Introduction

In previous editions of the book *High-Risk Pregnancy: Management Options*, this Element was published as a chapter titled 'Fetal Distress'. This is a term that is still commonly used, but it has always been difficult to define, leading to significant subjectivity in its use, and its retrospective attribution as a "diagnosis" when neonatal outcomes are suboptimal. For many years the term "fetal distress" has been taken to indicate the presence of hypoxia, leading to fetal acidosis. However, it has become clear that other clinical variables such as maternal/fetal temperature[1], chorioamnionitis[2], and passage of meconium into the amniotic fluid (which can lead to meconium aspiration syndrome) [3] can adversely affect the fetus during labor. External events can also contribute to fetal compromise, including trauma, cord prolapse, and head compression (which can occur from excessive molding even in spontaneous labor, but is more commonly associated with forceps and difficult cesarean deliveries)[4].

More recently, it has been demonstrated that formal addition of maternal, fetal, and obstetric risk factors, as well as the level of uterine contractility, can provide a contextualized evaluation of fetal heart rate (FHR) patterns and improve our ability to predict and possibly prevent poor perinatal outcomes. This approach requires a "paradigm shift," however, to conceptualize electronic fetal heart rate monitoring (EFM) or cardiotocography (CTG) as just one of the many screening tests commonly used in obstetrics. The concept of a "screening test" is widely appreciated in medicine and even in antenatal diagnosis, but CTG has yet to be properly appreciated as a screening test, rather than as a diagnostic test.

Simple, all-inclusive terms such as "fetal distress" should therefore be avoided. "Fetal distress" does not distinguish minor and inconsequential factors from catastrophic ones, or indicate the precise nature of the fetal compromise [5]. Such usage is similar to labeling everyone in an adult intensive care unit as being "ill" irrespective of whether they have cardiovascular, neurological, traumatic, or infectious problems. For this reason, this Element is retitled *Fetal Compromise*. It will address in turn the various factors which can lead to fetal compromise, both separately and in combination.

Monitoring and evaluating fetal well-being during labor are difficult, mostly because there is limited access to the baby. The easiest parameter to measure is the FHR. The first reported auscultation of the fetal heart sounds was by the French physician Marsac in the seventeenth century, then in 1818 by Francois Mayor, a Swiss surgeon, and in 1821 by a French nobleman, Jean-Alexandre Le Jumeau, Vicomte de Kergaradec. Each physician independently confirmed the audible beating of the fetal heart. An essay on "obstetric auscultation, or means

of detecting life or death of a fetus before birth" by Evory Kennedy of Dublin was published in 1834. By 1906, Cremer had described the detection of the fetal electrocardiogram (ECG), using electrodes placed on the mother's abdomen and in her vagina. However, this signal was weak and usually overwhelmed by electrical activity produced by the mother's rectus muscles. It was not until the 1960s that Edward Hon introduced a method using a fetal scalp electrode passed through the cervix which could produce a sufficiently large and clear signal for continuous intrapartum monitoring of the FHR. Using a less invasive approach, the first commercial "fetal monitor" (cardiotocograph [CTG]), designed by Konrad Hammacher in Germany and introduced commercially by Hewlett-Packard, initially used phonocardiography (picking up the fetal heart sounds with a microphone). Hon's pioneering work led to the option of monitoring the fetal heart using the ECG obtained via a fetal electrode. Doppler ultrasound to detect the fetal heart movement via the maternal abdomen was introduced in 1968 by a British company ("Sonicaid"). This approach became widely used in the 1970s.

Despite 50 years of increasingly sophisticated fetal heart signal processing, pulse rate alone cannot make a definitive diagnosis of fetal status. In an intensive neonatal care setting after birth, the medical staff monitor several physiological variables in addition to the heart rate, that include pulse oximetry, respiratory rate, and blood pressure. When pediatricians assess the initial condition of the neonate following delivery, they rely upon multiple measurements, including heart rate, respiratory effort, neurological performance (tone, reflex irritability), and peripheral circulatory function (color). Together, these measurements make up the Apgar score, which once was widely considered as the gold standard measure of "birth asphyxia"[6], and low scores were used to indicate hypoxia and acidosis[7]. However, as early as 1967, Beard and coworkers pointed out that the Apgar score "does not differentiate between asphyxial and non-asphyxial depression of the newborn"[8].

In 2005 the American College of Obstetricians and Gynecologists (ACOG), in a guideline decrying the inappropriate use of the terms "fetal distress" and "birth asphyxia," defined birth asphyxia as "intrapartum hypoxia sufficient to cause neurological damage"[9], which required all of the following four features to be present before such a diagnosis could reasonably be made:

- umbilical artery cord blood pH < 7.00
- 5-minute Apgar score ≤ 3
- moderate or severe neonatal encephalopathy
- multiorgan dysfunction (e.g. cardiovascular system [CVS], renal, pulmonary)

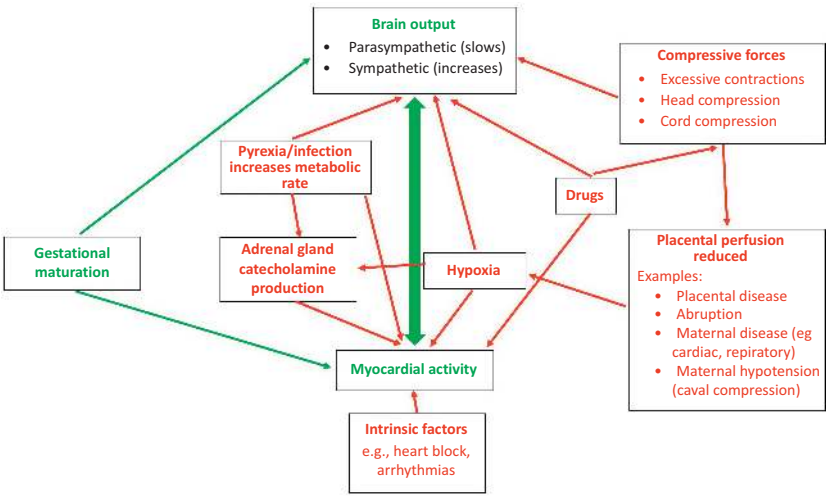

Figure 1 Factors influencing the fetal heart rate.

Since then, the complexity of defining "birth asphyxia" has become even more apparent, leading to a move to avoid the expression altogether (the 2005 guideline has since been withdrawn). For example, in 1982, Sykes and colleagues pointed out that there was a poor correlation between acidosis at birth (which they defined as an umbilical artery pH < 7.1 and base deficit >13 mmol/L) and a low Apgar score (only 27% of those babies with acidosis had a 1-minute Apgar score < 7, and only 21% of those with a 1-minute Apgar score < 7 were acidotic)[10]. It was subsequently reported that most babies who were depressed at birth and required resuscitation were, in fact, not acidotic, nor did they have an abnormal FHR pattern in labor[11]. Instead, their depression was often due to anesthetics given to the mother, trauma, meconium aspiration, and/or other stressors including maternal fever and/or chorioamnionitis.

Thus, FHR pattern analysis alone is not sufficient to evaluate intrapartum fetal condition but must be combined with other clinical features such as fetal growth restriction, length of labor, presence or absence of meconium in the amniotic fluid, and/or whether the mother is pyrexial (Figure 1).

The Physiology and Pathophysiology of Heart Rate Patterns

Fetal heart rate alterations are predominantly mediated by two mechanisms [12][13]:

- reflex slowing of the heart due to firing of the vagus nerve
- slowing of the heart by direct myocardial depression by the generation of lactate from anaerobic metabolism (due to inadequate oxygen supply)

Increases in the FHR can be caused by fetal release of catecholamines and stimulation of the sympathetic nervous system, by an increase in temperature (and therefore metabolic rate), or by various cytokines (as, for example, with infection). In addition, metabolic and endocrine factors and alterations in cerebral blood flow can indirectly influence the FHR pattern by affecting the cardiovascular control center in the brain (situated in the medulla). Unfortunately, it can be very difficult to identify the various influences leading to a pathological change in the FHR. Clinically, the most common changes seen are variable decelerations (secondary to head or umbilical cord compression that trigger FHR slowing by the vagus nerve. When umbilical cord compression occurs, cardiac output is reduced in order to prevent a potentially damaging rise in intracranial pressure due to a sudden increase in peripheral resistance as blood flow through the cord is cut off). Other less frequent alterations in the FHR pattern are late decelerations (secondary to hypoxia) and tachycardia (most commonly due to pyrexia, but sometimes due to catecholamine release). These alterations are described in more detail below.

The normal ranges quoted in this Element have been derived from a large body of observational data and interpreted by expert opinion. These data show that a normal FHR pattern has a good negative likelihood ratio, i.e. when it is normal there is a very low chance of hypoxia (and therefore of acidosis), i.e. a high negative predictive value. In contrast, when features of the FHR recording historically associated with adverse fetal or neonatal outcomes such as prolonged or severe bradycardia, prolonged decreased variability, and variable or late decelerations are seen, they are still commonly associated with babies born in good condition (a low positive predictive value). Thus, many FHR abnormalities are actually "false positives," a conclusion that can only be made reliably in retrospect.

It is therefore clear that the CTG (cardiotocography: continuous electronic assessment of the FHR and uterine contractions) should be regarded as a classic screening tool, and not a diagnostic test. Intrapartum FHR abnormalities are common, and trigger interventions in 10–20% of monitored labors. In contrast, severe perinatal asphyxia (causing death or severe neurological impairment) is very rare. When first introduced, CTG was designed to identify which patients should have a fetal blood sample (FBS) taken (usually from the scalp, occasionally from the buttock) to directly measure acid/base status. Despite, in retrospect (in our view) insufficient data, from the 1980s onward in most parts of the world, CTG interpretation alone was considered sufficient to predict acidosis, so FBS and pH estimation were widely abandoned. However, little attention was paid to the statistical performance metrics of CTG alone, i.e. how much using the CTG alone diminished the accuracy in predicting the neonatal condition.

There is no conclusive scientific evidence that the currently advocated normal ranges of multiple variables such as pH, Base Excess, PO_2, PCO_2, and others are the best ones on which to base clinical decision-making. The concept of "normal" is always liable to lead to an inappropriate metric when applied to physiological variables, because there is usually no sharp cutoff between "normal" and "abnormal." Instead, there is a Gaussian distribution around the mean value, such that the further a measurement is from the mean, the more likely it is to be associated with pathology. This is particularly true at the upper end of the range of FHR, where the likelihood of abnormality increases steadily within the range 150–180 beats per minutes (bpm). However, in this Element we have accepted the normal ranges recommended by the major clinical guidelines[14][15] as the "gold standard," although it could be argued that some of these ranges should be changed.

Baseline Fetal Heart Rate

The baseline fetal heart rate refers to the average recorded FHR after excluding accelerations and decelerations. It is calculated over a period of 5–10 minutes and is expressed in beats per minutes (bpm). Baseline FHR reflects the function of the fetal heart (myocardium) and the central nervous system centers (sympathetic and parasympathetic) and is modified by factors that act on the brain or the heart (e.g. β-sympathomimetic drugs). Therefore, a stable baseline FHR on a CTG trace (albeit with sufficient baseline variability, see below) generally reflects good oxygenation of the myocardium and the centers in the brain that control the heart rate. Although a wide range (110–160 bpm) is considered normal, baseline FHR varies from fetus to fetus, and therefore should be determined individually. Baseline FHR is higher in very early gestation and can be as high as 180 bpm at six weeks' gestation. The parasympathetic component of the central nervous system progressively matures with advancing gestation and decreases baseline FHR. Thus, a preterm fetus has a slightly higher average baseline FHR, due to unopposed activity of the sympathetic nervous system. However, most of this change has taken place by the beginning of the third trimester, and from 32 weeks onward there is no clinically significant change in the average or range of the baseline rate (Figure 2).

While some aspects of CTG should be interpreted in the moment, for example, a profound sustained bradycardia, most CTG assessments do not reflect "sentinel events" and require consideration of the trend of the baseline FHR over time. The fetal response to evolving intrapartum hypoxic stress involves a steady increase in catecholamine levels and therefore heart rate. For example, although a baseline FHR of 155 bpm is still within the "normal"

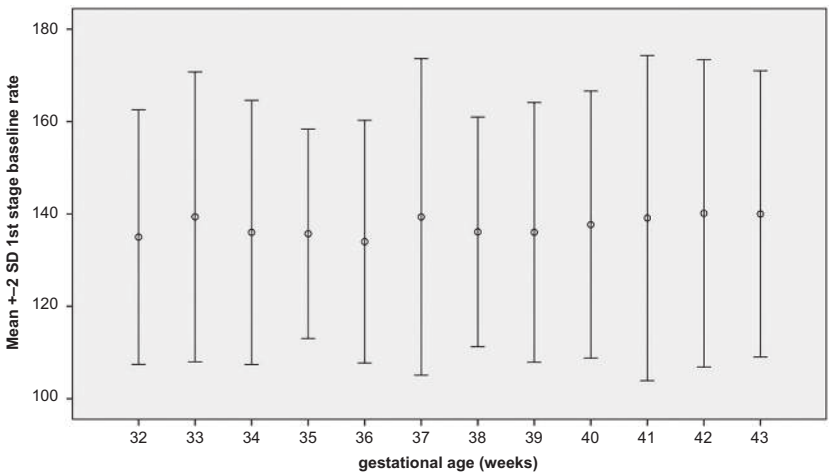

Figure 2 Mean FHR in the first stage of labor at gestational ages from 32 to 43 weeks. The range shown is ± two standard deviations (equivalent to the 2.3 and 97.7 percentiles). Data from the study by Steer PJ *et al*., *Obstet Gynecol* 1989; 74: 715–21[16].

range (100–160 bpm), an increase from a baseline rate of 110 bpm at the start of the CTG recording may reflect an ongoing stress response to hypoxia. A baseline tachycardia which is associated with preceding decelerations and/or a loss of baseline FHR variability should be appreciated as significant, and measures should be undertaken to improve fetal oxygenation whenever possible. Similar evolving patterns are seen with pH and Base Excess (BE) and will be addressed later.

Abnormalities of the electrical or conducting system of the heart may also lead to changes in baseline FHR (sinus tachycardia or atrioventricular heart blocks). A sudden and sustained fall in the baseline heart rate below 110 bpm is termed a prolonged deceleration. It may occur secondary to acute intrapartum accidents (placental abruption, umbilical cord prolapse, or uterine rupture) or due to correctable factors (maternal hypotension, umbilical cord compression, or uterine hyperstimulation). A prolonged deceleration persisting for more than 10 minutes is termed a baseline bradycardia.

A common error is to misinterpret a prolonged moderate bradycardia as a "wandering baseline." It should be remembered that fetuses (and adults) respond to stress with a tachycardia, and apparent falls in the "baseline rate" during labor should always be regarded with suspicion. The FHR at the end of a period of uterine relaxation (just before the next contraction) is often the best indicator of the true baseline.

Baseline Variability

Variation of the FHR above and below the baseline (often referred to as the "bandwidth") reflects the continuous interaction of the sympathetic and parasympathetic components of the central nervous system that regulate the FHR. Normal baseline variability of 5–25 bpm implies that these autonomic nervous system centers in the brain are not depressed and that fetal hypoxia is unlikely. However, this variability is not random, but has a specific undulating pattern in normal fetuses, with cycles every 15–20 seconds. When it becomes abnormally exaggerated, it can indicate hypoxemia[17] and predispose to the development of acidosis[18]. In some instances, this pattern can resemble a sinusoidal pattern, a so-called pseudo-sinusoidal pattern (Figures 3 and 4).

Loss of Variability

Moderate loss of variability is seen with acidosis secondary to hypoxia or metabolic conditions such as maternal ketoacidosis[19]. Complete loss of variability is associated with previous or ongoing brain damage[20], although it can occasionally result from other causes such as maternal exposure to depressant drugs (for example, magnesium sulfate[21], or occasionally opioids) (Figure 5).

Cycling

It is normal for a moderately reduced baseline FHR variability (i.e. < 5 bpm but > 2 bpm) to be seen for up to 40 minutes in the last trimester during quiet fetal

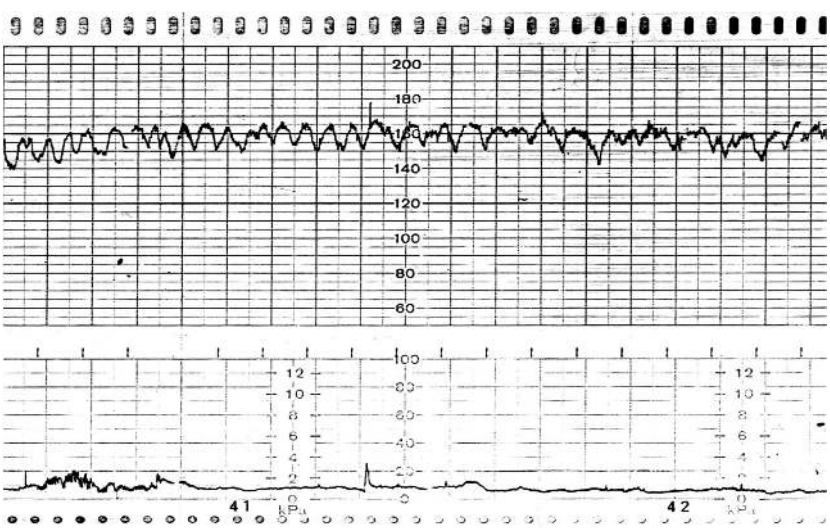

Figure 3 Pseudo-sinusoidal FHR pattern (tracing speed 1 cm/min).