An overview on Fetal Monitoring
# Table of Contents

Understanding fetal monitoring

1. Scope ................................................................................................................................. 3
2. Introduction .......................................................................................................................... 3
3. Background .......................................................................................................................... 3
4. Fetal Heart Rate ................................................................................................................... 4
   4.1 Why do we want to monitor FHR? .................................................................................. 4
      4.1.1 Doppler Ultrasound ............................................................................................... 4
      4.1.2 Fetal ECG ................................................................................................................ 6
5. Fetal Movement ................................................................................................................... 7
   5.1 Why do we want to monitor fetal movement? ................................................................. 7
      5.1.1 Handheld patient event marker .............................................................................. 7
      5.1.2 Automatic fetal movement detector (FMD or Actogram) ....................................... 8
6. Maternal contractions ......................................................................................................... 8
   6.1 Why do we want to monitor maternal contractions? ...................................................... 8
      6.1.1 External toco .......................................................................................................... 8
      6.1.2 IntraUterine Pressure monitoring .......................................................................... 9
7. Print-out ............................................................................................................................... 9
   7.1 How does thermal paper work? ................................................................................... 10
8. Trace interpretation ........................................................................................................... 11
9. Software analysis ............................................................................................................. 11
10 About the author ............................................................................................................... 12
11 Disclaimer / references .................................................................................................... 12
Understanding fetal monitoring

1. Scope
This document provides an overview on fetal monitoring, covering a description of the device, the techniques used to acquire clinical data, and an insight into its clinical application. It is not intended to be a substitute for full and comprehensive training on understanding, and using, fetal monitors, which is beyond the scope of this document. There are many text books on this difficult area of pregnancy management.

2. Introduction
Fetal monitors are used to monitor 3 key fetal / maternal parameters:

- Fetal heart rate (FHR)
- Fetal movement
- Maternal contractions (aka ‘uterine activity’ or ‘toco’)

Additionally, top of the range feto-maternal models can also monitor maternal parameters:

- Blood pressure
- Maternal SpO₂
- Maternal heart rate (MHR)

The above data is printed onto a chart printout for review. In the UK the chart speed used is very slow at just 1cm/min (3cm/min in USA) and fetal monitoring is more to do with looking at the long term trends and patterns than looking at spot measurements – hence the low chart speed. The problem this presents, is that interpretation of the patterns & trends relies on ‘eye-balling’ the trace & forming highly subjective opinions about what it shows. Studies have shown that this process is associated with high inter- & intra-observer variation of a degree that can significantly impact on the trace interpretation and subsequent management of the pregnancy. Sadly, this has been shown to be associated with significant morbidity & mortality rates.

The proper name for the device used for fetal monitoring is a ‘cardiotocograph’. ‘Cardio’ for heart, ‘toco’ for contractions & ‘graph’ because it produces a graph type presentation of the data, more commonly referred to as a trace, or printout. The cardiotocograph is more commonly referred to as a CTG or fetal monitor.

3. Background
Fetal monitoring in its current form was introduced in the 1960s & it is well established worldwide for monitoring pregnancies from ~26 weeks gestation right through to labour & delivery.

Antenatally, pregnant women are monitored for, typically, 20 to 30 minutes at a time, repeated at intervals determined by their risk level. This will depend on their obstetric history, social factors, medical & clinical factors. In the UK, NICE have issued guidelines for trace interpretation, together with appropriate decision support & clinical management pathways.

In labour, pregnant women are typically monitored continuously throughout labour, right up to delivery. Again, NICE guidelines are in place for labour management.
4. Fetal Heart Rate

4.1 Why do we want to monitor FHR?

FHR is a fundamental indicator of fetal life. Ideally, we would also like to monitor fetal oxygenation but not being able to physically access the fetus means this is not possible. Monitoring FHR is the next best available option and provides some level of indication of fetal oxygenation and how the fetus is coping in its environment. Unfortunately, fetal monitoring is often relied on as the ultimate indicator of fetal condition. It is not, and never will be. It is just one small piece of a massively complex jigsaw. Managing pregnancy is unique in healthcare, in that you are actually managing two highly interactive lives – mum & baby. While you can talk to, & examine mum, the fetus is remote – it can't communicate and can't be examined. These two lives are highly dependent, one on the other. It is therefore essential to use fetal monitoring in the context of an holistic approach to the whole clinical scenario. It must also be recognised that, while fetal monitoring has a fairly high negative predictive value, it does not have a good positive predictive value. It should therefore be used more as a screening tool for normality, than as a diagnostic tool for detecting abnormality.

The terms normality & abnormality, in the context of fetal monitoring, relate only to how well the fetus is being supported via the placenta in terms of oxygenation, and provides a level of indication as to the development of the autonomic nervous system, and how the fetus is coping with the stresses it may be exposed to in-utero. It is not able to detect congenital abnormalities and any other physiological or developmental conditions fetuses may present with.

There are two methods for detecting & monitoring FHR.

- Doppler ultrasound
- Fetal ECG

4.1.1 Doppler Ultrasound

Doppler ultrasound is the most widely used technique.

This uses ultrasound (just like ordinary sound but at a frequency (pitch) well above the human hearing range which is nominally 20Hz to 20kHz (kHz - thousand cycles per second). The ultrasound used in fetal monitors is typically in the range 1 to 2 MHz (MHz – million cycles per second).

An ultrasound transducer is strapped onto the abdomen using an elasticated belt. It transmits a beam of ultrasound into the body – think of it as a torch shining a beam of light. Unlike a beam of light, however, ultrasound doesn’t travel through air very well, so a water based gel must be applied to the contact area between the transducer and the skin to get best performance.

As human tissue is ~90% water, ultrasound travels extremely well through the body. The ultrasound beam is reflected off any tissue boundary layers in the beam profile (for example a change from soft tissue to muscle or bone, or from the walls of the fetal heart). The reflected signals are detected by the transducer. If the reflecting body (eg. the fetal heart) is moving, this movement results in a Doppler shift, or a change in pitch of the reflected signal.
The Doppler shift is a phenomenon whereby any movement between the source of a sound (or ultrasound) & the receiver of that sound, results in a change in pitch (or shift in frequency) of the sound. This phenomenon can be heard, for example, when a train approaches a station with its whistle blowing. As the train moves towards you, the pitch of the whistle goes up (not to be confused with the volume which also goes up!). As it passes you & moves away, the pitch of the sound drops. The amount by which the pitch of the sound changes is directly proportional to the speed of the train. Another example in everyday life is an approaching/receding police car siren.

This Doppler shift is detected by the electronics in the fetal monitor & is used to produce an audible sound. Although this sound is actually generated artificially from this Doppler shift phenomenon, it is perceived by users as representing the actual fetal heart sounds. Unfortunately, these ‘fetal heart’ sounds are often swamped by other sounds produced by other movements in the ‘torch beam’. These might, for example, include fetal movement, maternal movement (eg. Coughing, breathing, etc.) & may also include sounds from the maternal, placental & umbilical cord blood flow.

The user listening to these sounds will normally find it easy to pick out the regular repetitive beat sounds from the fetal heart. However, to do this electronically is extremely difficult – unlike the human brain, the electronics is not easily able to identify specific sounds in amongst all the other sounds.

To help understand this, an analogy would be to imagine a room full of people at a party. Although there is a high level of ‘babble’ from everyone talking at the same time, you can separate, from this high noise level, the sounds being made by the person you are talking to & hold a conversation. The human brain is incredibly powerful in its ability to process, & separate out, these sounds.

The electronic technique used in fetal monitors to try to separate out the fetal heart sounds is called autocorrelation. A full understanding of this process is beyond the scope of this document but it can be thought of as a form of pattern matching, which tries to ‘lift’ the repetitive fetal heart sounds out of the general noise. This is generally accepted as the best technique currently available.

However, with even the most powerful electronics in the world, we cannot replicate the power of the human brain with artificial ‘intelligence’. This leads to some compromises & some situations where the fetal monitor simply cannot reliably separate out the fetal sounds. In this situation, the monitor will stop displaying the FHR & stop printing it out on the chart, despite the user still being able to hear the fetal heart sounds. This results in gaps in the trace (sometimes referred to as drop-out) & the often seen annotation written on the trace of ‘FHH’ (Fetal Heart Heard). This is entirely normal & does not represent a failure of the fetal monitor, simply a fundamental limitation of today’s technology. If periods of drop-out are prolonged or repetitive, the user should try to re-position the transducer to get a better fetal heart signal with less background noise.

Other factors which may effect this would include:

- Lack of gel – gel can dry out over a period of time in long labour monitoring sessions, or poor quality gels may flow away from where it’s needed.
- Loose belt – it is important to apply enough belt tension to ensure that firm contact with the skin is maintained.
- Transducer movement – it may have slipped due to maternal movement, pulling the cable, etc.
- Fetal movement – the fetus may have moved out of the ultrasound beam
• Poor transducer positioning. This is an acquired skill and should include palpation of the fetus to determine the best position for the transducer (over the fetal left scapula). Often, transducers are applied without palpation & this can result in poor performance.

Other limitations of the fetal monitoring technology include:

• **Half-rating** – the fetal monitor may display/print half the true rate:
  - when half the true rate falls within the active range (typically 50-210bpm), a half-rate may be displayed/printed instead of the true rate (particularly if the true rate is outside the active range. For example, if the true rate is 180bpm, a rate of 90bpm may be displayed/printed.

• **Double-rating** – the fetal monitor may display/print twice the true rate:
  - when twice the true rate falls within the active range (typically 50-210bpm), a double rate may be displayed/printed instead of the true rate (particularly if the true rate is outside the active range. For example, if the true rate is 90bpm, a rate of 180bpm may be displayed/printed.

• **Maternal rate** – the fetal monitor may display/print maternal rate instead of fetal rate:
  - if there is no fetal signal (possibly due to fetal death), a maternal blood flow signal, for example from the maternal aorta, may be detected. A trace derived from a maternal signal can look like a normal fetal trace, as a normal maternal rate may be doubled, raising it into the normal range for a fetus, or if the mother is tachycardic.

All of the above issues are well documented and safety authorities in the UK and other markets have issued appropriate safety notices relating to these inherent limitations that relate to all makes/models of fetal monitors. It is essential that all users are aware of these issues & are fully trained in the safe & effective use of fetal monitors, and in the interpretation of the data presented by the fetal monitor.

On the plus side, the Doppler audio sounds will always be beating at the true heart rate, so it is very important to listen to the sound, as well as the displayed/printed trace. This will usually make it obvious if the fetal monitor is, for example, half or double rating.

4.1.2 Fetal ECG

The alternative to Doppler ultrasound for FHR detection is to pick up the fetal ECG signal. Just as in adults, if you apply electrodes to the fetus, you can pick up the electrical signals from the heart. This technique also has its limitations, and it’s use is therefore limited. Clinical indications for its use should be limited to cases where it’s not possible to get a good quality trace from ultrasound AND there are high risk factors. Often, however, it gets used when it is not indicated, as there is a perception that it gives better quality ‘beat to beat’ FHR information – this is not the case.

Limitations include:

• As direct physical access to the fetus is required to attach the electrode, it can only be used when the membrane has ruptured.

• As the fetal environment is a liquid one, and there is often hair present, it is not possible to use conventional stick-on ECG electrodes as used for adult ECG. Instead, a special curved, or helical, needle, often referred to as a ‘Fetal Scalp Electrode’ (FSE), is inserted into the presenting part of the fetus to ensure good signal contact. Reference electrodes are in contact with the wall of the cervix and the maternal thigh, via a ‘leg plate’ electrode.
• This is therefore an invasive procedure which has risks associated with it:
  o Stick injuries – the clinician can suffer stick injuries while inserting the electrode
  o Cross-infection – rupturing the skin breaks the natural barrier between mum & baby and significantly increases the risk of cross-infection, for example, where mum has HIV or Hepatitis
  o Excess penetration – if the electrode is inserted too deeply, this can penetrate the dura and lead to brain damage. The most widely used electrode design in the UK does limit the depth of penetration and therefore eliminates this risk, but some electrode designs still present this risk
  o Fetal injury – the electrode is applied to the presenting part of the fetus. In a normal cephalic presentation, this is the fetal scalp. However, cases have been reported where electrodes have been applied to the eyes, genitals, and other parts of the body with resultant possible trauma. Also, if the electrode wires are pulled during labour, the electrode may pull out, causing skin tears.
  o Cost – the electrodes have to be sterile single use items, increasing the cost per session.

The benefit of this technique is that, particularly during the second stage of labour, with all the maternal pushing & movement, and the fetus moving down through the birth canal and into the pelvic region, it can be very difficult to get a good quality trace using ultrasound. FECG to some extent overcomes this and will provide a more continuous trace in difficult situations.

5. Fetal Movement
The second fetal parameter monitored by fetal monitors is fetal movement. Again there are two techniques used:

• Handheld patient event marker
• Automatic fetal movement detector (FMD)

5.1 Why do we want to monitor fetal movement?
Fetal movement is an indicator of fetal well-being. As adults, if we’re not feeling well, we’ll go & lie down and be passive – we won’t go running a marathon! The fetus is just the same – a well nourished ‘happy’ fetus will exhibit periodic periods of activity, including ‘running a marathon’ – ask any mum who’s experienced intense periods of kicking & movement!

So fetal movement is an important indicator of fetal well-being in the antepartum period and can help to clarify difficult to interpret FHR patterns where there is a differential interpretation of complicated tachycardia or continuous accelerative patterns – the one being potentially pathological, the other being a sign of a normal ‘happy’ & active fetus.

5.1.1 Handheld patient event marker
This is very simply a push button on the end of a wire. Mum is asked to hold this and to push the button whenever she feels the baby move. This prints a marker on the chart to record maternally perceived fetal movement episodes.
5.1.2 Automatic fetal movement detector (FMD or Actogram)

While maternally perceived fetal movement recording is important, it cannot be relied on. Mums may not be compliant or may be asleep. It is also well documented that often a fetus can be active without the mum feeling anything.

There is therefore a ‘back-up’ form of detecting fetal movement, derived from the Doppler ultrasound transducer. As described above, Doppler ultrasound works on the principle of detecting movement – movement of the fetal heart being the primary focus for FHR detection. However, when this is being used to monitor FHR, it will also produce sounds as a result of any movement in the ultrasound beam. So if the fetus moves (referred to as gross body movement) this will produce a Doppler sound. The electronics in the fetal monitor is able to differentiate from the low velocity body movements from the higher velocity heart movements, and use this information to determine fetal movement. This again triggers the printing of a marker on the chart – a different style marker in a different position on the chart to avoid confusion.

A degree of caution must be exercised in using this function, as it can be triggered by any significant low velocity movement in the ultrasound beam, or of the transducer itself.

The most robust record of fetal movement is gained from a combination of the two techniques detailed above.

6 Maternal contractions

The third (maternal) parameter monitored by fetal monitors is maternal contractions, during labour. Again there are two techniques used:

- External ‘toco’ transducer
- Internal IntraUterine pressure monitoring (IUP)

6.1 Why do we want to monitor maternal contractions?

During labour, it is important to have some indication of how labour is progressing, and to monitor the build-up of contractions, both in terms of frequency and strength, particularly where drugs are used to try to stimulate more rapid progress. The uterus is a very powerful muscle and when it starts contracting, it applies significant levels of stress to the fetus. It can also cut off the maternal blood supply to the uterus/placenta, leading to periods of transient hypoxia. It is important to monitor how the fetus is coping with these stresses. A well-nourished ‘happy’ fetus will have little difficulty in coping with these transient stresses. However, if labour is prolonged, the fetus may get tired and get into difficulties. In fetuses that may not be so well nourished, due perhaps to a degree of placental insufficiency, it may not have the reserves it needs to cope with these stresses. This will be reflected in changes in FHR in response to contractions. By plotting the contractions on the same chart as the FHR, the relationship between the two parameters can be closely monitored.

6.1.1 External toco

The most widely used method for contractions monitoring is using an external pressure sensor, or ‘tocodynamometer’ strapped onto the abdomen, positioned over the fundus (top) of the uterus. This indirectly records contractions through sensing changes in skin tension arising from the uterine muscular activity.
This provides only a relative measure of contractions strength, calibrated in % over the range 0-100%. This relative measurement is sufficient for normal fetal monitoring, giving an indication of how contractions strength is increasing (hopefully!) as the labour progresses, & showing the frequency of the contractions.

This is the only technique in normal regular use in the UK.

6.1.2 IntraUterine Pressure monitoring

In some markets, this alternative technique is used, typically in higher risk pregnancies. It works by inserting a catheter into the amniotic fluid space surrounding the fetus inside the uterus. A pressure sensor is integrated into the tip of the catheter, providing an accurate, absolute, measure of pressure calibrated in mmHg or kPa (user selectable). It is an invasive procedure and, although the risks are less than those associated with the use of FSEs, there are still risks of introducing infection and damage to maternal (uterine wall) or fetal tissue. The sensors are expensive and are supplied sterile for single use.

As there are no established guidelines (to the author’s knowledge) as to what represents normal, & safe maximum, pressures, the value of this technique as opposed to the external toco method is uncertain.

Indications quoted for its use include:

- VBACs – mums who’ve had a previous C-section, who are now trying for a normal vaginal delivery on a subsequent pregnancy
- Mums with raised BMIs – these can be difficult to monitor with an external toco
- Failure to progress
- High risk pregnancies (although how internal monitoring helps in most high risk scenarios is uncertain)

The way the contractions data is presented on the printout is no different from external toco – only the scale numbers change from % to mmHg or kPa.

7 Print-out

All the above data is presented on a ‘strip chart’ format printout.

The industry standard is 6” (150mm) wide thermal paper, with a ~80mm wide FHR scale and a ~50mm wide contractions scale on which the appropriate trace data is printed, at a chart speed of 1cm/min (3cm/min in USA).

In some monitors, the scales are pre-printed; on others, plain paper is used with the scales being printed at the same time as the data. In between the two scales, data such as date, time, chart speed & operating mode are printed. Scale settings & chart speeds are different in USA & some other markets.

A sample printout is shown below:
7.1 How does thermal paper work?

Domestic computer printers use ink cartridges and the ink is ‘sprayed’ on to the paper to produce the required images.

Thermal paper is fundamentally different in that the ink is already embedded in tiny cells within the paper itself – there is no ink cartridge in the monitor, and therefore, it can never run out of ink!

Applying heat to the surface of the paper releases the ink to produce an image on the paper. This can be simulated by simply running a sharp edge (e.g., Fingernail) over the paper. The friction generates heat & releases the ink.

In fetal monitors, a thermal printhead device is used to produce the image on the paper. This has a row of tiny heating elements across the width of the printer. As the paper passes under the printhead, individual heating elements controlled by the electronics apply heat in a controlled way to produce the image on the paper.

Users must be aware that thermal paper does have a disadvantage compared with conventional paper – over time, the image created on the paper fades. This is accelerated by exposure to UV light, heat, certain chemicals, plastics & liquids. Under ideal storage conditions (controlled temperature & humidity, no exposure to light, heat, etc.), standard thermal paper will last for between 5 – 10 years. Long life paper is available from some manufacturers which can extend this to up to 25 years but it is more expensive & is not normally supplied as standard with fetal monitors.
8 Trace interpretation
A full understanding of how to interpret the trace presented by a fetal monitor is beyond the scope of this document.

In essence, it's about looking at the overall picture of the trace and forming a subjective opinion as to fetal 'well-being'. There are certain key features around which this opinion is based. These include:

- **Baseline rate** – while there is no clear, absolute, definition of baseline rate, it is derived by assessing the average FHR while the fetus is quiescent – ie. in the absence of accelerations and decelerations.

- **Accelerations** – these periods of raised FHR reflect a normal physiological response to increased levels of activity, returning to baseline rate when the fetus returns to a resting state.

- **Decelerations** – these periods of reduced FHR reflect a defensive mechanism, usually an autonomic one, to protect the fetus during periods of transient hypoxia. Transient hypoxia is typically due to contractions, umbilical cord compression or other factors limiting the oxygen supply to the fetus. During the antenatal period, decelerations are considered pathological, requiring further investigation. In labour, so long as the deceleration occurs simultaneously with the contraction (early decels), there is a rapid return to baseline rate and all other aspects of the trace are normal, this is of reduced concern. If the deceleration is delayed relative to a contraction (late decels), this is a more ominous pattern. Decelerations may also be asynchronous with contractions (variable decels) and may be caused by cord compression or certain drugs (eg. hyperstimulation with syntocinon).

- **Variability** – there is much confusion on this aspect of trace assessment, with many users believing that this is a measure of ‘beat to beat’ changes from one beat interval to the next. This is not the case – the fetal monitor is not able to print beat to beat data (at the chart speeds/scales used, there is not enough resolution), and even if it could, there is no established clinical significance of, or guidelines as to the interpretation of, such data. The formal definition of variability is based on taking the highest and lowest rates during a 1-minute section of trace, while the fetus is quiescent, to give a measure of variability plus/minus relative to baseline rate.

- **Fetal movement** – of particular significance during the antenatal period, as a sign of fetal well-being, in association with other normal trace patterns.

9 Software analysis
CTG trace interpretation traditionally relies on a highly subjective opinion based process. This has been shown to be associated with significant inter- & intra-observer variation. Additionally, when a clinician then tries to communicate his/her interpretation to a colleague, this has to be communicated in very subjective terms – for example, “the trace looks a bit flat”. One person’s idea of a ‘flat’ trace can be different from another’s.

Both of the above opinion based processes have, unfortunately, been shown to be associated with poor outcomes – both morbidity & mortality.

To address this, 2 clinicians, Dawes (deceased) & Redman, at Oxford University built up the world’s largest database of CTG traces, together with outcomes, from which they have developed a very sophisticated software
analysis programme (available either integrated into the CTG or as a stand-alone software package with some additional benefits) to provide totally objective & numeric interpretation of antenatal CTG trace.

Known internationally as ‘The Dawes/Redman criteria’, this eliminates the highly subjective, opinion based processes as detailed above. Instead of describing the trace as looking “a bit flat”, the software provides a numeric measure of this, and other parameters, allowing robust numeric descriptions of the trace, for example, “the STV is 4.6” rather than the rather vague “it looks a bit flat” (STV is one of the measures of how “flat” the trace is).

It is strongly recommended that this analysis software is used at all times in conjunction with antenatal fetal monitoring to ensure the highest standards of care.

10 About the author
The author has worked in the fetal monitoring market for 30 years as a designer, engineering manager, product manager & business unit manager. During this time, he has attended many national & international conferences and has been privileged to have worked with some of the leading obstetric clinicians. He has presented to audiences around the world on fetal monitoring and lectured to university student & post-graduate midwives on fetal monitoring.

11 Disclaimer / references
The author is not clinically qualified and this information is provided as an introduction to fetal monitoring by way of an overview only, and is not intended to be used as clinical training material. Where views are expressed as to the application of fetal monitoring, or any other aspect of fetal monitoring, these are the author’s views and do not represent an official statement of recommendations or guidelines for clinical use of fetal monitors.

For official guidelines on the use of fetal monitors and the clinical protocols & practices relating to its use, readers are referred to:

- Local hospital or clinic guidelines
- National guidelines (eg. NICE in the UK)
- International guidelines (FIGO – International Federation of Gynaecologists & Obstetricians)

For further reading on this subject, there are many publications on fetal monitoring. While not intended as a recommendation or endorsement, one such publication, used by the author, is:

- **Title:** Fetal Monitoring in Practice
- **Authors:** Donald Gibb / S. Arulkumaran
- **Publisher:** Butterworth Heinemann

David Stanger.
Global Business Unit Manager,
Obstetric Systems,
Huntleigh Healthcare.

www.huntleigh-diagnostics.com