Detection of the fetal ECG during labour by an intrauterine probe

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ABSTRACT
The feasibility of detecting the fetal ECG (FECG) from within the uterus in labour by a technique which is non-invasive to the fetus, has been investigated. The design of a special multi-electrode flexible probe has demonstrated that the FECG can be obtained with signal amplitudes of 20–500 $\mu$V and a success rate similar to that of the scalp electrode. Under favourable conditions very large signals can be detected in utero compared to a scalp electrode, but average signal amplitudes are lower. The probe is suitable as a carrier for other sensors such as pressure and temperature transducers. Currently, simultaneous FECG and intrauterine pressure measurement using a commercially available transducer within the same probe has been achieved.

Keywords: Fetal and neonatal monitoring, ECG, intrauterine probe

INTRODUCTION

Twenty-five years after the introduction of electronic fetal monitoring during labour, there has been little advance in the way fetal heart activity is detected. Most developments have concentrated on improving electronics and data processing techniques. This has led to the current position where a dedicated and very sophisticated piece of equipment is capable of producing only two items of data, namely heart rate (FHR) and an indication of uterine activity.

A prospective randomized controlled trial of continuous electronic fetal heart rate monitoring (EFHRM) in labour, involving some 12,000 women, has shown that EFHRM can halve the incidence of neonatal seizures, as compared with a group monitored with the Pinard stethoscope. Of all neonatal problems, seizure activity has the closest correlation with long term neurodevelopment. Therefore the value of fetal heart rate monitoring is well established.

The use of EFHRM has also been widely reported to increase operative intervention rates. Fetal distress rates have risen sharply in the last 10 years partly because of an increase in the incidence of 'fetal distress', but also because of an increase in the diagnosis of 'failure to progress'. This latter has also been associated with higher rates of operative intervention. The mechanism for this is unknown but it is related to increased maternal anxiety. The present use of separate detectors (e.g. a scalp-ECG and a catheter — open ended or cannulated — for intrauterine pressure (IUP), is a major disincentive to monitoring during labour. If fetal monitoring is to be extended by the measurement of variables additional to FHR and IUP, the need for the insertion of yet more separate transducers is likely to prove unacceptable to most women.

This paper reports on the feasibility of detecting the fetal heart activity using an intrauterine probe which is non-invasive to the fetus. The probe may also be used as a carrier for other sensors such as pressure and temperature transducers.

THEORETICAL CONSIDERATIONS

Two methods of detecting fetal heart activity from within the uterus are available. First, there is the electrical activity of the fetal heart as it appears either on the fetal skin or in the amniotic fluid near to the fetal skin surface. This may be detected by suitably placed electrodes which are non-invasive to the fetus. Second, the mechanical movement of the heart may be detected by a very sensitive pressure transducer or accelerometer with a good frequency response (a close-proximity acoustic system) or by local Doppler ultrasound methods. The electrical method is preferred for the following reasons.

1. An ECG waveform has a very distinctive character and may be recognized with relative ease in the presence of noise (e.g. EMG).
2. The well defined R wave peak of the QRS complex provides an ideal event marker for rate counting.
3. A heart pressure or acoustic pulse would be mixed with other, much larger components induced by fetal and maternal movements including maternal breathing, posture changes, abdominal movements and those due to uterine contractions.
4. The diffuse nature of such a pressure pulse is
likely to provide no distinctive event marker and a 'best fit' correlation techniques would be required to derive a rate. Even then, such techniques would not guarantee accurate determination of the exact time of the event. The same is true for signals derived by Doppler ultrasound.

5. An electrode system is easier to use and more economical than a highly sensitive mechanical sensor or ultrasound system.

A pilot study to examine the feasibility of detecting the electrical fetal heart activity has been carried out. Initially conventional polythene open-ended catheters, as used for IUP measurement, were equipped with stainless steel tips forming an electrode that could be passed into the uterine cavity. A second electrode held within either the vagina or cervical canal served as the reference electrode. In six trials with this type of catheter the FECG was detected on three occasions with amplitudes that ranged between 20 and 300 μV varying not only between insertions but during the period of recording. Signal amplitudes varied from the noise level to some four to six times those normally found on conventional scalp-clip electrodes. Using such a probe it was impossible to position the electrode tip accurately. Electrode to fetus positioning appeared to be critical and may have required actual fetal contact. The maternal ECG (MECG) was also noticed on most of these recordings.

In order to see what signals should be attainable from a fetus we studied the distribution of signal amplitudes from new born babies. As our intention was to insert the intrauterine probe such that it lay along the fetal back we chose a point at the rear of the neck as a reference. Signals were then taken at several points down the spine (Figure 1a). This was carried out with the neonate in both wet and dry conditions. In order to mimic the intrauterine environment an attempt was made to obtain ECG signals while the baby was having a salt water bath. In the event this proved too difficult as most babies were too active!

The study demonstrated that a maximum of up to 700 to 1000 μV was available along the dry back of a neonate. The maximum value occurred when the two electrodes were positioned either side of the fetal heart. The amplitude of the signal depended on the electrical axis of the heart and the degree of separation of the electrodes above the surface of the heart.

In a similar examination of signal amplitudes along the backs of adults, maximum values of 340 to 80 μV were found. The shape and polarization of the ECG were nominally the same (Figure 1b). Signal amplitudes from wet newly-borns, were obtained by lying the baby still covered with amniotic fluid directly on an array of electrodes placed in the base of an incubator cot. The values obtained showed a

![Figure 1](image)

**Figure 1** ECG R wave amplitudes, with typical complexes, obtained at various points from, a, the fetal back, both on dry and wet skin, and, b, the male adult back, dry skin only. In all electrode pairs, number 1 is used as the reference. Note polarity of adult ECG between electrodes 5 and 6 (see text)
In view of the low impedance of the amniotic fluid, the impedance between the two electrodes can only be minimized by reducing the volume of electrolyte between the two electrodes in an attempt to electrically isolate them. This can be achieved by ensuring that only one face of the electrode is exposed and embedding it in a structure that permits its close proximity to the fetal skin while surrounding it with an area of insulation. In this way if the probe face is squeezed against the fetal skin the electrolyte surrounding the electrode should be expelled, reducing it to a thin film having a relatively high electrical impedance.

In order to observe the above effect, in vitro impedances were measured (Figure 3). A film was produced by saturating layers of thin tissue paper with electrolyte. As the area and fluid volume was defined the fluid film thickness could be estimated. These tissues were used to connect one electrode to the other, separated by 80 mm. A triangular voltage pulse simulating an ECG R wave was fed to the electrodes via a 10 kΩ series resistor. The amplitude of the pulse, across the electrodes, was measured with saline of various concentrations and several samples of amniotic fluid wetting the paper. The results
Figure 4  Plot of electrolyte impedance versus electrolyte film thickness (1 cm wide) for 18 cm electrode separation. The three amniotic fluid samples are shown with black symbols.

shown in Figure 4 indicate that as film thickness increases the impedance between electrodes drops to a level dictated by the bulk impedance of the solution. Amniotic fluid appears, under these conditions, to behave as a 0.6% w/v NaCl solution, suggesting that its electrical impedance is slightly higher than that of physiological (0.9%) saline. As the film is reduced to less than 1 mm in thickness the impedance over the 80 mm length rises rapidly. The mean volume resistivity (\(\rho\)) of the samples of amniotic fluid was calculated as 106 ohm cm. Assuming an electrode to skin impedance of around 1 k\(\Omega\), then isolating the electrode from its surroundings with a similar impedance should permit detection of at least 50% of the available signal. For the design outlined below this requires a film thickness of approximately 0.5 mm. Therefore under favourable conditions it should be possible to detect up to 500 \(\mu\)V.

![Cross Section of Probe Through Electrode](image)

**Figure 5** Intrauterine probe with four ECG electrodes. Detail shows cross-section through probe at an electrode.

**PROBE DESIGN**

From both the electrical considerations outlined above and those of the utero-cervical anatomy the design of the intrauterine probe has to take certain criteria into account. The body of the probe must be of non-conducting and non-toxic flexible material. It must be stiff enough to allow insertion through the cervix and round the fetal head. Measurements taken on newborn babies of neck to buttock distances suggest a probe with an 'active' length of 190 mm. The fetal head, cervix and vaginal canal dictate a total probe length of some 500 mm.

The probe must be shaped so that the orientation of the surface mounted electrodes can be maintained during insertion. A profile with a flat sided oval cross-section will achieve this. The flat sides enable the easy positioning of the electrodes while fulfilling the requirement of surrounding the electrodes with an insulating material. The shape also offers probe flexibility along the surface lying against the fetus while providing a certain amount of transverse rigidity allowing the clinician to have some control over the direction of insertion.

The design of our probe is shown in Figure 4. The cross-section is 10 mm wide and 3 mm thick. The overall length is 500 mm. The electrodes are stainless steel domed buttons with an exposed diameter of 3 mm. They are surrounded by insulation which is a minimum of 3.5 mm wide across the probe. These electrodes, numbering three to five, are spread over a distance of 180 mm. Connection of the electrodes is via a strip of flexible printed circuit to which they are mounted. This is embedded into the probe body by an injection moulding technique with a two-part polyurethane compound. The electrodes are slightly raised from the surface of the probe body to provide direct electrode contact with the fetal skin.

The electrical signals on the electrodes of the probe are connected via a lead selector to a small battery-operated low noise amplifier so that any combination of two electrodes can be examined. The amplifier output is coupled via a fibre-optic link to a cassette recording system.

The probe has proved easy to insert even with a cervix dilated as little as 10 mm. In fact it has been noted that insertion at an early stage is preferred while the fetal head is high up. Occasionally difficulties have been experienced once the fetus has descended and engaged in the pelvis. The extra resistance on the probe can cause it to flex and kink. The most favourable position of insertion is such that the probe face lies along the fetal back so that at least one electrode is sandwiched between the fetal head or neck and the cervix. Uterine pressure has
the fetal head/neck or back thereby increasing the electrical isolation needed for good detection.

No clear correlation was noted with the strength of signal versus electrode spacing but overall the electrodes spaced at 120 and 180 mm produced the best result, although the relative polarities of both the fetal and the maternal ECGs varied considerably. One would expect the polarity of the maternal complex to remain constant as the two electrodes should be spaced out on only one side of the maternal heart (see Figure 1b—lead position between electrodes 5 and 6). For a head presentation with electrodes spaced out on either side of the fetal heart then maternal and fetal complexes should be of opposite polarity. This was not demonstrated and may be an indication that the probe was not laying in the uterus as imagined.

CONCLUSION

A preliminary investigation into the feasibility of detecting the FECG from within the uterus without piercing the fetal skin has been carried out. The presence of amniotic fluid attenuates the available signals even when intimate electrode to skin contact can be made. Consideration of an electrical model shows that good skin contact and a degree of electrode isolation are required for optimum detection of the high signal levels potentially available. A probe has been designed that allows easy insertion and encourages the conditions for good signal detection. It has been found that both fetal and maternal ECGs can be detected with a success rate of around 90% although signal strengths vary greatly. Further investigations are required to establish the best position and insertion procedure for the probe and to optimize the design of the probe and its electrodes. Special data processing will be required to separate the fetal from the maternal complexes in order to derive both fetal and maternal heart rates. The probe has been used to measure IUP using a commercial transducer embedded within it. Similarly, the probe could become a vehicle for taking other sensors into the uterine environment.

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REFERENCES