hz triangular wave, corresponding to a 250 msec period, and is fed through the FEGG input of the processor. Using the processor scope as a means of adjusting the sampling time of the processor's internal RC clock, the time standard is set for the processing system.

The strip chart recorders are then adjusted for proper full scale deflections and zero levels. The Brush strip chart recorder is watched for proper presentation of time code and event marking. The Elema strip chart recorder is checked for proper average FEGG printout in pulse width and height, and also correct event marking. See figures 20 and 21 for strip chart recorders calibration recordings.

To obtain a calibrated amplitude level on the digital tape, the analog tape's calibration pulses are replayed. When the strip chart recorder prints out a reference level, and then an event marking pulse is displayed, a record is impressed on the digital tape corresponding to the reference amplitude digitized. This process is shown in Figure 22.
Figure 19

A block diagram of the calibration set-up.
Figure 20

Calibration of the Elema strip chart recorder.
Amplitude reference recording on the digital tape recorder. At the moments indicated by the arrows, a digital record is made of each of the amplitude reference levels.
Processing is now ready to proceed; however, the "R" peaks of the FECG waveforms are monitored to insure that they remain above the threshold level. In case they fall below, the zero level of normalizer 1 is raised.

THE OUTPUT DATA

With the digitized FECG on tape, the conversion of raw data to a computational form is completed. The tape is sent to a computer facility where the digital data is printed out together with the desired calculated parameters.¹

A sample output print-out can be found in the appendix.

The different variables calculated and printed out are of two kinds, duration and amplitude.

The duration values printed out consists of six time measurements and one amplitude measurement. They are defined, as programmed by the pattern recognition of FECG (PATREC) program, as follows:

1) Q-R-S From the onset of the Q wave to the offset of the S wave;
2) V-A-T (Ventricular Activation Time) From the onset of the Q wave up to the peak of the R wave;
3) R From the peak of the Q wave up to the peak of the S wave;
4) P From the onset of the P wave up to its offset;

¹Computing assistance was obtained from the health sciences computing facility, UCLA, sponsored by NIH special research resources grant RR-3.
5) P-Q  From the onset of the P wave up to
the onset of the Q wave;
6) Q-T  From the onset of the Q wave up to
the offset of the T wave;
7) S-T  From the offset of the S wave up to
the onset of the T wave.

Along with the duration outputs, single value FHR and UC data are
printed out which coincide with the FECG data.

The amplitude values, as calculated by PATREC, are defined
by the individual waves of the FECG waveform. Inflection parameters
(TMNA, PMNA1, PMNA2) are also calculated as well as baseline levels.
An illustration of the definition of various waveform parameters
is shown in Figure 23.

With these various parameters printed out, data can be
gathered for studies correlating fetal stress versus fetal heart
activity. And consequently, providing a tool for the diagnosis
of fetal distress.
Figure 23

Definition of intervals of the different parameters on the computer print-out.
V. RESULTS AND CONCLUSIONS

In conclusion, the instantaneous fetal heart rate processing method provides an accurate source of fetal stress information. Compared with other monitoring techniques, such as stethoscopic monitoring, where not all of the FHR data is obtained, or FHR are averaged out, the instantaneous monitoring technique is more complete; it provides FHR records with a beat-to-beat accuracy.

The diagnostic value of the strip chart recordings can be seen from the examples in Figures 24, 25, and 26. A sample of the output data from the FECG processing system can be found in the appendix. As of this time, however, no direct quantitative correlation has been made between the digitized FECG data and different conditions of fetal stress. But it is hoped, with the use of the processing system's output, that a numerical method of fetal stress classification can be devised; and that future research will enable mechanization of the FECG processed information as an "on-line" diagnostic tool.
Normal FHR baseline level throughout the record except for the last 10 minutes when moderate bradycardia is present. The minimal irregularity noted in the first two sections of the record is replaced by moderate irregularity in the last section. The periodic FHR changes are those of U.P.I. patterns which are present throughout the FHR tracing. (In the last section U.P.I. patterns are difficult to diagnose because of the moderate irregularity present.) The uterine contractions are occurring at about eight contractions per 10 minutes and the uterine tone is about 25 mm Hg throughout (5).
This record is of cord compression where the first episode is associated with a transitory episode of cardiac arrest. The FHR drops abruptly from a baseline of about 150 bpm to 60 bpm where it remains momentarily before the sinus node is completely depressed and transitory cardiac arrest occurs. With the abrupt fall in FHR the P wave of the FECG is first markedly diminished in amplitude and then finally absent. If the A-V node does not escape, cardiac arrest occurs. In the small number of patients where this has been recorded in our studies these sudden unpredictable episodes of cardiac arrest have been transitory; however, it is not unlikely that in some circumstances cardiac arrest due to this mechanism may be more prolonged or even permanent (5).
Baseline FHR levels vary between a normal level to moderate tachycardia. Average to minimal irregularity and U.P.I. patterns are present. The marked uterine hyperactivity observed in the first section of the record falls to about five contractions per 10 minutes in the last section of the record. The uterine tone is about 15 mm Hg except during uterine hyperactivity when it is about 25 mm Hg. This record demonstrates well the close association between the degree of uterine activity and the severity and frequency of the U.P.I. patterns, i.e., as uterine activity increases, there is an increase in the degree and frequency of U.P.I. patterns (5).
BIBLIOGRAPHY


Appendices

The following three appendices contain samples of the output of the FECG processing system for one patient.
Appendix A

The output of the Elema strip chart recorder. Printed out are the raw FECG and the averaged "one-out-of-eight" FECG.

The numbers in black print are event marking references which can be related to the FHR print out from the Brush strip chart recorders.
Appendix B

The output of the Brush strip chart recorder.

Containing the time code, FHR, UC, and event marking information, it is more compressed than the Elema strip chart output because it is run at a much slower speed.
Appendix C

The output of the computer processed data.

The bulk of the listing contains the digitized FECG data, of which only a few pages are taken. The calculated amplitude and duration parameters appear at the end of the listing.
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**Table Data:**

- Case 1: IV/EH = 0.5, Alpha = 0.3, Beta = 0.2, EOE = 0.1, Delta = 0.05
- Case 2: IV/EH = 0.6, Alpha = 0.4, Beta = 0.3, EOE = 0.15, Delta = 0.07
- Case 3: IV/EH = 0.7, Alpha = 0.5, Beta = 0.4, EOE = 0.2, Delta = 0.09
- Case 4: IV/EH = 0.8, Alpha = 0.6, Beta = 0.5, EOE = 0.25, Delta = 0.11

**Notes:**

- The table above represents various case scenarios with different values for IV/EH, Alpha, Beta, EOE, and Delta.
- Each case is uniquely identified and parameterized to illustrate different outcomes or behaviors.
- The table is designed to provide a clear and organized view of the data for analysis and comparison.