The pre-ejection period of the fetal heart: Patterns of change during labor

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The pre-ejection period (PEP) of the cardiac cycle, fetal heart rate, and uterine contractions were monitored in a series of unselected patients in labor to assess the practicality of our current Doppler ultrasound technique for detecting PEP and to relate any change in PEP to fetal status and fetal heart rate patterns. The results showed that with the dedicated efforts of a research team it is possible to obtain PEP patterns during labor, but that for general use PEP monitoring cannot yet be considered practical. However, its potential value was demonstrated with the observation that PEP changed clinically in a manner predicted in experiments with stressed fetal lambs—umbilical cord compression prolonged PEP and hypoxemia shortened it. These changes are essentially independent of heart rate and therefore PEP can be considered as an independent parameter for fetal assessment.

THE PRE-EJECTION period of the cardiac cycle (PEP) is defined as the interval from the beginning of the QRS complex of the electrocardiogram to the onset of left ventricular ejection, i.e., the onset of aortic valve opening. In a recent study, we showed that when aortic valve opening was detected with a Doppler ultrasound technique PEP could be reliably measured during labor.[1] A concurrent series of experiments on the stressed term fetal lamb showed that both umbilical cord occlusion and hypoxemia (secondary to administration of pure nitrogen to the ewe) produced changes in PEP; cord occlusion caused a prolongation of PEP and hypoxemia shortened it.[2] Moreover, the shortening of PEP from hypoxemia was consistent, whereas the simultaneously monitored fetal heart rate increased at times, decreased at others.

This report considers the technical practicality of the present Doppler ultrasound method of measuring PEP and presents our first findings on the effect of fetal stress on PEP during labor. The measurement of PEP

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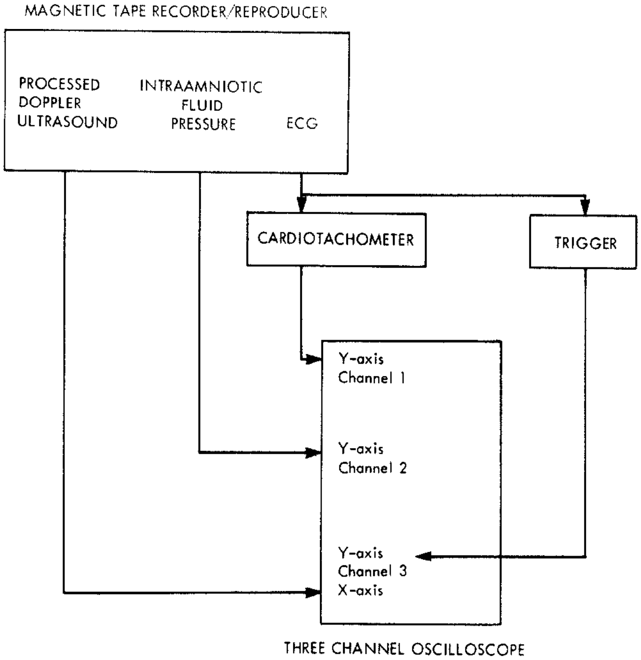

Fig. 1. Electronic instrumentation used to present data for photographic measurement of PEP and FHR patterns.

requires the fetal ECG and some indicator of aortic valve opening. Obtaining good quality fetal ECG's is no problem with fetal scalp leads. The problem of PEP monitoring revolves entirely around the capability, or lack of it, of consistently detecting aortic valve opening. When PEP can be consistently determined over several uterine cycles then a PEP pattern, comparable in concept to a fetal heart rate pattern, can be obtained by simultaneously displaying PEP duration and intra-amniotic fluid pressure on two channels of chart paper.

Material and methods

Forty-three unselected patients in active labor at Mount Sinai Hospital, Toronto, were used in this study. In each, a scalp clip electrode was applied to the fetal scalp to obtain the ECG, a catheter inserted transcervically into the amniotic cavity to record uterine contractions, and an ultrasound transducer positioned on the mother's abdomen to detect aortic valve opening using a technique described previously.[1] It consists essentially of amplifying the broad band Doppler ultrasound signal and eliminating low-frequency myocardial wall components from the higher frequency valvular components by using a high pass filter centered at 1,000 hertz. The signal, now a short burst containing frequencies in a band about 1,000 hertz, is conditioned for display as a pulse-like wave form by rectification and envelope detection. The position of the ultrasound transducer on the mother's abdomen is varied until a valvular area is detected by listening on an audio monitor for the sharp high-pitched sound characteristic of heart valves. The temporal relationship between the Doppler ultrasound wave form and the fetal ECG is observed on an oscilloscope to ensure that the valvular event, or at least one of the valvular events (if more than one is present) being detected is aortic opening.

The fetal ECG, intra-amniotic fluid pressure, and Doppler ultrasound wave form were stored on magnetic tape for subsequent analysis which required a simultaneous plot of fetal heart rate (FHR), uterine contractions, and PEP. Two methods were used to obtain a writeout of PEP:

1. *Manual measurement of PEP and FHR patterns.* This rather laborious method con-

sisted of sampling the output tape data every 5 seconds on a storage oscilloscope and measuring R-R interval for FHR, intra-amniotic fluid pressure for uterine contractions, and interval between onset of QRS complex and onset of aortic valve opening wave form for PEP. In fact, each 5 second point was sampled twice, once with a slow oscilloscope sweep speed for FHR and uterine contractions, and a second time with a faster sweep speed to allow accuracy in PEP measurement. FHR, uterine contractions, and PEP values were plotted every 5 seconds, and adjacent points connected. The manual method was simplified later in the study by using a three channel polygraph and applying the FHR and uterine contraction signals directly to two of the channels. The pen of the third channel was manually controlled to indicate PEP as values were read from the oscilloscope display. Although not done for this study it should be noted that given a good ultrasound signal, it is now possible to completely automate the procedure by electronically determining the value of PEP.[3]

2. *Photographic measurement of PEP and FHR patterns.* The general organization of instrumentation for this technique is shown in Fig. 1. Intra-amniotic fluid pressure is applied directly to the channel 2 Y-axis of the oscilloscope. The ECG is applied to (A) a cardiotachometer for conversion to heart rate which is then displayed on channel 1 Y-axis of the oscilloscope. (B) A trigger circuit.

Channels 1 and 2 have no time sweep, i.e., they are stationary in the X direction. Beam movement occurs only in the positive Y direction, with vertical deflection in channels 1 and 2 proportional to FHR and intra-amniotic fluid pressure, respectively. The processed Doppler ultrasound wave form, representing aortic valve opening, is applied to the channel 3 X-axis of the oscilloscope. Channel 3 has beam movement in the positive Y and negative X directions. The Y-axis is a time base with total sweep time 80 milliseconds, with the sweep triggered by the ECG via the trigger circuit. Once activated the trigger circuit shuts off and cannot be re-

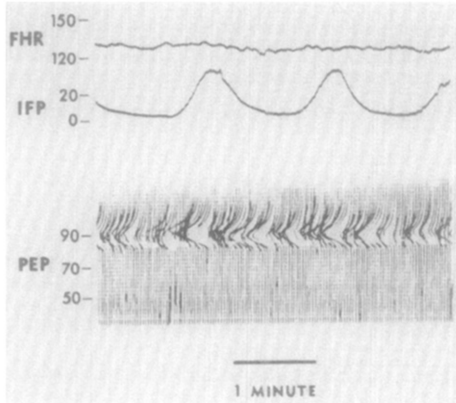

Fig. 2. Record of FHR and PEP pattern obtained by the photographic method. Units: FHR, beats per minute; IFP (intra-amniotic fluid pressure), mm. Hg; PEP, milliseconds.

activated for 2 seconds so that there will be slightly fewer than 30 Y-axis sweeps in channel 3 per minute. The ultrasound wave form appears as a deflection in the negative X-axis direction.

The oscilloscope screen is photographed with a 35 mm. Grass kymograph camera with shutter always open and film moving at a speed of 15 mm. per minute. As a result of the film movement, the stationary display on the oscilloscope screen will be converted to a 35 mm. film record such as shown in Fig. 2, a tracing obtained during uncomplicated labor. PEP is given by the Y-axis deflection in channel 3, measured vertically from the beginning of the sweep to the onset (negative X deflection) of the aortic wave form. Note that the beginning of the sweep is 32 milliseconds, not 0 milliseconds, because the sweep trigger pulse does not occur at the onset of the QRS complex but at some constant point within it, here 32 milliseconds from its onset. The average value of PEP in this record is 80 milliseconds. In our previous series, PEP averaged 73 milliseconds with standard deviation 10 milliseconds.[1] PEP representation becomes more vivid with the photographic method by rotating the figure through 90 degrees to produce a "mountain range" effect. The photographic method was evolved for the present work because the raw data are retained in the display of PEP, and factors such as variability of ultrasound wave

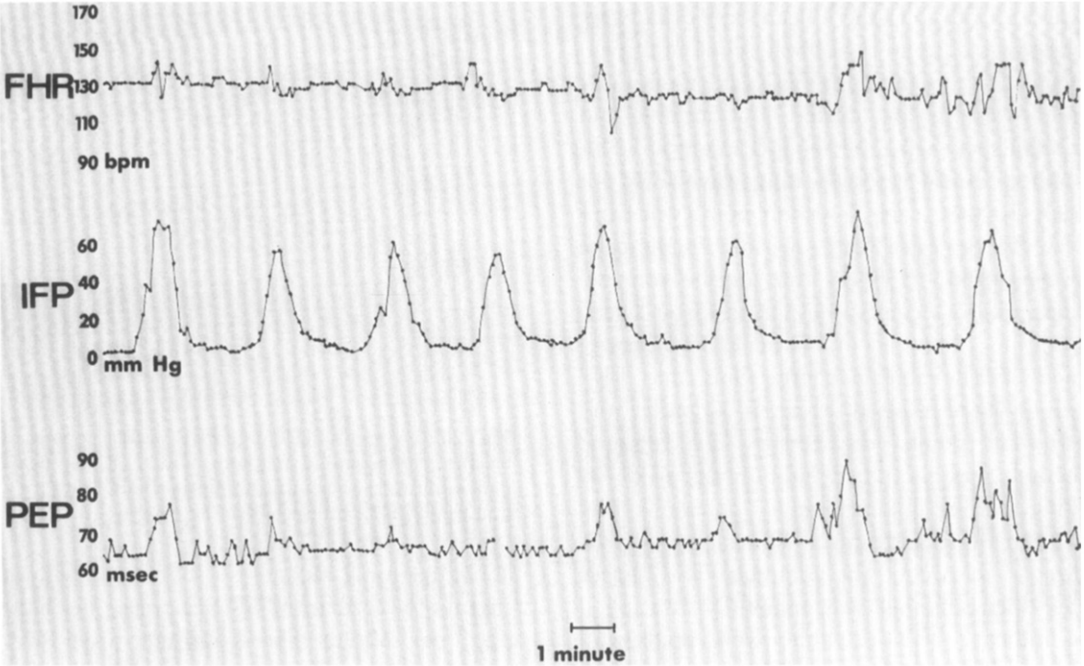

Fig. 3. Record of FHR and PEP pattern, obtained by the manual method, showing prolongation of PEP with uterine contractions.

form, presence of artifacts, detection of mitral valve closure in addition to or instead of aortic opening are readily apparent.

Results

PEP patterns of varying degrees of acceptability were obtained in 39 of the 43 patients studied. Some of the 39 records were practically nonusable because of frequent aortic signal loss, others were technically excellent with long periods of continuously detected aortic valve opening as in Fig. 2. No PEP writeout at all was possible in 4 patients. In 3 this was due to a poorly defined aortic opening wave form, i.e., its onset was either variable or too gradual. In the fourth only mitral valve opening and closing could be obtained. Excellent PEP records were the exception rather than the rule, with the typical result being adequate PEP runs of several minutes' duration interspersed with signal loss due to spontaneous fetal movement or uterine contractions. However, a sufficient number of samplings of PEP retained over several uterine cycles were obtained in this series to allow some degree of confirmation of predictions of PEP change based on the PEP experiments in the stressed fetal lambs.

In general when FHR showed only normal base-line variations between contractions and no acceleration or deceleration patterns with contractions, PEP was observed to have only base-line variations as well. The well-documented inverse relationship between FHR and PEP was often observed under these circumstances when the fetus could be assumed not to be distressed—increased FHR was related to decreased PEP and vice versa. An increase in PEP with contractions could be detected in 7 of the patients monitored. In three of these there was variable deceleration of FHR suggesting umbilical cord occlusion; one showed early deceleration of FHR and one with no significant change in heart rate underwent cesarean section for cephalopelvic disproportion. Another, shown in Fig. 3, had biphasic changes in heart rate during contractions or later widely variable heart rate. This figure was produced by the manual method of measurement and was taken from an uncomplicated labor. PEP consistently increased with contractions in

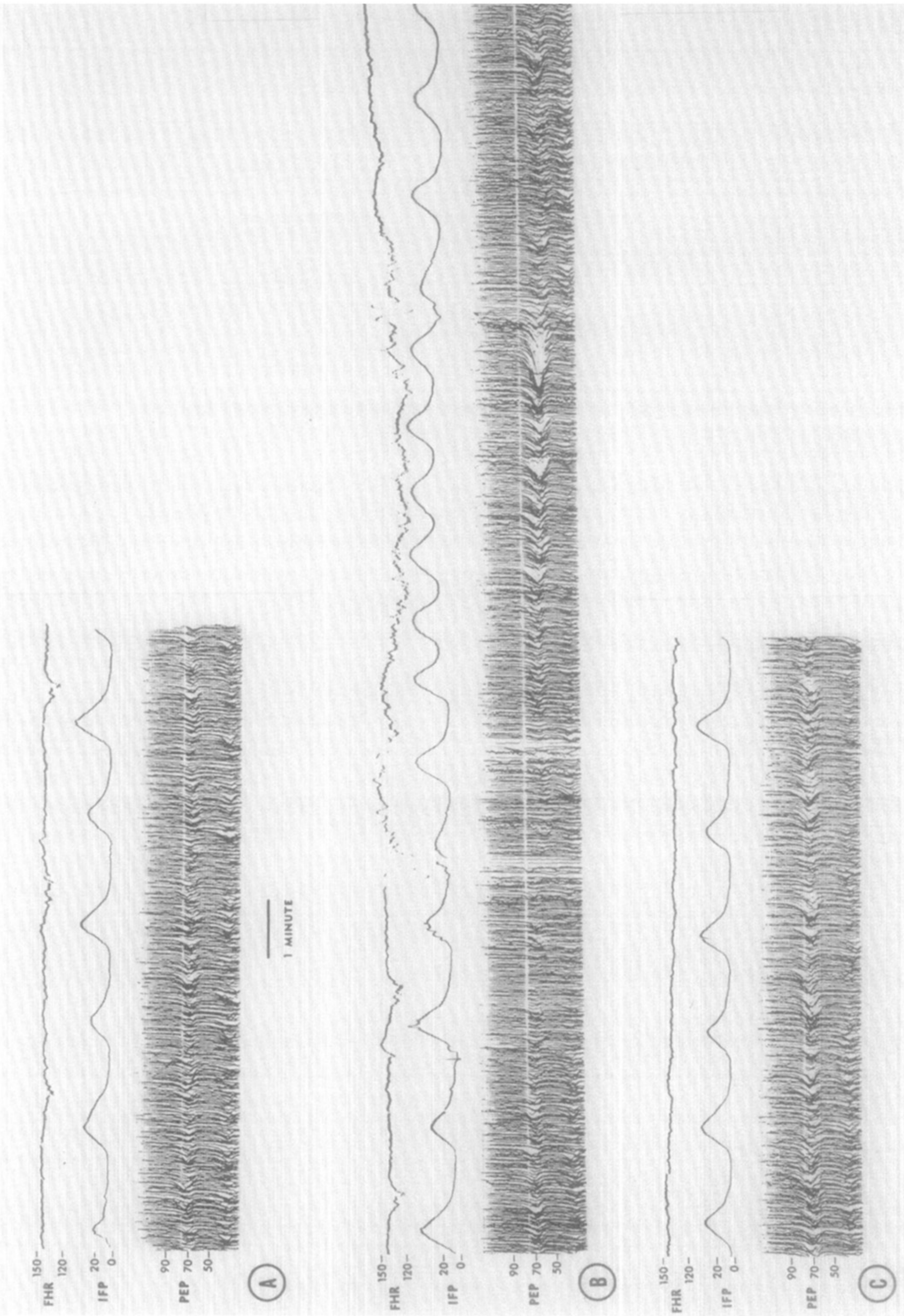

Fig. 4. Response of FHR and PEP to inadvertent overstimulation of the uterus by an oxytocic agent. *A,* A control record, taken about 10 minutes before *B*. *B,* Increased uterine tone and frequency of contractions, prolonged bradycardia, and shortened PEP. *C,* About 10 minutes later, return to prestress conditions. Also of interest in Fig. 4 is the presence of the smaller mitral valve closing wave form at about 30 milliseconds and the late decelerations of the heart rate in *A* and the first part of *B*.

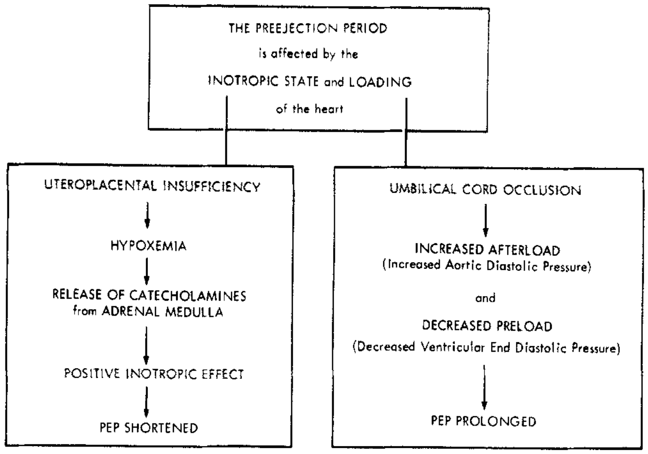

Fig. 5. Proposed mechanisms of change of PEP with stress during labor.

this patient regardless of whether FHR was increasing or decreasing.

A decrease in PEP over several uterine cycles was observed in 3 subjects; in 2 this was associated with late deceleration patterns, in the third there was no significant change in FHR. Fig. 4 illustrates a decrease in PEP, and also the cause of the uteroplacental insufficiency which produced it. Fig. 4, *A* is a control, taken about 10 minutes before the decrease in PEP. The average value of PEP was 58 milliseconds during this period. The decrease of PEP to a minimum of 48 milliseconds is shown in Fig. 4, *B,* as is the increased uterine tone and frequency of contractions produced by too rapid infusion of intravenous Pitocin. FHR showed a prolonged decrease from 140 beats per minute in Fig. 4, *A* to 115 in Fig. 4, *B*. PEP returned to 60 milliseconds, its prestress range, as shown in Fig. 4, *C* taken about 10 minutes later.

Comment

The use of the pre-ejection period as a diagnostic or prognostic index of myocardial status in arteriosclerotic heart disease or myocardial infarction has been disappointing, for although there are trends to increased PEP in the diseased myocardium, the changes are not large enough or consistent enough to be of practical value.[4] This probably results from the varying influence of several factors which determine PEP—myocardial contractility, left ventricular end diastolic pressure (preload), and aortic diastolic pressure (afterload).[5] QRS duration is a factor which becomes significant with conduction defects. The observed trend to increased PEP most likely reflects the predominating influence of depressed myocardial contractility.

In our experiments on stressed term fetal lambs PEP invariably decreased with hypoxemia and increased with umbilical cord occlusion. This allowed predictions to be made as to PEP change in the clinical situation—decrease with uteroplacental insufficiency and increase with umbilical cord compression. The results of this present series are consistent with these predictions, indicating the potential usefulness of PEP in assessing changing fetal environment. The phrase "fetal environment" is a key to understanding why PEP could be useful in the fetus but not in the adult. In the adult, integrity of myocardial function per se is being assessed. This is not the case with the fetus where the myocardium is not a site of pathology, especially with the large glycogen reserves of the fetal myocardium for sustaining periods of anaerobic metabolism. The concept then is an intact fetal heart reacting to environmental changes imposed by umbilical cord compression or uteroplacental insufficiency. The measure of the reaction is the PEP. The initial effect of umbilical cord compression is to increase aortic diastolic pressure (increase afterload) and decrease left ventricular end diastolic pressure (decrease preload) from decreased venous return to the heart. Both factors produce prolongation of PEP. Uteroplacental insufficiency, of course, results in hypoxemia. We have previously postulated that the effect of hypoxemia is mediated through the adrenal medulla since a hypoxic stress is known to stimulate this gland to liberate catecholamines into the circulation.[6] The catecholamines exert a positive inotropic effect on the myocardium, i.e., increase its contractility and therefore shorten PEP. These proposed mechanisms of response to PEP to cord compression and uteroplacental insufficiency are summarized in Fig. 5.

There are several features of PEP which make it an attractive choice as a parameter for fetal assessment. There is the experimental evidence of reliability of PEP change with fetal stress, and now early clinical evidence indicating similar changes in the PEP of the human fetus during labor. The direction of PEP change is opposite for uteroplacental insufficiency and cord compression, whereas FHR decelerates in both cases. PEP appears to exhibit a short-term memory after hypoxemia, remaining decreased until the circulating catecholamines are removed. It is not yet possible to state whether PEP is an alternative to heart rate monitoring or complementary to it; whether it is the method of choice or is of no added value. From the technological point of view PEP monitoring has not achieved a practical status for general use, and will not do so until aortic valve opening can be consistently detected, either by improving the existing technique or developing alternative ones.

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