Measurement of the pre-ejection period during labor with the use of arterial pulse time

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A new fetal parameter, the arterial pulse time, is described. It is the time from the onset of the fetal electrocardiographic recording to the arrival of the arterial pulse wave recorded at the fetal head. Since arterial pulse time differs from the pre-ejection period by only an apparently constant value, it is proposed as a potential method for obtaining the pre-ejection period during labor.

THE ABILITY TO DETECT significant changes in fetal status during labor has improved over the past several years with the use of continuous heart rate monitoring and scalp capillary blood sampling for pH and blood gases. Both techniques have limitations. Heart rate patterns cannot always unequivocally indicate the presence or absence of fetal distress, and scalp sampling is technically too cumbersome. In previous work we have shown that a new fetal parameter, the pre-ejection period (PEP), can be measured during labor.[1] PEP is defined as the time from the beginning of the QRS complex of the electrocardiogram to the onset of ejection of blood from the left ventricle, i.e., aortic valve opening (Fig. 1). Experiments in stressed fetal lambs showed that PEP reflects changes in umbilical blood flow and fetal Po_2 in a reliable, consistent manner.[2] These changes are thought to be produced by effects on the inotropic state and loading of the fetal heart as previously reported and illustrated in Fig. 2.

Determination of PEP requires the fetal electrocardiogram and some indicator of the time of the aortic valve opening. There is no technologic problem in obtaining the fetal electrocardiogram—the scalp clip electrode technique has been used successfully for many years. The entire problem is that of detecting aortic valve opening. This report describes our progress in a new technique with the use of arterial pulse wave detection for measurement of PEP.

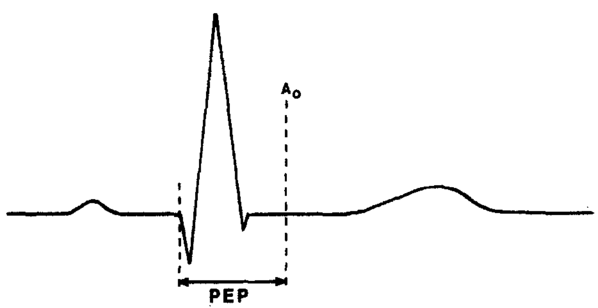

Fig. 1. The PEP of the cardiac cycle. A_0, aortic valve opening.

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Method

Ejection of blood into major vessels during the systolic phase of the heart cycle produces a peripheral arterial pulse distributed throughout the body. The arrival time of the pulse at any given point in the periphery depends on distance from the heart and elasticity of the arterial tree. In addition, systolic heart movement, as, for example, during isovolumetric contraction, and subsequent blood ejection are associated with reaction forces which produce instantaneous minute whole-body movements, especially in the direction of the long-body axis. Detecting and recording these reaction movements constitutes the ballistocar-

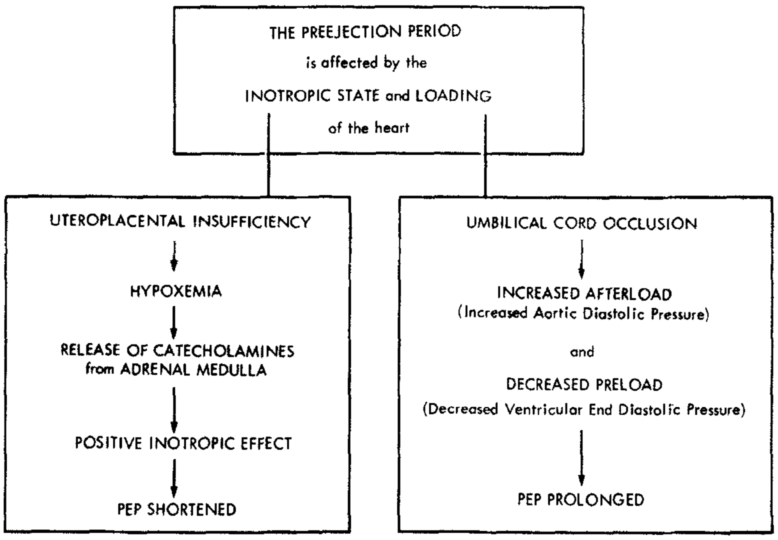

Fig. 2. Proposed mechanisms of PEP change during fetal stress.

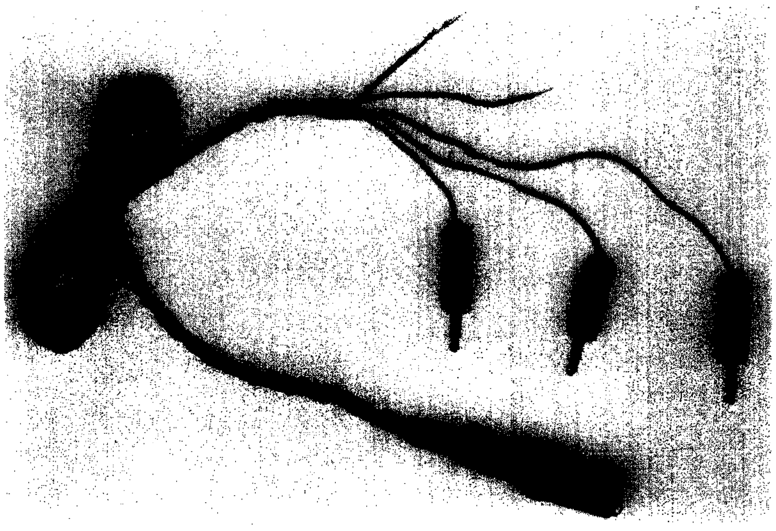

Fig. 3. The combined sensor for attachment to the fetal scalp to record both body movements and the electrocardiogram.

diogram. Since both the arterial pulse wave and the ballistocardiogram are associated with systolic ejection, a technique that records movements produced by one or both of these sources will contain a wave form related to aortic valve opening.

The movement sensor used in this study was a miniature compression-type piezoelectric accelerometer.* The accelerometer and a preamplifier were encapsulated in an aluminum cylinder 30 mm. long and 14 mm. in diameter. Three slightly curved, sharpened, stainless steel wires were mounted around the circumference of one end of the cylinder to form a spiral electrode configuration (Fig. 3). This served the dual purpose of providing a means of connecting the device to the fetal scalp and, as well, a source of the fetal electrocardiogram. Eleven patients in normal labor at Mount Sinai Hospital, Toronto, were used in this study. The protocol consisted of insertion of an intra-amniotic catheter, followed by connection of the combined accelerometer/electrode to the fetal scalp at a site not over a fontanelle. Fetal heart rate and uterine contractions were displayed on a standard fetal monitor, while the acceleration data, fetal electrocardiogram, and intra-amniotic fluid pressure were stored on magnetic tape in a tape recorder* operated in the

*No. 8303, Bruel & Kjaer.

*Model PI-6200, Precision Data, Inc., Mountain View, California.

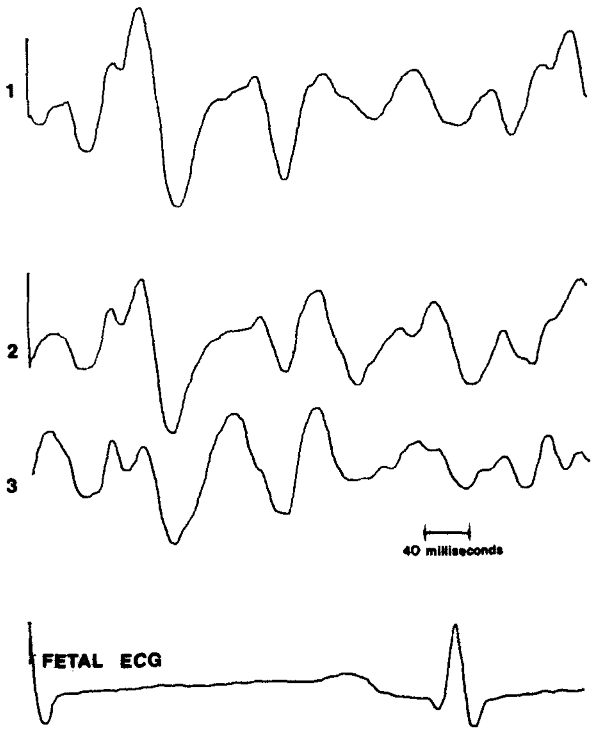

Fig. 4. Three consecutive acceleration arterial pulse waves recorded at the fetal head. Each is an average of eight individual pulse waves. The simultaneously recorded fetal electrocardiogram is used as a time reference.

FM mode with band pass DC to 1 kHz. In three patients, Doppler ultrasound recordings of aortic valve movement were also obtained and stored.

The accelerometer signal was electronically averaged on a Signal Analyzer System* over eight consecutive heartbeats to enhance the signal-to-noise ratio. Eight was chosen empirically from the observation that, as a rule, signal clarity improved up to about this number and tended to "average out" beyond it due to trend variations in wave-form latency. The resultant waveform is called an arterial pulse wave. This wave form is a record of acceleratory movements because of the nature of the transducer and, therefore, is more rigorously termed the "acceleration arterial pulse wave." It was observed that its derivative, the jerk arterial pulse wave, contained more easily identifiable peaks when comparing results from different subjects. The jerk arterial pulse wave was obtained by first passing the accelerometer signal through a differentiator linear to 1 kHz. and then averaging eight heart cycles as above.

*Model 5480B, Hewlett-Packard Co., San Diego Div., San Diego, California.

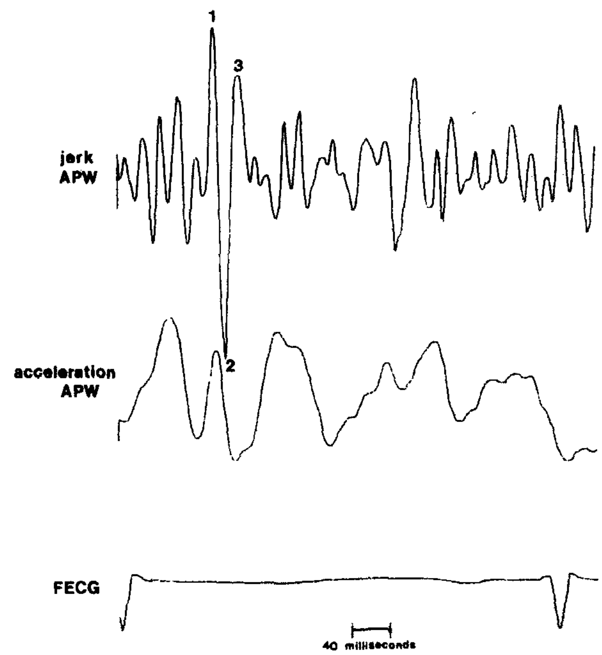

Fig. 5. The effect of differentiating the acceleration arterial pulse wave *(APW)* to obtain the jerk *APW*.

Results

Three acceleration arterial pulse waves, obtained consecutively in the same fetus, are shown in Fig. 4. The averaged fetal electrocardiogram is shown at the bottom of the figure. Fig. 5 is a record of the jerk arterial pulse wave and the acceleration pulse wave from which it was obtained. Use of any one of the relatively sharp peaks—1, 2, or 3—of the jerk arterial pulse wave allows easy determination of arterial pulse time by measuring along the time axis from the fetal electrocardiogram to a chosen peak. We used Peak 3 in this study. Arterial pulse time was measured manually from the averaged data (jerk arterial pulse wave and fetal electrocardiogram) stored on the oscilloscope screen of the Signal Analyzer. One measurement of arterial pulse time was determined for about every 10 seconds of labor. Records of arterial pulse times, together with fetal heart rate and uterine contractions, are shown in Figs. 6 and 7, with patterns suggestive of those seen experimentally in the fetal lamb and clinically in the human fetus with Doppler ultrasound used for PEP determination.[3] Most results were not technically as good as the ones shown, and computation was laborious, but feasibility is demonstrated.

Comment

The initial objective of our research was to obtain the fetal ballistocardiogram by attaching an accelerometer

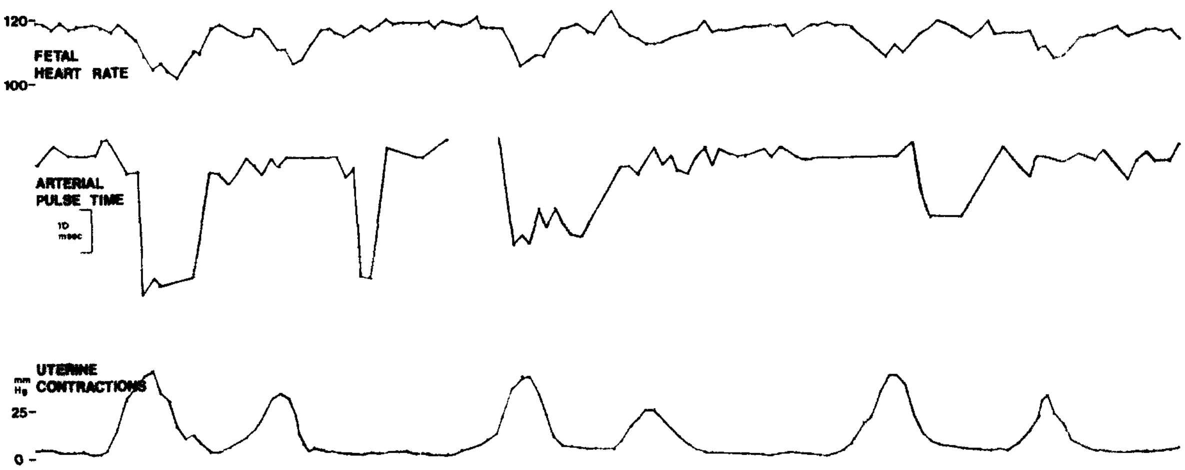

Fig. 6. An arterial pulse time "pattern." Absolute values for arterial pulse time are not indicated because of the arbitrary nature of the choice of reference points for its determination.

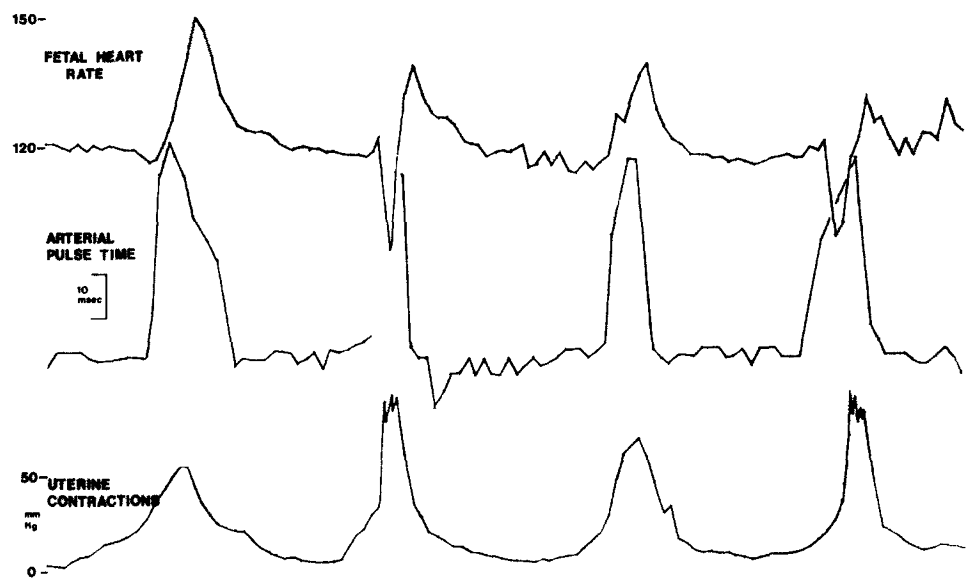

Fig. 7. An arterial pulse time "pattern."

transducer to the fetal head. The fetal ballistocardiogram has been obtained by Curran and associates[4] from signals produced by the movement of a frictionless, air-bearing bed supporting the pregnant woman near term. The maternal ballistrocardiogram is, of course, also available. This traditional method of obtaining a ballistocardiogram is not suitable for the labor room environment because the ballistocardiographic bed is essentially an unyielding weighted slab on rails and because of the requirement for the mother to remain motionless. To substantiate whether or not the movement recorded at the fetal head by the accelerometer was, in fact, a ballistocardiogram, simultaneous records were obtained of the accelerometer output, the fetal electrocardiogram, and the aortic valve opening obtained by Doppler ultrasound. Fig. 8 illustrates the results. The processed accelerometer output—the jerk response—occurs after aortic valve opening. This implies that it is produced by an arterial pulse wave arriving at the fetal head and not by the ballistocardiogram because a ballistocardiogram wave form would have started before aortic valve opening since it contains components related to isovolumetric contraction.

This finding was further substantiated by an exper-

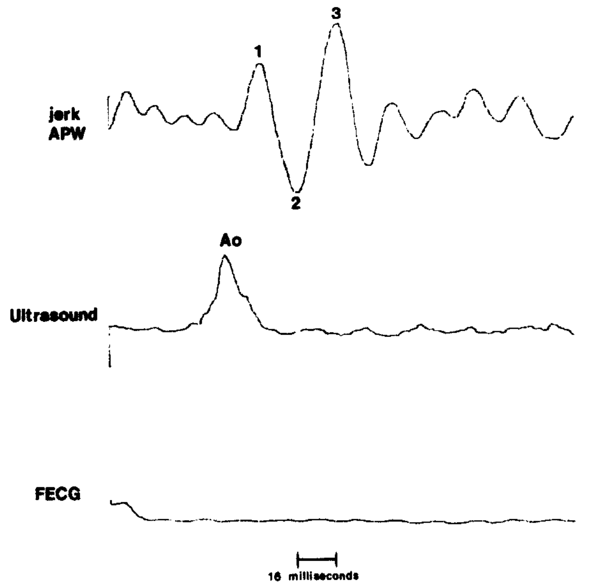

Fig. 8. Simultaneously recorded jerk arterial pulse wave *(APW)*, Doppler ultrasound for aortic vlave opening *(Ao)*, and fetal electrocardiogram.

iment on an adult subject where the combined accelerometer/electrode was taped first over the carotid artery and then on the vertex, and the results were compared. The electrocardiogram, obtained in a conventional manner, was recorded to serve as a timing reference. The wave form produced by the combined device mounted on the lateral aspect of the neck over the carotid artery would result primarily from carotid artery movement with relatively little from the ballistocardiogram because the accelerometer was perpendicular to the long axis of the body, which is the main direction of ballistocardiographic movement. The accelerometer, when mounted on the vertex, was oriented in the direction of the long-body axis to allow a significant ballistocardiogram component, if present, to be recorded. The results, in Fig. 9, show a longer latency of the wave form at the vertex than at the

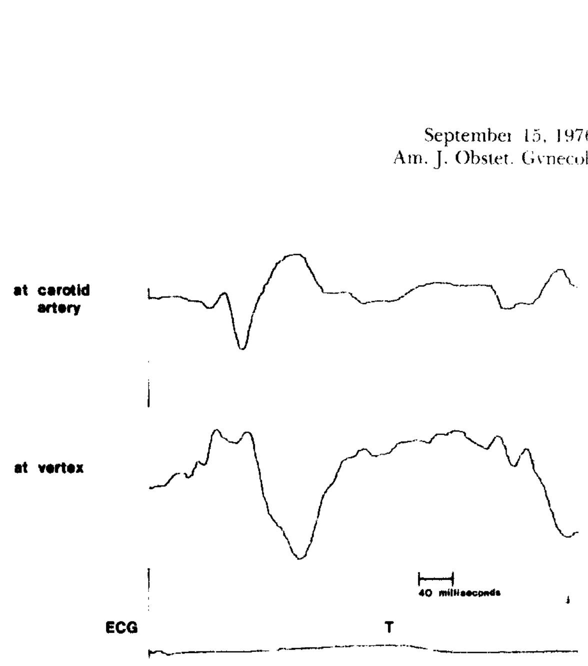

Fig. 9. The arrival time of the acceleration arterial pulse wave at the carotid artery and at the vertex of an adult subject.

carotid artery—further evidence that an arterial pulse rather than the ballistocardiogram is recorded at the vertex.

Arterial pulse wave velocity is dependent upon arterial distensibility, becoming faster with decreasing distensibility. Therefore, arterial pulse time is subject to an influence not necessarily related to the PEP. However, variation in arterial distensibility between fetuses is almost certainly insignificant. It is likely, then, that arterial pulse time differs from PEP only by a segment of time which appears to be constant and, therefore, could be useful as an indicator of the PEP because changes, rather than absolute values, are most significant. Since the arterial pulse "shock wave" rather than the acceleratory whole-body movements is the phenomenon measured, other transducers, sensitive to displacement or velocity, could be used in an attempt to increase sensitivity and decrease size.

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