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## Abstract

The objective of this paper is to discuss the complexity of fetal movement detection encountered during development and implementation of an automated single Doppler ultrasonic transducer based instrument. The single transducer instrument was intended to better quantify the duration, velocity, and magnitude of fetal movements. A Corometrics Model 116 fetal heart rate monitor was modified, and a fetal movement detection algorithm (Russell Algorithm) was developed to detect fetal movements on one and two (data fusion) transducers. A Hewlett-Packard (HP) M-1350-A fetal monitor and the Russell Algorithm were used to detect and record fetal movements concurrently on sixty patients between the gestation ages of 31 to 41 weeks. Using a computer-controlled SVHS PC-VCR, the instrumental detection of fetal movements was time-linked with real-time video ultrasound. This allowed the fetal movements to be scored by expert examiners on a second-per-second basis. A total of 52,478 seconds of fetal movements was scored using this system. Neither system could accurately define the entire duration, velocity, or magnitude of the fetal movements as detected by real-time ultrasound. The complexity of detecting fetal movements using only one transducer has many shortcomings, such as: the amplitude of the returning Doppler signal, the small area of the fetus monitored by a single transducer, the position of the fetus, the type and variety of fetal movements, and material size and shape.

## Introduction

Clinicians today are becoming increasingly impressed with the importance of fetal movements as an assessment of fetal well-being (Neldam, 1980). Fetal movements may be classified as: general body, breathing, hiccups, and isolated extremity movements such as arms, legs, and head (Rayburn, 1982, 1987).

Maternal perception of fetal movements is an inexpensive method of assessing fetal well-being, but maternal perception of fetal movements may vary statistically due to subjective thresholds (Johnson et al., 1990; Schmidt et al., 1984). Differentiation between types of movement such as, extremity kicks, movement of the head, or gross body movements, are difficult, if not impossible, to determine by the mother (Rayburn, 1982). Maternal perception of short duration or weak movements tend not to be recorded by the mother.

Researchers are currently investigating Doppler instrumentation to detect fetal movements to alleviate the dependence on maternal perception (Wheeler et al., 1987; Besinger et al., 1989; Johnson et al., 1990; Melendez et al., 1989). They have shown that a single transducer Doppler instrument has the same problems as maternal perception. Current manufactures of fetal-movement detection instrumentation include Hewlett Packard and Toitu. The Hewlett Packard includes in their fetal heart rate monitor a circuit for one transducer movement detection that can detect simple gross body movement. Toitu of Japan produces an actocardiograph that provides the physician with unprocessed Doppler signals which are plotted on a strip chart recorder.

Over the last two years, we have been developing an automated Doppler ultrasound-based fetal-movement-detection instrument which will better define the duration, velocity, and amplitude of fetal movements. We have found that the detection and subsequent classification of fetal movements using only one Doppler ultrasonic transducer is very complex. The difficulties were linked to four major areas: 1) The Doppler frequency shift is dependent on the direction of fetal movement. 2) The amplitude of the returning signal is dependent on the angly of incidence and the attenuation of the signal due to the tissue. 3) The diameter of the Doppler signal is only five m 4) The fetus is a very complex reflecting surface moving in complex patterns.

*Doppler Effect.*--The Doppler effect is defined as a frequency change in the carrier source due to the motion of the emitter or reflecting target (Sabbagha, 1980). The Doppler frequency shift is given by

$$fd = \left[\frac{2f_o v}{c}\right]\cos(\theta)$$

where $f_d$ = Doppler frequency shift, $f_o$ = carrier or transmitter frequency, v = velocity of the reflector, $c$ = speed of sound in the medium, and $\theta$ = angle of incidence (Sabbagha, 1980). The accepted speed of sound in the medium is 1540m/s (Sabbagha, 1980). The Doppler frequency shift equation is very dependent on the angle at which the target is moving. A target moving directly toward or away from the source will produce the greatest frequency shift since $\cos(\theta) = 1$.

*Propagation of Sound in Soft Tissue.*--The amplitude of the sound wave is directly proportional to the generating source, and as the sound wave propagates through soft tissues, it is attenuated or absorbed by the tissue. For simplicity, fat, muscle, spleen, bladder, liver, kidney, and brain will be categorized as soft tissues; therefore, the equation

$$\alpha = af^b$$

can be used to approximate the attenuation of signal in soft tissue, where $\alpha$ = attenuation of signal in *dB / cm - MHz*, $f$ = transmitter frequency (MHz), $a$ and $b$ are tissue coefficients (Ziskin et al., 1993). Using average values for a and b, then

$$\alpha = 0.70f^{1.1}.\text{(Ziskin et al., 1993)}$$

Many authors generally accept 1dB/cm-MHz for soft tissue attenuation (Wells, 1977). If the propagating sound wave encounters a medium change or a boundary, then reflection, refraction, and transmission will affect the amplitude and/or direction of the sound wave as illustrated in Fig. 1.

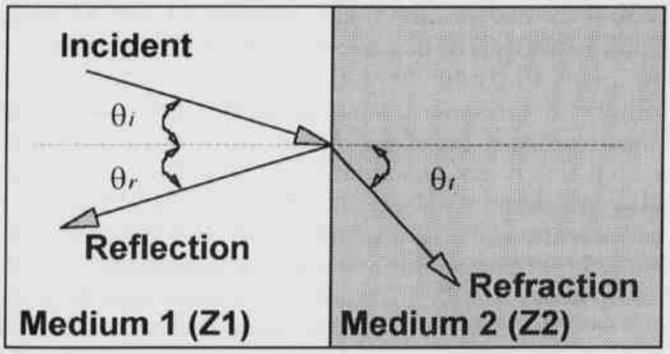


Fig. 1. Porpagating Sound Wave Encounters a Medium Change.

Snell's Law applies in soft tissue if the wavelength is short in comparison with the size of the tissue at the boundary (Ziskin et al., 1993). Snell's Law is given by

$$\frac{\sin(\theta_i)}{\sin(\theta_t)} = \frac{c_1}{c_2}$$

where $c_1$ = speed of sound in medium one and $c_2$ = speed of sound in medium two and

$$\theta_i = \theta_r.$$

Using conservation of energy, it can be shown that

$$E_i + E_r = E_t,$$

where the impedance of a medium is

$$Z = \rho c,$$

and $\rho$ = density of the medium, and $c$ = speed of sound in the medium (Sabbagha, 1980, Ziskin et al., 1993). Using Snell's Law, the conservation of energy, and the impedance of the medium, the amplitude ratio of the reflected sound to the incident wave is given by:

$$R = \frac{Z2^*\cos(\theta_i) - Z1^*\cos(\theta_t)}{Z2^*\cos(\theta_i) - Z1^*\cos(\theta_t)}$$

where $Z = \rho c$ (Sabbagha, 1980, Ziskin et al., 1993). The impedance of different materials is provided in Table 1.

The interface between fat and bone will produce a very high amplitude reflection ratio compared to fat and muscle as shown in the calculations below:

$$R = \frac{Z2 - Z1}{Z2 + Z1} = \frac{1.38-0.92}{1.38+0.92} = 0.2 \text{ Bone to Fat Interface}$$

$$R = \frac{Z2 - Z1}{Z2 + Z1} = \frac{1.07-0.92}{1.07+0.92} = 0.075 \text{ Muscle to Fat Interface}$$

where the calculations assumed $\theta i = 0$. This difference in amplitude reflections is the physical property used in medical imaging instrumentation.

Table 1. Impedance of different mediums (Wells, 1977; Sabbagha, 1980).

| Material | Density (g/ml) | Velocity (m/s) | Impedance $10^6$kg/($m^2$-s) |
|---|---|---|---|
| Bone (skull adult) | 1.38-1.81 | 4080 | 3.75-7.38 |
| Fat | 0.92 | 1460 | 1.35 |
| Muscle | 1.07 | 1600 | 1.65-1.74 |
| Water | 1.00 | 1480 | 1.52 |
| Air | 0.00112 | 330 | 0.0004 |

## Materials and Methods

A Corometrics Model 116 dual fetal heart rate monitor (Coro 116) was modified to allow fetal movement detection on one or both transducers. The One or Two (data fusion) Transducer Russell algorithm and analog electronics were developed to detect fetal movements using the Coro 116. The Coro 116 fetal heart rate monitor uses a nine element transducer which produces a transmitted beam diameter of approximately five centimeters. The diameter which remains approximately five cm in diameter within the desired viewing volume (O'Connell, 1994).

***Russell Algorithm.***--The Russell one and two (data fusion) transducer fetal-movement detection algorithm was developed for Corometrics Medical Systems, Inc. in Wallingford CT. The primary specification for the Russell algorithm was it had to be as-good-as the Hewlett Packard M-1350-A fetal monitor. Due to the proprietary nature of the Russell algorithm, it will not be published or discussed further. However, the one transducer Russell algorithm has been tested extensively and is undergoing FDA 510K clinical trials in a Corometrics Medical Systems Model 150 fetal monitor.

A Hewlett-Packard (HP) M-1350-A fetal monitor was used with the Russell algorithm to detect and record fetal movements concurrently on sixty patients between the gestation ages of 31 and 41 weeks.

A computer-controlled NEC SVHS PC-VCR was used to time-link the instrumental detection of fetal movements with two 3.5 NHz real-time ultrasounds. The real-time ultrasounds were a Corometrics Aloka Model 620 and a General Electric Model 3000. The two video images of the fetus were compressed onto the video section of the NEC SVHS PC-VCR.

The time synchronization of the real-time video images of the fetus and the instrumental detection of fetal movements allowed the expert examiners to score the VCR tapes on a second per second basis and store the scored results in a time-linked file. A total of 52,478 seconds (14.6 hours) of fetal movements was scored using this system.

The measurement of fetal motion on a second per second basis provides a simple way to objectively measure the performance of any fetal motion detector. During each second of measurement, the machine either agrees with the expert file or it does not. Scoring movements on a second per second basis has provided information that allows calculated values not previously reported by other authors. Common indices of agreement (or disagreement) are now weighted in proportion to time while the measurements of previous investigators were not.

***Indices of Agreement or Disagreement.***--The indices of agreement or disagreement used in the statistical study are sensitivity, specificity, positive and negative predictive values, and odds ratio (Rosner, 1990). A frequency summary will aid in the calculations of the indices of agreement of disagreement and is presented in Table 2.

Table 2. Frequency summary table.

| Frequency Table | Expert Movement | Expert Non-Movement | Total |
|---|---|---|---|
| Machine Movement | A | B | A+B |
| Machine Non-Movement | C | D | C+D |
| Total | A+C | B+D | N |

The counts or frequencies (A,B,C,D) are based on the second-per-second resolution of the PC-VCR tapes. On the second-per-second basis the expert or machine will either score a movement or a non-movement. The counts A and D are the number of seconds that the expert and machine agree and counts B and C are the number of seconds that the expert and machine do not agree. The indices of agreement or disagreement are further defined by: (Rosner, 1990)

| | |
|---|---|
| **Sensitivity:** | The conditional probability that the expert and machine both indicate a movement. SEN = A/(A+C) |
| **Specificity:** | The conditional probability that the expert and machine both indicate a non-movement. SPEC = D/(B+D) |
| **Positive Predictive Value:** | The posterior probability of a movement given a score by the machine. PPV = A/(A+B) |
| **Negative Predictive Value:** | The posterior probability of a non-movement given a non-movement score by the machine. NPV = D/(C+D) |

## Results

During this study, we conducted a total of 60 examinations with fetal gestation ages between 31 and 41 weeks. Upon investigation of several maternal demographic factors, we concluded that their affect on the common indices of agreement were insignificant. AT any time, there was transducer movement on the real-time ultrasounds which was excluded from the analysis, due to lack of visualization of the fetus. AFter removal of transducer movements, we had a total of 52,478 seconds (14.6 hours) of fetal movements for analysis. The movement detection results from the One Transducer Russell algorithm and the HP M-1350-A and the movement detection results from the Two Transducer (data fusion) Russell algorithm are presented in Table. 3.

Table 3. One and two transducer russell algorithm and the Hewlett Packard M-1350-A Statistics.

| Number of Patients = 60 | Sensitivity | Specificity | Positive Predictive Value | Negative Predictive Value |
|---|---|---|---|---|
| One Transducer | 43.66 | 90.65 | 50.28 | 89.80 |
| Two Transducer (Data Fusion) | 63.47 | 90.51 | 52.91 | 92.95 |
| HP | 31.12 | 90.05 | 33.61 | 88.28 |

### Discussion

The fetus is a very complex reflecting surface for Doppler instrumentation. The fetus also is capable of moving in complex patterns (Rayburn, 1982, Rayburn, 1987). A representation of the fetus and the Doppler transmitter beam is illustrated in Fig. 2.

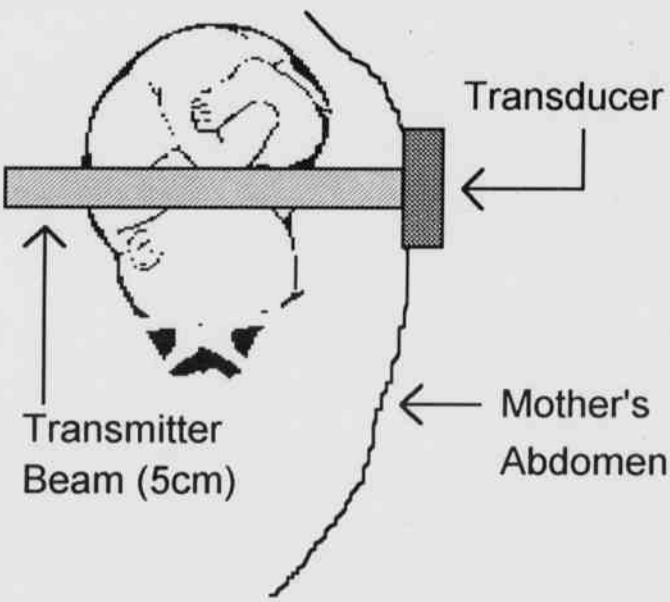


Fig. 2. Fetal representation.

Even though the fetus is enclosed in a small space (the uterus), it still has many degrees of freedom of movement. The directional vectors of the movements are directly linked to the cos(θ) in the doppler frequency shift equation, resulting in a spectrum of Doppler shift frequencies received. The signal is further complicated by the complex biophysical profile of the fetus and its reflecting surfaces. As the fetus moves, highly reflective and poorly reflective surfaces are presented to the transmitter at different angles of incidence. During this type of movement, Snell's Law and the amplitude ratio of the reflected sound become the dominate factors influencing the complexity of the returning signal. The combination of these three factors working together on the returning signal, results in the detection-skip-detection pattern of movement scoring. The fetal head and extremities can also become active reflectors for the transmitting signal during a fetal movement.

A solution to correct the one transducer Doppler and Snell's Law dependence on the cos(θ) could be to increase the number of transducers as with the Two Transducer (data fusion) Russell algorithm. The Two Transducer (data fusion) Russell algorithm statistics did indicate that a substantial increase in sensitivity could be achieved. The data fusion increase was almost 20% better than the one transducer method. The switch from Doppler detection to pulse-echo (A-mode) detection of fetal movements could also be a viable detection technique.

Figure 2 clearly illustrates that the entire fetus is not covered by the five-cm transmitter beam. Increasing the beam diameter is not an option to increase fetal movement coverage. If the beam diameter is increased, the transmitter power ($W/cm^2$) also must be increased to counteract the soft tissue signal attenuation. Increasing the transmitted power would increase the risk of over exposure of ultrasound for the mother, since, the transducer is making contact with the maternal abdomen in one small area. However, the entire fetal area could be covered by placing more transducers on the maternal abdomen without increasing the single transducer transmitter power.

### Conclusions

Our research goal was to develop a one transducer Doppler ultrasonic fetal-movement detection algorithm that was as-good-as the HP M-1350-A fetal monitor. Table 3 clearly indicates that the one transducer Russell algorithm made a statistical improvement over the HP M-1350-A. During development of the one transducer algorithm, we encounter several limiting factors for detecting fetal movements with only one transducer as discussed earlier. To prove that two transducers are better than one, we added another transducer. Using an adapted Russell algorithm and data fusion, the sensitivity increased to 63.4% (see Table 3). The two transducer Russell algorithm was 32.4% better in sensitivity than the HP M-1350-A. The two transducer Russell algorithm reassured us that increasing the number of transducers will increase the fetal movement detection sensitivity and

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eliminate some of the one transducer limiting factors.

## Literature Cited

**Neldam S.** 1980. Fetal movements as an indicator of fetal well being, Lancet, Vol. 2, 1222 pp.

**Rayburn W.** 1982. Clinical implications from monitoring fetal activity. American Journal of Obstetrics and Gynecology, Vol. 144, 967 pp.

**Rayburn W.** 1987. Monitoring fetal body movements, Clinical Obstetrics & Gynecology, Vol. 3, No. 4, 899 pp.

**Johnson T., E. Jordan,** and **L. Paine.** 1990. Doppler recordings of fetal movement: II. Comparison with maternal perception, Obstetrics & Gynecology, Vol. 76, 42 pp.

**Schmidt W., I. Cseh, K. Hara** and **F. Kubli.** 1984. Maternal perception of fetal movements and real-time ultrasound findings, Perinatal Medicine. Vol. 12, 313 pp.

**Wheeler T., K. Roberts, J. Peters** and **A. Murrills.** 1987. Detection of fetal movement using doppler ultrasound. Obstetrics and Gynecology, Vol. 70, No. 2, 251 pp.

**Besinger R.,** and **T. Johnson.** 1989. Doppler recordings of fetal movement: clinical correlation with real-time ultrasound. Obstetrics & Gynecology, Vol. 74, No. 2, 227 pp.

**Melendez T., W. Rayburn** and **C. Smith.** 1992. Characterization of fetal body movement recorded by the Hewlett-Packard M-1350-A fetal monitor, American Journal of Obstetrics & Gynecology, Vol. 167, No. 3, 700 pp.

**Sabbagha R.** 1980. Diagnostic Ultrasound Applied to Obstetrics and Gynecology, J.B. Lippincott Company, Philadelphia.

**Ziskin M.** and **P. Lewin.** 1993. Ultrasonic Exposimetry, CRC Press Inc., Boca Raton, Florida.

**Wells P.N.T.** 1977. Biomedical Ultrasonics, Academic Press, New York.

**O'Connell B.** 1994. Personal Communications, Corometrics Medical System Inc. Wallingford, Connecticut.

**Rosner B.** 1990. Fundamentals of Biostatistics, Third Edition, PWS-Kent Publishing Company, Boston, Massachusetts.