The pre-ejection period of the fetal heart: Detection during labor with Doppler ultrasound

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The use of Doppler ultrasound, together with the fetal electrocardiogram, was investigated as a method of determining the pre-ejection period (PEP) of the fetal cardiac cycle during labor. The PEP, which is related to myocardial contractility, is defined as the period from the beginning of the QRS complex to the opening of the aortic valve. It was found that by suitably filtering the detected ultrasound signal, in the range of 750 to 1,000 Hz, a pulse corresponding to the aortic valve opening was obtained more often than for any other valvular movement (in 77 per cent of the subjects studied). The time of occurrence of this pulse was stable from beat to beat as well as over longer periods of time so that the calculation of PEP based on its onset was felt to be reliable. The average value of PEP was 73 msec., with a standard deviation of 10 msec. The intrapartum availability of the PEP to a degree greater than has been considered possible should allow its consideration as a parameter for following changing fetal status during labor.

DOPPLER ultrasound for detecting fetal life has gained wide acceptance because of its simplicity and reliability. With this technique an ultrasonic wave, generated by a transducing head placed on the mother's abdomen, is directed toward the area of the fetal heart. Part of the incident ultrasonic beam will be reflected from each of several intervening surfaces as well as from the heart and be received back at the transducer. If the reflecting structure is in motion, the frequency of the reflected beam will differ from that of the incidental one, i.e., the Doppler frequency shift, with the frequency difference proportional to the velocity of the reflecting surface. It is this frequency difference which is detected and amplified by the transducing head to produce the typical Doppler sounds of heart movement. Each component sound will depend on the velocity and pattern of movement of the reflecting structure. Most relevant here is the fact that, since the velocity of valvular structures is greater than that of the myocardial wall, the resultant Doppler frequency shift and therefore the sound generated will be higher for valves.

This study was undertaken to investigate the feasibility of using the Doppler technique during labor in combination with the fetal electrocardiogram for obtaining the pre-ejection period (PEP) of the cardiac cycle. This period is measured from the beginning of ventricular depolarization (the QRS complex) to the beginning of ventricular ejection. Since ejection begins with the opening of the aortic valve, the main technical problem becomes the detection of this particular

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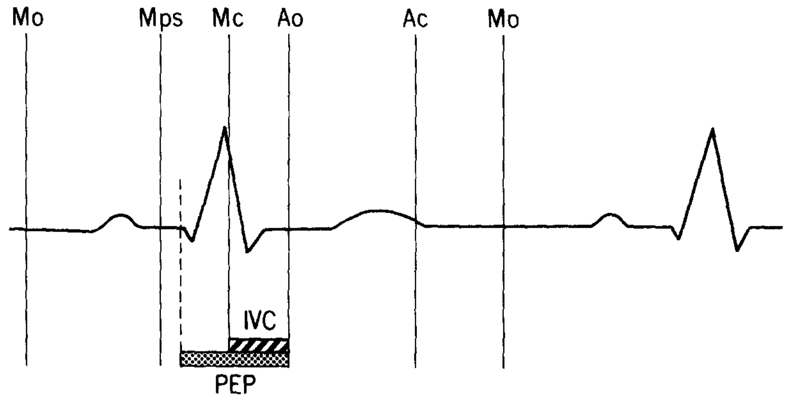

Fig. 1. The relationship between mitral valve opening and closing, *(Mo, Mc)* aortic valve opening and closing *(Ao, Ac)*, and the electrocardiogram. Also shown is the isovolumetric contraction time, *IVC*, and the pre-ejection period, *PEP*. *Mps* is due to mitral valvular movement from inflow of blood into the ventricle at the time of atrial contraction.

valvular movement with Doppler ultrasound. Interest in the PEP lies in its relationship to myocardial contractility,[1] with the duration of the PEP decreasing as myocardial contractility increases. This relationship results principally from the inclusion of isovolumetric contraction time in the PEP. Both these intervals and the time of occurrence of valvular movements relative to the electrocardiogram are shown in Fig. 1. The availability of the PEP during labor would offer a potentially useful means of fetal assessment through changes in myocardial contractility.

Material and methods

Simultaneous recordings of Doppler ultrasound and the scalp lead electrocardiogram of the fetus were obtained on 26 patients during active uncomplicated labor. The ultrasound transducer was held manually against the mother's abdomen at several sites to produce as many different Doppler sounds as seemed available in a given subject. All data were monitored on an oscilloscope and stored on magnetic tape for analysis.

The ultrasound transducer had two lead zirconate half discs of 1 cm. radius, one for transmitting the ultrasound beam, the other for receiving its reflection. The transmitted beam was a 2 megahertz plane wave with an energy of 25 mw. per square centimeter. No automatic gain control was employed in the detector/amplifier circuits, and the amplifier had lower and upper 3 db points at 50 and 1,500 Hz.

Analysis of the ultrasound data proceeded as shown in Fig. 2. The output from the tape recorder was passed through a Krohn-Hite band-pass filter, model 330N,* usually with both the low-frequency and high-frequency cutoff controls set to the frequency being studied and with critical damping. The characteristic of the filter is such that the attenuation on either side of this frequency was 80 db per decade. After passage through the filter, the signal was full-wave rectified and its envelope was detected and then either processed further (Subjects 1 to 14) or displayed on a Type 564 Tektronix storage oscilloscope† and photographed on Polaroid film‡ (Subjects 15 to 26). Data from the first group were processed further by computer averaging on a Fabri-Tek Model 1072§ about 50 consecutive similar-sounding heart cycles. The averaged ultrasound wave form and the electrocardiogram which was also averaged over the same period were then printed on a Hewlett-Packard Moseley Model 7035 AM X-Y recorder.|| These averaged and therefore hopefully typical

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†Tektronix, Inc., Beaverton, Oregon.
‡Polaroid Corp., Cambridge, Massachusetts.
§Fabri-Tek Instruments, Inc., Madison, Wisconsin.
||Hewlett-Packard Co., Palo Alto, California.

ultrasound wave forms were related to their Doppler sound and were also identified with the event in the cardiac cycle likely to have generated them by comparison with the electrocardiogram.

In the second group of subjects, computer averaging was bypassed because attention was devoted entirely to detecting valvular events and because the results from the first group showed that for valves there was essentially no variation in time of occurrence when a single sample was compared with the averaged group from which it was taken. The nonaveraged ultrasound wave form and the simultaneously occurring electrocardiogram were stored on the oscilloscope and then photographed.

Results

Computer-averaged series. When the wideband (50 to 1,500 Hz) audio output was monitored, various sounds came to be recognized:

1. Stethoscopic, i.e., the "lub dup" similar to that heard on auscultation. There were occasional variations, for example, a third sound added to give "lub da da" sounding like a gallop rhythm.

2. Sawlike, a "ru-u-f ru-u-f" which was quite like the sound produced by the to-and-fro motion from handsawing wood. Both 1 and 2 were low-frequency sounds, shown by filtering to contain most of their energy between 100 and 300 Hz.

3. A high-frequency sound almost certainly related to movements of heart valves. Its sound can be described as varying between a sharp slap and a watery gurgle and is easily recognized.

Figs. 3 and 4 show the effect of filtering the ultrasound data. The top record in both figures is the unfiltered signal, with a band-pass filter of 50 to 1,500 Hz. The changes produced by filtering the signal at 50, 100, 200, 350, 500, 750, 1,000, and 1,500 Hz is shown proceeding from above downward. The amplification required, relative to the unfiltered data set at 1, is indicated to the right of the record. It can be seen that filtering at 750 or 1,000 Hz

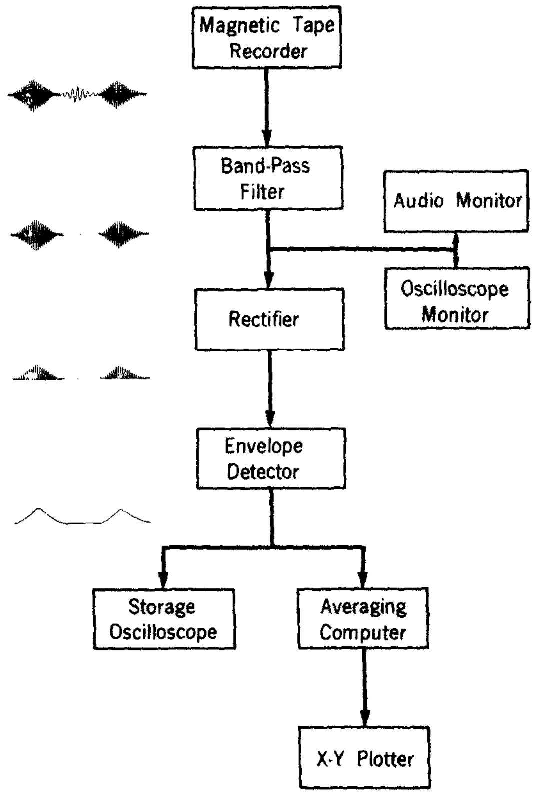

Fig. 2. Analysis of ultrasound data. The change in the signal as it is processed is shown on the left of the figure. One cardiac cycle is represented.

provides the best compromise between rejection of low-frequency myocardial wall components and retention of high-frequency valvular components. The simultaneously recorded and averaged scalp lead fetal electrocardiograms are of normal configuration with an inverted P wave and a shallow or absent T wave.[2] Measurement of the PEP from the beginning of ventricular depolarization to the onset of aortic valve opening is shown in both figures. Isovolumetric contraction (IVC) time can also be obtained from the record of Fig. 4 because of the detection of mitral valve closing and aortic valve opening.

Valvular movements were detected in 13 of the 14 subjects studied and included at least semilunar (aortic) opening (Ao) or atrioventricular (mitral) closing (Mc). Semilunar closing and atrioventricular opening were less frequently detected. Ao was detected in 79 per cent of subjects (11 of 14) and Mc

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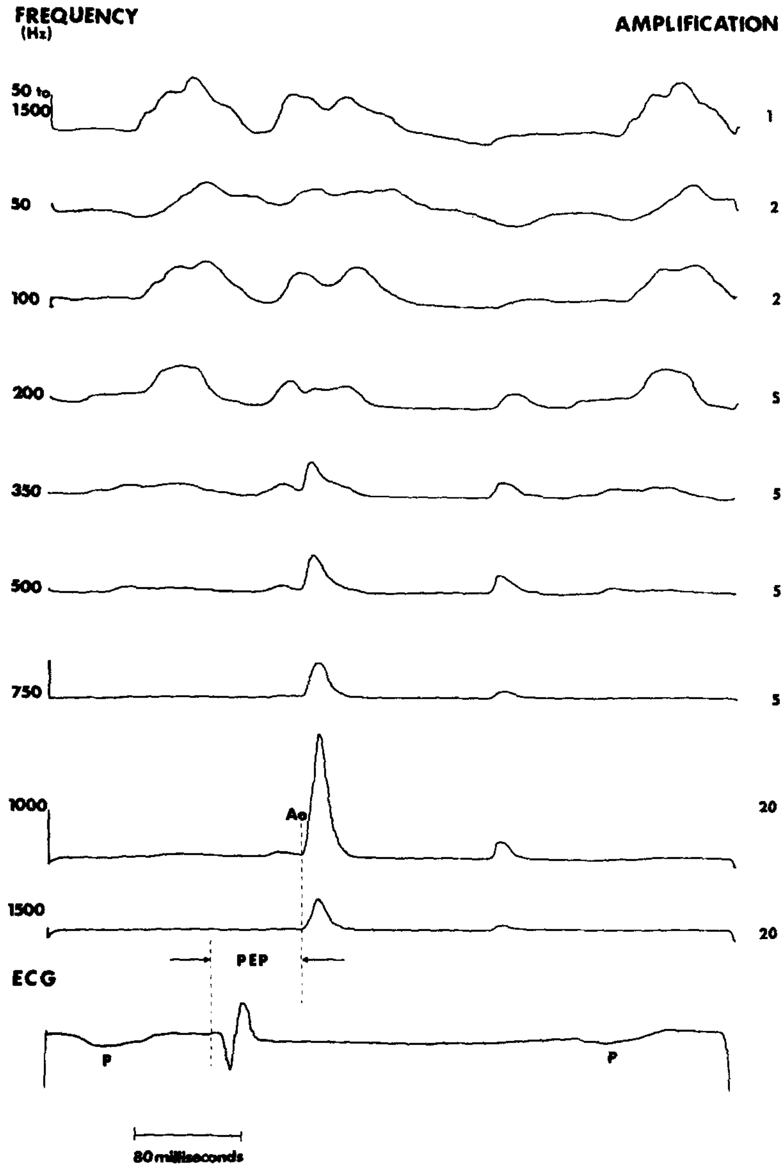

Fig. 3. Effect of filtering the ultrasound data. The top record is unfiltered, all others filtered at the frequency indicated to the left of the record. The amplification required relative to the unfiltered record set at 1 is indicated on the right. *Ao,* aortic valve opening; *PEP,* pre-ejection period.

in 64 per cent (9 of 14). In 36 per cent (5 of 14), both Ao and Mc were detected in the same record, allowing measurement of the IVC time. Extracting single samples of valvular signals from an averaged population and comparing with the group average showed that there was virtually no variation in time of onset from sample to sample.

Nonaveraged series. A further series of 12 subjects was obtained and analyzed without averaging. Valvular events could be detected in 10 of the 12 subjects and again included predominantly Ao or Mc. Ao was detected in 75 per cent of subjects (9 of 12) and Mc in 67 per cent (8 of 12). In 42 per cent (5 of 12), both Ao and Mc were detected in the same record. Fig. 5A illustrates a sample analysis with each line representing a different filtering frequency. Again, the values 750 and 1,000 Hz appear best for detecting

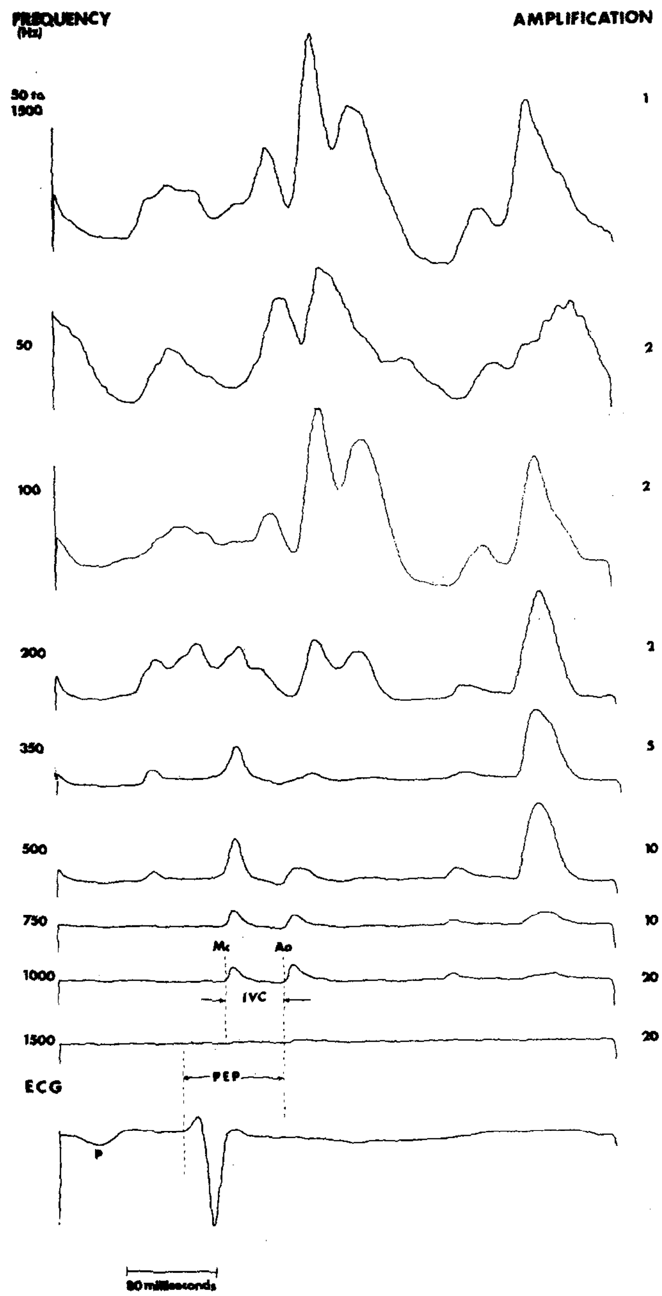

Fig. 4. As in Fig. 3. Legend: *Mc,* mitral valve closing; *Ao*, aortic valve opening; *IVC,* isovolumetric contraction time; *PEP,* pre-ejection period.

valvular movements. Mo, Mc, and Ao are all present in the sample shown. The PEP is measured by recording the 1,000 Hz filtered signal at an increased oscilloscope sweep speed, as shown in Fig. 5B. Fig. 6 was taken 8 minutes later from the same subject to illustrate the stability of PEP measurement, here 64 ± 2 msec. in Figs. 5B and 6. Fig. 7, from another subject, shows that in a relatively short period of time it is possible to have a change in the valvular movements detected.

No attempt at long-term monitoring was made in this study. However, over short periods and, most significantly, during periods in which a contraction occurred, it

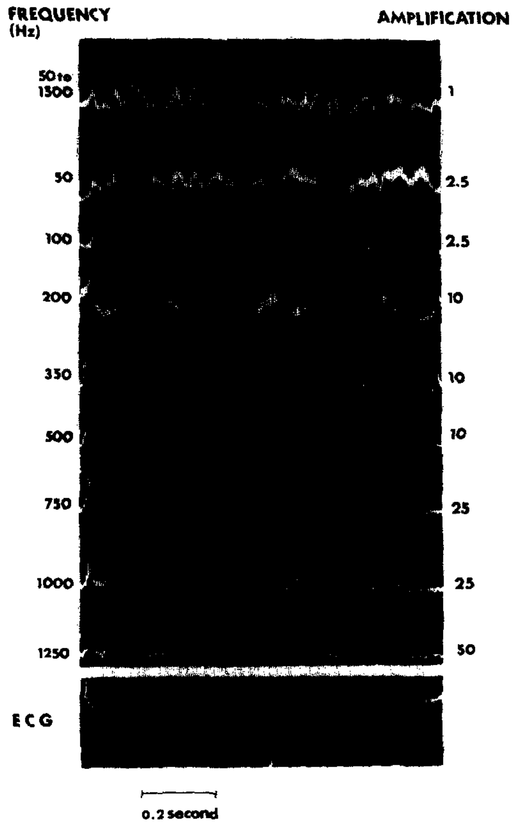

Fig. 5A. Oscilloscope photograph of results of analysis of ultrasound data that were not averaged. Filtering frequency is indicated to the left and relative amplication to the right. Three valvular movements are identified in the 750 Hz record: *Mo*, mitral opening; *Mc*, mitral closing; *Ao*, aortic opening. The p wave of the fetal electrocardiogram is identified on the bottom tracing.

was possible to retain the signal from a given valvular movement such as Ao or Mc. How frequently this could be done or over what length of time was not assessed. The fact that it can be done at all, however, opens the possibility of obtaining PEP patterns by simultaneous recording of Doppler ultrasound, fetal electrocardiogram, and uterine contractions.

Comment

The use of Doppler ultrasound for the detection of valvular movements in the adult has been used by many investigators over about the past 15 years.[3-5] Valvular signals are separated from those produced

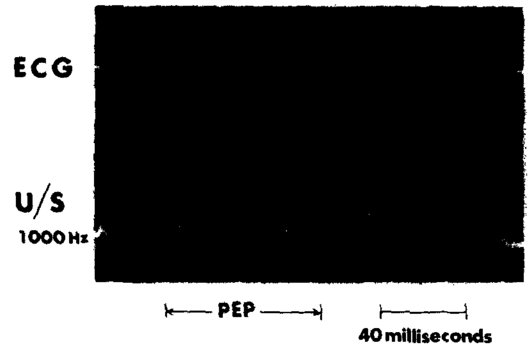

Fig. 5B. Same signal as Fig. 5A, displaying the 1,000 Hz filtered record with an expanded time base, showing Mc and Ao in that order and the measurement of the pre-ejection period, *PEP*.

by the myocardial wall with the use of high-pass filters with a center frequency of usually about 1,000 Hz. The fact that these high-frequency signals originate from valves or related structures was confirmed in the adult by simultaneously recording and displaying the electrocardiogram, phonocardiogram, and filtered Doppler ultrasound and in the experimental animal by applying an ultrasound transducer to the surface of the exposed heart over valvular areas and verifying that these sites generated the high-frequency signals.

Filtered Doppler ultrasound has received only cursory attention in the fetus,[6, 7] with little comment or enthusiasm about its value for assessing fetal status. However, when viewed solely as a source of Ao for calculation of the PEP and when used with a suitable high-frequency filter, the application of this technique becomes more promising because aortic valve opening, of all valvular movements, is most frequently obtained—in 77 per cent of subjects studied (20 of 26). The reason for this is not clear. From echo ultrasonic cardiography, the velocity of the aortic valve is seen to be appreciably faster than that of the mitral valve,[8] a factor which favors the detection of movement of the aortic valve when high-frequency filtering is used. Another factor must be the magnitude of the effective reflecting surface of the valve or its supporting structures and the manner in which this surface varies dur-

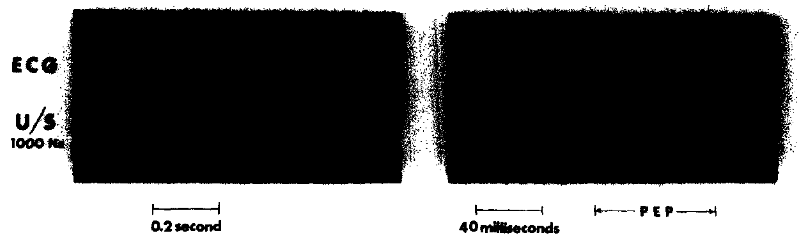

Fig. 6. A 1,000 Hz ultrasound record from same subject as in Fig. 5A and 5B but 8 minutes later. Ao is now very prominent. There has been no change in the pre-ejection period.

Fig. 7. Ultrasound data obtained with 750 to 1,500 Hz filtering. *A,* Mitral valve opening; *B,* 2 minutes later, mitral valve closing; *C,* one minute later, aortic valve opening and closing.

ing valvular opening and closing and during myocardial movement in general. The average value of the PEP was 73 msec., with a standard deviation of 10 msec.

With the Doppler technique, it is impossible to determine whether the reflecting fetal valve is mitral or tricuspid on one hand or aortic or pulmonary on the other because each pair moves almost simultaneously. It would therefore be more correct to refer to atrioventricular or semilunar valves. But their indistinguishability is not a disadvantage for the present application because only Ao, the time of onset of opening of the aortic valve, is required, and it is immaterial whether the information was generated by reflection from the aortic or pulmonary valve or perhaps both. This is particularly valid for the fetus because the right and left ventricles work in parallel against the same (systemic) pressure because of the presence of the ductus arteriosus.

The PEP, sometimes referred to as the QAo interval, can therefore be evaluated in the majority of fetuses during labor by simultaneously recording the fetal electrocardiogram and filtered Doppler ultrasound. The evaluation of aortic valve opening by ultrasound is reliable. Still open are such important questions as how long one can usually "hold on to" a given valvular signal and how long the signal must be retained for fetal assessment. Safety of the prolonged use of continuous-wave ultrasound must be considered. A recent study[9] has shown that at intensity levels of about 500 mw. per square centimeter and below there were no structural changes, congenital malformations, or chromosomal aberrations in irradiated fetal mice. The ultrasound output used in this series was 25 mw. per square centimeter.

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