PRESENT PLACE IN OBSTETRICS FOR FOETAL PHONOCARDIOGRAPHY AND ELECTROCARDIOGRAPHY WITH THE NEWER TECHNIQUES OF FOETAL ELECTROENCEPHALOGRAPHY AND MOVEMENT-RECORDING

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Foetal heart rate, rhythm, and waveform can be studied by phonocardiography and electrocardiography from the maternal abdominal surface. The present value of these instrumental observations in relation to foetal welfare and clinical obstetric practice is reviewed and the basic design features of the instruments employed for the survey are given.

The subject is divided into: (1) conditions determining the choice between the two methods of foetal heart recording; (2) recording techniques and description of the quantities measured; (3) principal applications; (4) details of apparatus; (5) examples of typical recordings and their interpretation; (6) other instrumental observations on the foetus; and (7) discussion of foetal distress and its treatment.

Choice of Method

Phonocardiography is the most suitable method for recording heart rate and rhythm and for estimating the systolic and diastolic time intervals. It is always practicable when the heart is audible with a stethoscope; it is impossible when the heart is inaudible to an experienced obstetrician or midwife listening in a quiet room. In some instances an active heart can be recorded when it has not been heard with certainty because of acoustic masking by uterine souffles, maternal heart sounds, or other foetal heart beats in a multiple pregnancy. In certain cases of severe foetal distress the heart sounds may be so uncharacteristic that they are not recognized as such, and then phonocardiography is helpful.

Electrocardiography has its field of usefulness when the heart cannot be heard. The technique is also possible, of course, in other cases, but it is then less convenient than using the phonocardiograph. Electrocardiography is possible in all patients from 16 weeks' gestation to term, with a few exceptions between 30 and 34 weeks, when some foetuses are totally covered with vernix caseosa, an electrical insulator (Wimmer, 1954).

Recording Techniques and Quantities Measured

Phonocardiography

The microphone must be firmly applied at the point on the abdomen where the heart can best be heard; it may need to be repositioned if the foetus moves.

Phonocardiography is not unduly disturbed by extraneous noises, but is very severely affected by the mother's speech or movement and by intestinal disturbances. While the recording is in progress, therefore, the patient is asked to lie still and quiet.

In our particular studies we have used devices which register the intensity of the first and second heart sounds and their time relationships, and we have paid little attention to the acoustic quality of the sounds—that is, to the

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waveform. Many murmurs which are heard from the foetus disappear with the circulatory changes that occur at birth. The presence of high frequencies in the sounds depends not only on their production in the heart but also on the foetal position and the volume of surrounding maternal tissue and liquor amnii. Consequently, muffled sounds are not necessarily indicative of reduced cardiac output. Attempts to relate cardiac performance to sound levels must take account of relative movements between foetus and microphone, even for short-time changes in a particular patient. This we assumed to be too difficult, and limited our studies principally to time relationships. The measurement of systolic and diastolic times is of sufficient clinical value to justify phonocardiography in the labour ward, even if the more elaborate problems of sound analysis are omitted.

FIG. 1.—Foetal electrocardiograph in use.

Electrocardiography (Figs. 1 and 2)

The electrodes are formed by the two feet of a small metal box containing the pre-amplifier. These should rest firmly on the linea alba—for vertex presentations, one just above or below the umbilicus, and the other just above the pubic-hair line. A metal belt for the indifferent electrode is placed around the patient's waist between fundus and heart. Good contact is made under the belt and under the electrodes with "Cambridge" electrode jelly. The bladder should be empty. Other electrode positions are satisfactory but more influenced by maternal heart and muscle potentials.

Interference can be prevented when it arises from extraneous sources, but the recordings are disturbed by movements of the patient and by potential changes arising in organs other than the foetal heart. For this reason records of P and T waves are difficult to distinguish with certainty, but the QRS complex can be recorded faithfully in amplitude and duration. Maternal heart waveforms are usually also registered, but, since a maternal heart beat only occasionally coincides with a foetal one, the record is little impaired.

When clinical requirements necessitate a full foetal E.C.G. with P and T waves (for example, in cases of severe foetal distress or before caesarean section in a suspected cardiac abnormality), then intrauterine electrodes should be passed through the cervical canal, preferably after rupturing the membranes, and their positions, if necessary, ascertained by radiography.

Applications

The principal uses of phonocardiography are: (1) to monitor the foetal heart in a sleeping or overanxious patient; (2) to check regularity of rhythm, and rate after version (success or failure), after surgical induction of labour, during oxytocin therapy, during the induction of anaesthesia, and during forceps application and traction; and (3) diagnosis of foetal distress.

With the aid of phonocardiography the effects of administering oxygen, taking pressure off the presenting part, relaxing the uterus, pressing upon the placental site, and inducing regular uterine contractions with oxytocin (to improve the foetal circulation) can be followed speedily. Measurement of the systolic and diastolic times by recording both heart

sounds enables a failing myocardium, or pulmonary stenosis, to be distinguished from impeded venous return, for the former lengthens the systolic time and the latter the diastolic time (Palmrich, 1951, 1952a, 1953).

Pressing the presenting part into the pelvis in patients with placenta praevia will slow the heart by lengthening

FIG. 2.—Foetal electrocardiographic pre-amplifier arrangement and circuit.

FIG. 3.—Circuit arrangement and frequency performance of phonocardiograph (Electrovac). Note rectifiers (1) to prevent acoustic instability and (2) to enable envelope of heart sounds to be recorded.

the diastolic time, but there is a reactionary tachycardia when pressure is released.

The volume of the heart sounds is reduced in foetal myocardial failure together with an increase of the systolic time. It is of doubtful value to judge foetal distress on the volume of sound alone, for, while reduction in sound is significant, the reliability of the measurement is affected critically by the position and firmness of the application of the microphone.

The principal uses of electrocardiography are: (1) the differential diagnosis of pregnancy and multiple pregnancy from other tumours (for example, a hydatidiform mole); (2) to give evidence of foetal life in cases of threatened abortion; (3) differentiation of breech from cephalic presentation; (4) recordings of rhythm and waveform will show evidence of certain cardiac abnormalities, myocardial failure, impeded circulation, and fibrillation—diagnosis of complete heart-block normally requires intrauterine electrodes; and (5) used in conjunction with phonocardiography, other diagnostic cardiological techniques become applicable to the foetus.

Details of Apparatus

Phonocardiography

This requires microphones, frequency-selective wave-filters, amplifiers, and loudspeakers or waveform-recording oscillographs (Steer and Hertsch, 1951; Gunn and Wood, 1953).

Microphones are chosen for (1) sensitivity in the lower frequency audible range; (2) freedom from response to extraneous noises, and (3) mechanical robustness. In our early experiments we tried piezo-electric, moving-coil, and condenser microphones because of the faithfulness of reproduction of the sounds. We finally decided, however, that moving-iron microphones were the most practical and had sufficient robustness and sensitivity. The ones employed resemble telephone earpieces, with the additional feature of adjustable magnet spacing. It seems preferable to space the microphone diaphragm away from the skin to avoid frictional noises, employing a sponge-rubber spacing annulus to avoid air leaks.

The wave-filters and amplifiers are frequency selective in the range 30 to 200 cycles per second. The loudspeaker, if used, has to be situated in a different room from the microphone to prevent "howling round" or acoustic insta-

bility. This can also be prevented by rectifying the sound-wave signals before they reach the speaker. This changes the true note into a sort of "plop" sound, and the loud-speaker can be left at the bedside.

The amplifier, wave-filter system, and acoustic stabilizing circuits which we use and have found most satisfactory are included in the equipment built by the firm Electrovac, of Vienna, in conjunction with Dr. A. H. Palmrich and Professor Antoine (Palmrich, 1952b). Fig. 3 shows the circuit arrangement and frequency response.

The Electrovac phonocardiograph can be connected to any recording electrocardiograph to produce a written record of the heart sounds to the upper frequency limit of the recorder; alternatively, the rectified sound intensity can be recorded irrespective of the frequency. This latter arrangement is particularly necessary for the measurement of systolic and diastolic time intervals (Fig. 4).

Electrocardiography

The apparatus used at present is similar to that described previously (Bell, 1938; Smyth, 1953), with mechanical changes for convenience and increased portability.

The present instrument comprises a Cossor electrocardiograph and a pre-amplifier. The pre-amplifier is in a small metal box with two legs, which form the electrodes. In Fig. 1 it can be seen held to the mother's abdominal surface; its design is shown in the scale drawing of Fig. 2.

Switches were added to the electrocardiograph to enable the time-constant to be reduced to 0.1 or 0.02 second from 2 seconds. This avoids long-term blocking of the amplifiers when interfering signals arrive unexpectedly. Reducing the time-constant gives some improvement in the signal-to-noise ratio, but it also gives an increase in waveform distortion.

Most electrocardiographs contain direct-current blocking condensers in the input circuit. Where these are not present condensers must be included between the pre-amplifier and the electrocardiograph; they are shown dotted (C₁) in Fig. 2, and can be housed within the pre-amplifier case. Values between 0.1 and 0.02 microfarad are suitable, depending on the time-constant required.

Reduction in time-constant results in some reduction of the P and T waves in relation to the QRS complex, but, since P and T waves cannot be recorded regularly above the background of other bio-electric potentials, the loss is seldom consequential, and the long time-constant circuit can be restored by switching when desired. Southern (1954) has described the recording of P and T waves and their diagnostic importance, but he gives no details of the apparatus, and does not state how they are consistently to be distinguished from artifacts. We do not wish to detract from the importance of recording P and T waves, if such recordings are technically possible. We have not found them reliable.

Typical Recordings

Phonocardiography

Severe Foetal Distress in Labour.—Fig. 5 was taken immediately after a low artificial rupture of the membranes had been performed to induce labour. The heart became progressively slower and more irregular, both the systolic and diastolic time intervals were increased, there was only a slight improvement with oxygen therapy, and the baby

FIG. 4.—Phonocardiogram. A=First heart sound. B=Second heart sound. S=Systolic time. D=Diastolic time.

FIG. 5.—Phonocardiogram. Severe case of foetal distress. Long diastole indicates obstructed foetal-placental circulation.

was delivered by caesarean section about an hour later. Unfortunately it was too severely injured by "intra-partum asphyxial changes" to survive for more than an hour. Occasional cases such as this illustrate that electrical diagnostic measures need to be backed up by quick decisions and prompt surgical service.

Foetal Distress in Pregnancy.—In one case irregularities of the foetal heart were recorded three weeks before the expected date of delivery. Braxton Hicks contractions and manual pressure on the abdominal surface produced marked slowing of the foetal heart. The QRS complex and the systolic times were normal, but the long diastolic times showed some impediment to foetal venous return. The effect was intermittent. The patient was advised to avoid tight clothes or pressure on the abdomen, and a frequent watch was kept on the heart until labour began at term. On delivery the cord was found to be twisted around the leg and compressed each time the knee was flexed.

Slowing of Heart Rate During Contractions.—In an example in early labour the heart was slowed by an increase in diastolic time only, demonstrating impaired venous return (Fig. 6).

FIG. 6.—Slowing of heart during uterine contractions due to increase in diastolic time; impaired foetal venous return.

Electrocardiography

Forceps Delivery.—Fig. 7 shows changes in the foetal heart rate during forceps extraction. Such recordings can be used at the time to warn the surgeon of the effects on the foetus of the application of the forceps and traction.

FIG. 7.—Electrocardiogram during forceps delivery. Note slowing of heart rate.

Diagnosis of Twins.—This was a suspected case of hydatidiform mole (18 weeks' gestation). The E.C.G. (Fig. 8A), however, gave a clear recording for twins, which were, in fact, aborted a week later.

Threatened Abortion.—Difficulty had been found in hearing the foetal heart with a stethoscope at 20 weeks' gestation. The E.C.G. (Fig. 8B) confirmed foetal life; the heart rate is within the normal range.

Moribund Foetus.—We have had cases in which the foetal heart was heard feebly until 15 minutes before delivery and then the foetus was born with slight signs of maceration. Fig. 9 is an example of a foetal E.C.G. taken three days after the heart was last heard. On delivery by caesarean section one hour after the recording, the foetus was severely macerated, but the heart tissue was still normal. Clearly, the E.C.G. must

FIG. 8.—Electrocardiographs (electrodes on maternal abdomen) demonstrate foetal life. (A) Twin pregnancy in case of suspected hydatidiform mole, 18 weeks' gestation. (B) Case of threatened abortion at 20 weeks' gestation.

not be accepted as evidence of foetal viability if the heart cannot be heard when, by reason of the length of gestation, it should be audible with a stethoscope. It is only fair to point out, however, that all cases in which this phenomenon has been observed have had a very abnormal heart rate—that is, above 300 beats per minute. The case recorded in Fig. 9

FIG. 9.—Foetal electrocardiogram three days after heart became inaudible and one hour before delivery of a severely macerated foetus.

had at one time a rate of 700 beats per minute, and this was slowed to 350 before the section by administering digoxin to the mother. Another patient had a rate of 300 beats per minute. Presumably, in such extreme cases the heart is maintained in fibrillation nourished by blood circulated by the action of the uterine contractions on the placental-heart flow. The heart muscle fibrillates, with a high-speed circus movement, and has no substantial effect on the circulation. There is a state of morbid hypotension leading to peripheral maceration. N. J. Brown (1957, personal communication) states that in macerated foetuses he has occasionally found live blood cells in the heart and placenta when other organs were in an advanced state of decomposition.

After Termination of Pregnancy by Hysterotomy.—In two cases the entire conceptus was put into normal saline immediately after removal and the E.C.G. recorded until the foetus died. One was allowed to cool, while the other was oxygenated and maintained at constant temperature. Both cooling and oxygen lack reduced the heart rates.

Other Instrumental Observations on the Foetus

Recording of Foetal Movement

During the recordings of uterine contractions by abdominal tocodynamometry the slowly changing curve of uterine action is often disturbed by kicks and bodily foetal

movements causing sharp changes of pressure. Whether the foetus is attempting reflexly to remove the tocodynamometer, to jerk its way to a different presentation, or just exhibiting *joie-de-vivre*, is not clear, but the frequency of movements varies from perhaps 30 in half an hour to none at all. Some foetuses respond to finger pressure or flicks on the abdominal surface by kicking or moving, while others appear oblivious.

These findings have not been related to the condition of the baby at birth, but various theories concerning the

FIG. 10.—Recording of contractions showing foetal movements superimposed.

possible loss of consciousness of the foetus during labour have been advanced; principally anoxia, analgesics, or compressive forces are blamed. Here we draw attention to the possible value of this investigation as a means of anticipating neonatal asphyxia, or

the need for additional care in searching for an unexpected onset of foetal distress.

Fig. 10 is an example of a tracing of uterine action during labour, which shows how readily foetal movements are recorded.

Foetal Electroencephalography

During foetal electrocardiography employing abdominal electrodes various potential variations are recorded in addition to those expected to arise from the heart. These are due to activity in the maternal bladder and other visceral organs, to arterial pulsation synchronous with the maternal heart and, it is thought, to the foetal brain. With vaginal electrodes there is an increase in the non-cardiac waveforms, and the recordings in some respects are not unlike electroencephalograms.

To investigate this, a portable two-channel Ediswan recorder (having a time-constant of 1 second) was borrowed. A few recordings were done, of which Fig. 11 is an example,

FIG. 11.—Presumed foetal electroencephalogram taken with intra-vaginal electrodes.

using pure silver, chlorided vaginal electrodes placed in the fornices. These recordings have been variously interpreted by experts in this country and France as 100% artifacts, doubtful, and undoubted evidence of gross anoxia. The subject has received more attention from Bernstine and Borkowski (1955, 1956).

Until the interpretation of the electroencephalogram of the newborn is well documented in relation to anoxia, head moulding, maturity, foetal movements *in utero*, and other factors, work on the foetus must be limited to improvements in technique and the collection of data for research analysis.

Foetal Distress

Clinical opinion holds that if an irregular heart improves with oxygen therapy prompt delivery is desirable, even necessary, because this is a sign of impaired oxygen transfer following placental separation or damage, and is unlikely to be relieved by relaxing pressure on the cord or placenta. This is a good working rule, but pressure on the cord or placenta can slow the heart, and, so long as the systolic time and the duration of the QRS complex remain normal, relaxation of uterine tone or repositioning of the foetus may relieve the distress; if the distress is severe, as in the case illustrated in Fig. 5, there is little time for these manoeuvres. If, however, the distress is slight and the uterine contractions are less frequent than one every five minutes, a weak oxytocin infusion will start a regular uterine rhythm, reduce the tone, and, by improving placental-foetal circulation, may relieve the foetal distress.

It would appear very probable that the first sign of anoxia is acceleration of the foetal heart, which can be slowed with oxygen; later there may be a dramatic slowing of the heart, and in such cases oxygen therapy will accelerate it. The first sign of impaired circulation caused by compression of the cord or placenta is undoubtedly a slowing of the foetal heart. Infection or pyrexia must also be considered as possible causes of a fast foetal heart. Hence the factors underlying a heart of abnormal rate need instrumental diagnostic tests. Thick meconium is an adverse prognostic sign, and its presence or absence ought to be determined in every case of foetal distress. For cases showing intermittent foetal heart irregularities, with slight distress, at the end of pregnancy, immediate delivery is not necessary. Such conditions, however, may suddenly become worse or better, and frequent monitoring of the heart is desirable, especially when the membranes rupture or labour begins.

Summary

Techniques for foetal phonocardiography, electrocardiography, electroencephalography, and movement-recording are described.

The fields of usefulness of the two methods of cardiography are defined, and the possible value of foetal electroencephalography and movement recording is discussed briefly.

Typical recordings are reproduced and discussed.

Observations on moribund foetuses increase our understanding of one manner of foetal death, and emphasize the danger of regarding the foetal electrocardiogram as conclusive evidence of foetal viability.

The differential diagnosis of foetal myocardial failure from impaired foetal venous return in cases of foetal distress is demonstrated.

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