The intrapartum deceleration in center stage: a physiological approach to interpretation of fetal heart rate changes in labor

Jenny A. WESTGATE, MBChB, MD,[1] Bert WIBBENS, MD,[1] Laura BENNET, PhD,[1] Guido WASSINK, MSc,[1] Julian T. PARER, MD, PhD,[2] Alistair J. GUNN, MBChB, PhD.[1]

From: 1. Departments of Physiology and Obstetrics & Gynaecology, Faculty of Medical and Health Sciences, The University of Auckland. 2. University of California, San Francisco, USA.

Correspondence to:
Alistair Jan Gunn,
Dept of Physiology
Faculty of Medical and Health Sciences
The University of Auckland
Private Bag 92019, Auckland, New Zealand
Phone number: [64](9) 373 7599 ext. 86763,
Fax number: [64](9) 373 7499

E-mail: aj.gunn@auckland.ac.nz

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Condensation

The mechanisms of intrapartum decelerations and associated changes in the fetal heart rate recording are reviewed in relation to their ability to predict fetal compromise in labor.

Key words. Fetal sheep; variable deceleration; fetal heart rate monitoring.

Abstract

One of the most distinctive features of fetal heart rate recordings in labor is the deceleration. In clinical practice there has been much confusion about types of decelerations and their significance. In the present review we examine uteroplacental perfusion in labor, describe the pathophysiology of decelerations and explain some of the reasons behind confusion about terminology. We summarize recent studies that have systematically dissected features of variable decelerations that may help identify developing fetal compromise, such as the slope of the deceleration, overshoot and variability changes. Although no pattern of repeated deep decelerations is necessarily benign, fetuses with normal placental reserve can fully compensate even for frequent deep but brief decelerations for surprisingly prolonged intervals before developing profound acidosis and hypotension. This tolerance reflects the remarkable ability of the fetus to adapt to repeated hypoxia. We propose that rather than focus on descriptive labels, clinicians should be trained to understand the physiological mechanisms of fetal heart rate (FHR) decelerations and the patterns of FHR change that indicate progressive loss of fetal compensation.

Introduction

Routine electronic fetal heart rate monitoring has been associated with a significant reduction in fetal mortality and early onset neonatal seizures.[1] However, the positive predictive value of changes in the fetal heart rate pattern is very low, and thus there has been a disproportionate increase in the rates of operative intervention in labor relative to the very modest reductions in neonatal encephalopathy.[2] Recent studies have demonstrated that post-asphyxial encephalopathy in term babies now derives almost entirely from low and medium risk pregnancies.[3, 4] This strongly suggests that the current model of obstetric care is very effective in high-risk populations but needs to be improved for wider application.[3] Thus, an important part of ongoing efforts to improve fetal surveillance in labor must be to improve our understanding of how different aspects of changes in fetal heart rate (FHR) relate to fetal condition.

One of the most distinctive features of fetal heart rate recordings in labor is the deceleration. In clinical practice there is much confusion about types of decelerations and their significance. In the present review we will describe the pathophysiology of decelerations and explain some of the reasons underlying confusion about terminology. We will dissect recent studies that have systematically examined various aspects of decelerations in relation to fetal condition and associated changes in FHR recording that may help to identify infants who are being compromised in labor. This review will not address the prolonged bradycardia that accompanies an acute, catastrophic event such as abruption or prolapse of the umbilical cord. Such extreme events account for approximately 25 to 30% of cases of moderate to severe post-asphyxial encephalopathy, are not difficult to detect, and are seldom predictable or even potentially preventable.[3]

Terminology

Confusion over terminology used to describe FHR patterns has been a longstanding problem. This was addressed by a workshop in 1997, which agreed on definitions of key FHR parameters.[5] These definitions have been widely supported. In our experience the terminology most resistant to change, and most likely to cause major errors, is that relating to decelerations. It is therefore relevant to review the history behind this.

Three types of decelerations (early, variable and late) were described by Hon on the basis of

both shape and timing of decelerations relative to the contractions.[6] Caldeyro-Barcia described Type 1 dips occurring with the contraction and Type 2 dips occurring after the contraction.[7] The brief shallow decelerations originally described by Hon as 'early' decelerations have mystified some clinicians who claim that early decelerations occur very infrequently, if at all. We believe the reason for this discrepancy lies in the paper speed at which the FHR is recorded. In America, paper speed is 3cm/minute whilst in most of Europe, the United Kingdom and Australasia 1cm/minute is used. The shallow early decelerations described by Hon with a paper speed of 3cm/min look like mild variable decelerations at 1 cm/min. Whatever the terminology used, brief and shallow decelerations *per se* are not associated with fetal acidosis. Unfortunately it is often mistakenly assumed that any deceleration which is synchronous with a contraction is an 'early' deceleration and is therefore innocuous, irrespective of its severity, with the potential for tragic results. In practice the majority of decelerations related to labor are 'variable',[8] with an abrupt fall in FHR from the baseline and frequently vary in shape, depth and duration. As we discuss in depth below, there is good clinical [9, 10] and experimental evidence [11-13] that frequent, deep variable decelerations can lead to serious fetal compromise.

We therefore propose that because of this unhelpful confusion terms such as 'early', 'vagal', 'reflex' and 'hypoxic' deceleration should be abandoned. The reasons for this recommendation are discussed below, however, it is likely that effective clinical fetal assessment will focus on assessing the key features of the deceleration (such as depth, duration and frequency) and associated inter-contraction FHR changes, such as variability, that reflect, however imperfectly, the severity of the fetal insult.[14-16]

Placental perfusion in labor

Fetal heart rate decelerations are not seen in most antenatal recordings of the fetal heart rate. When they occur more than sporadically they indicate that further assessment of fetal condition is urgently required.[17] However, during labor decelerations are common, particularly in second stage, and in the great majority of cases are mild and require no special action or intervention. The vast majority of intrapartum decelerations occur as a direct consequence of uterine contractions and consequent reductions in uterine or fetal placental blood flow and fetal oxygenation. Doppler studies have shown that uterine contractions are associated with increased intrauterine pressure and a nearly linear fall in maternal uterine artery blood flow.[18]

Indeed even physiological prelabor contractions are associated with a marked increase in maternal uterine vascular resistance.[19] The impact of contractions on umbilical blood flow in humans is not fully described and is likely to be more complex than changes in uterine artery blood flow. However, experimentally, fetal hypoxia is associated with reduced umbilical venous blood flow.[20-22] Consistent with this umbilical resistance increased significantly during contractions in human fetuses with a positive oxytocin challenge test, i.e. at risk fetuses who developed FHR decelerations,[23] suggesting that uterine contractions sufficient to cause a FHR deceleration are likely to be associated with reduced umbilical as well as uterine artery blood flow.

Thus, even during normal labor there is intermittent reduction of placental gas exchange. This reduction is associated with a consistent fall in pH and oxygen tension, and a rise in carbon dioxide and base deficit in normal, uncomplicated labor.[24-26] Most fetuses enter labor with a large reserve of placental capacity that helps accommodate the repeated brief reductions in oxygen supply during contractions. The effects of repeated hypoxia may be amplified in vulnerable fetuses, for example in those with pre-existing placental insufficiency.[13] Conversely, even a normal fetus with normal placental function, may be unable to fully adapt to tonic contractions or uterine hyperstimulation.[27]

The strict definition of asphyxia is a condition of impaired gas exchange which, if persistent, leads to hypoxemia and accumulation of waste products. Therefore, in this technical sense, essentially all fetuses may be said to be exposed to recurrent ‘asphyxia’ during labor. Fortunately, it is usually well tolerated by the fetus, and relatively severe fetal metabolic acidosis is required to compromise the fetus. The adaptive ability of the term fetus is strikingly illustrated by the consistent finding that neonatal complications and need for resuscitation are extremely uncommon below an acute base deficit in umbilical cord arterial blood of approximately 10 to 12 mmol/L.[28, 29] Unfortunately, both the lay public and many clinicians continue to associate the term ‘asphyxia’ with severe metabolic acidosis, and subsequent development of encephalopathy, and other end-organ damage or death. In our haste to avoid using the term, the normal recurrent hypoxemia of labor and the ability of the fetus to adapt effectively to it are often not fully appreciated.

Fetal heart rate decelerations

The acute fall in FHR (i.e. deceleration) during hypoxia is a key fetal adaptation, which is generally believed to help reduce myocardial work and oxygen requirements.[30] This initial fall in FHR is mediated by the fetal chemoreflex, and can be prevented by parasympathetic blockade (e.g. Figure 1).[31] Thus the observation of a brief deceleration in labor tells us that the fetus has responded to an hypoxic stimulus with a vagally mediated bradycardia.[32, 33] There are older data indicating that pressure on the fetal head in second stage can also cause bradycardia. Dural stimulation may be involved but the most likely mechanism for this is increased intracranial pressure and reduced cerebral perfusion.[34] If the degree of hypoxia is severe and prolonged (typically three minutes or longer), the initial vagal bradycardia is sustained by myocardial hypoxia.[35, 36] Fortunately, most episodes of hypoxia during labor are brief, lasting for a minute or less and thus are associated with only brief decelerations. Thus, decelerations due to true myocardial hypoxia are extremely uncommon, and only occur in the context of pathologically prolonged bradycardia.

The conflicting terminology and the common emphasis on distinguishing between reflex and hypoxic bradycardia are unhelpful in understanding decelerations. The chemoreflex, which mediates the first few minutes of the FHR deceleration,[37] is not only a significant component of fetal adaptation but is also a highly sensitive indicator of the presence of fetal hypoxemia. The depth to which FHR falls is broadly related to the severity of the hypoxia, in that shallow decelerations indicate a modest reduction in utero-placental flow, while a deep deceleration indicates near total or total reduction.[31, 38] Thus, by definition, a shallow deceleration in labor indicates a correspondingly mild fall in fetal oxygen tensions. The fetus can fully maintain normal oxygen delivery to vital organs during such mild to moderate hypoxemia,[39, 40] essentially indefinitely.[41, 42]

In contrast, whilst most intrapartum decelerations are ‘reflex’ in origin this term should not be used to imply that they are somehow ‘benign’ in their effect on the fetus. Each deep deceleration reflects profound, albeit transient, hypoxemia. Not surprisingly, prolonged deep decelerations in the fetal sheep are associated with a profound decrease in the availability of oxygen to the brain,[43] and can trigger neuronal injury after around 10 min in experimental studies of healthy term fetuses.[44] In contrast, as discussed in following sections, it is clear that healthy term fetuses can adapt to brief decelerations without injury for surprisingly long periods of time. Whether or not the repeated hypoxia associated with typical short FHR decelerations is benign depends critically on the fetal condition and adequacy of its prelabor

placental reserve and the duration and frequency of the decelerations.[11-13]

Summary, fetal heart rate decelerations: The central clinical diagnostic issue for fetal monitoring in labor is how to determine whether the fetus is, or is not, able to adapt to repeated deep brief decelerations. As will be discussed below, once deep decelerations are established, the subsequent changes in the pattern of changes in FHR are informative.

Experimental studies of brief repeated asphyxia

The majority of experimental studies of fetal heart rate responses have been performed in the chronically instrumented fetal sheep, *in utero*. The sheep is a highly precocial species, whose neural development approximates that of the term human around 0.8-0.85 of gestation.[45, 46] Thus the majority of studies have been performed at that age. The reader should note that the baseline heart rate of the fetal sheep is approximately 20 beats per minute higher than that of the human fetus.

Brief repeated asphyxia has been produced in the fetal sheep by repeated complete occlusion of the umbilical cord at frequencies chosen to represent different stages of labor. This allows us to examine not only FHR and blood gas changes but also the accompanying blood pressure changes and the effects on cerebral perfusion, information which is not available clinically. Recent studies compared the effect of one minute of umbilical cord occlusion repeated every five minutes (1:5 group) with that of one-minute occlusions repeated every 2.5 minutes (1:2.5 group). The former frequency of decelerations every five minutes is consistent with early labor while, the latter with decelerations every 2.5 minutes is consistent with late first stage and second stage labor. The fetal heart rate and blood pressure changes were monitored continuously as shown in Figure 2, and occlusions were continued for four hours or until fetal hypotension (a mean arterial blood pressure (MAP) < 20 mmHg) developed.[11, 12, 47-49]

1:5 occlusion series (Figure 2a). The onset of each occlusion was accompanied by a variable FHR deceleration with rapid return to baseline levels between occlusions.[13, 50] Fetal MAP rose at the onset of each occlusion and never fell below baseline levels during the occlusions. There was a sustained elevation in baseline MAP between occlusions. A small fall in pH and rise in BD and lactate occurred in the first 30 min of occlusions (pH 7.34±0.07, BD 1.3±3.9 mmol/L and lactate 4.5±1.3 mmol/L). Subsequently these values remained stable despite a further 3.5 hours of occlusions. This experiment demonstrated the remarkable capacity of the healthy

fetus to fully adapt to a low frequency of repeated episodes of severe hypoxia.

1:2.5 occlusion series (Figure 2b). Although this paradigm was also associated with a series of variable decelerations, the outcome in this group was substantially different.[11] The rapid occlusion frequency provided only a brief period of recovery between occlusions, which was insufficient to allow full recovery of fetal cellular metabolism and replenishment of glycogen stores.[51] Three distinctive phases of the fetal response to occlusions were observed in this 1:2.5 occlusion series, as follows.

First 30 minute period. During the first 3 occlusions there was a sustained rise in MAP during occlusions followed by recovery to baseline once the occlusion ended. After the 3rd occlusion, all fetuses developed a biphasic blood pressure response to successive occlusions, with initial hypertension followed by a fall in MAP reaching a nadir a few seconds after release of the occluder. However, minimum MAP did not fall below baseline values. Over this initial 30 min pH fell from 7.40±0.01 to 7.25±0.02, BD rose from –2.6±0.6 to 3.3±1.1 mmol/L and lactate rose from 0.9±0.1 to 3.9±0.6 mmol/L.

Middle 30 minute period. In the middle 30 minutes minimum FHR during occlusions fell and inter-occlusion baseline rose, compared to the first 30 min. Although the minimum MAP did fall over the course of this phase, it never fell below baseline levels. Despite a stable blood pressure response, without hypotension, the metabolic acidosis slowly worsened: pH fell from 7.14±0.03 to 7.09±0.03, BD rose from 11.8±1.1 to 13.6±1.2 mmol/L and lactate rose from 8.2±0.8 to 9.9±0.7 mmol/L.

Final 30 minute period. Finally, in the last 30 minutes, before terminal hypotension developed minimum FHR during decelerations continued to fall compared to the mid 30 min, but there was no further rise in interocclusion baseline FHR. Minimum MAP fell below baseline levels and the degree of hypotension became greater with successive occlusions. All animals developed a severe metabolic acidosis, with pH 6.92±0.03, BD 19.2±1.5 mmol/L and lactate 14.6±0.8 mmol/L by the end of occlusions. Studies were stopped after a mean of 183±43 min (range 140 to 235 min).

The key difference in outcome between these protocols was that frequent occlusions (1 min every 2.5 min) were associated with focal neuronal damage in the parasagittal cortex, the thalamus and the cerebellum, whereas no damage was seen after less frequent occlusions (1

min every 5 min).[12] These findings are highly consistent with clinical evidence that fetal intracerebral oxygenation is impaired during short contraction intervals (< 2.3 min) in labor.[27]

Summary, impact of repeated brief complete umbilical cord occlusion: These experimental studies demonstrate that a series of prolonged brief variable decelerations can ultimately lead to severe, repeated hypotension and profound metabolic acidosis even in healthy singleton fetuses, if they are repeated sufficiently frequently. The changes in the pattern of the FHR associated with this deterioration develop progressively and surprisingly slowly, even during frequent occlusions. The features of changes in FHR that may help identify a fetus that is progressively deteriorating are discussed next.

Useful features of the deceleration from experimental studies

The experiments described above have been used to evaluate features of the inter-occlusion fetal heart rate and shape of decelerations that are suggested to help distinguish the state of fetal compensation. These include the slope and timing of the decelerations, the presence or absence of overshoot tachycardia after the deceleration, and changes in interocclusion FHR and variability.

Slope of the FHR deceleration

Several studies in near-term fetal sheep have suggested that during repeated variable decelerations there is a progressive slowing of the initial fall in FHR.[52-54] However, whereas Akagi and colleagues found that reduced slope during complete occlusions corresponded closely with the development of fetal acidosis and hypotension,[52] others have reported a similar attenuation with repeated partial or complete cord occlusions without significant metabolic deterioration, which suggested that this phenomenon might reflect attenuation of the chemoreflex.[53, 54] This apparent finding, that repeated episodes of hypoxia seemed to blunt the chemoreflex response, is in many ways counter-intuitive. If, as other evidence suggests,[32, 38, 55, 56] the chemoreflex is central to fetal adaptation to severe hypoxia, then we might anticipate that its attenuation would compromise adaptation to labor.[53] Indeed, other chemoreflex responses, including cardiovascular centralization of combined ventricular output, are reported to be enhanced in chronically hypoxic fetal sheep compared with normoxic fetuses.[57, 58]

In view of these issues, a recent study in near-term fetal sheep examined whether repeated

complete short umbilical cord occlusions alone, or fetal compromise, as shown by the development of hypotension and acidosis, led to attenuation of the initial slope of fetal variable decelerations. This study found that the rate of initial fall in FHR actually increased during an occlusion series associated with severe developing acidosis, indicating sensitization, not attenuation, of the vagally-mediated chemoreflex.[50] Late recovery from the variable decelerations was only seen in a minority of fetuses at the time of developing profound hypotension;[11] there is some evidence that this may have been related to reversible subendocardial injury leading to cardiac dysfunction.[59] Further, there was a significant correlation in this group between the rate of initial fall of the FHR and the severity of evolving hypotension during the episodes of umbilical cord occlusion.[50] These findings strongly suggest that attenuation of the chemoreflex only occurs during episodes of relatively mild hypoxia that the fetus has been able to wholly adapt to.[53, 54]

Conceptually, it is important to consider that 'attenuation' should not necessarily be interpreted as meaning 'impairment'. In the present context, attenuation of the chemoreflex response seems to reflect better compensation for the hypoxic stress, such that there is maintenance of adequate homeostasis, and therefore the fetal responses do not need to be as rapid or sustained.

Summary, initial slope of the deceleration: The magnitude of the chemoreflex during repeated hypoxia adapts dynamically to the severity of fetal stress, such that during repeated brief decelerations developing acidosis is associated with a steeper, not slower rate of fall of the FHR.

Timing of the deceleration

The shallow late decelerations originally described by Hon, are relatively uncommon in active labor,[8, 60] occurring almost exclusively in antenatal or early labor recordings. In these circumstances the shallow late decelerations are usually accompanied by fetal tachycardia and reduced or absent variability, often with a history of reduced fetal movements or chronic intrauterine growth restriction. This combination of findings is almost always accompanied by chronic fetal hypoxia. Because of this association it has been assumed that all late decelerations must indicate direct myocardial hypoxia. This is not the case. 'Late' decelerations can occur for 90 to 100 minutes during labor before acidosis develops [61] and are

associated with soft markers of ‘fetal distress’ (low one minute Apgar scores or metabolic acidosis) in only 12 to 50% of cases.[62, 63]

During labor it is possible to observe decelerations which occur late in timing with respect to the onset and peak of the uterine contraction. Those with a rapid fall to the nadir of the FHR (<30 seconds) are classified as variable decelerations, and may be further subclassified as mild, moderate, severe or complicated.[64] Late decelerations are those with both a gradual fall to nadir (defined as more than 30 sec),[5] and with the nadir occurring after the peak of the contraction,[64]. This definition does not specify any further classification based on the amplitude, duration or any associated features of the late deceleration.

The specific mechanisms leading to variable decelerations which are late in timing and to late decelerations themselves remain unclear. In one experimental study the maternal aorta was occluded, up-stream from the fetus, resulting in a time lag between occlusion and the reduction in fetal oxygenation, and consequently the deceleration.[36] Another study associated late decelerations with background (i.e. pre-existing) hypoxia and acidosis during induced labor in the rhesus monkey.[65] In both studies, however, the deceleration was directly associated in time with the fall in fetal arterial saturation. Given that repeated partial (50%) reduction of umbilical cord blood flow is associated with a relatively slow onset of bradycardia,[53] we speculate that late decelerations may occur in a fetus with limited reserves, who is exposed to modest reductions in uterine blood flow that would not cause bradycardia in a healthy fetus. In a study of 5522 low-risk pregnancies the positive predictive value for low arterial pH (< 7.1) rose from circa 12% of 99 patients with recurrent late decelerations to over 50% (9 of 16) in the small subset of patients with recurrent late decelerations plus loss of FHR variability.[63] It is striking that these infants had a high rate of reduced variability on admission, strongly suggesting an element of antenatal hypoxia, preceding labor.[8] As yet we have no hypothesis to explain the occurrence of variable decelerations with a late fall to nadir, nor do we know whether such decelerations cause or indicate a greater or lesser degree of fetal hypoxia compared to late decelerations.

Summary, timing of nadir of the deceleration: Overall, the available evidence suggests that most cases of late decelerations reflect reduced fetal reserve rather than myocardial hypoxia or acidosis. The incidence is low, and it is likely that they are of most value in identifying fetuses at risk of hypoxia when they are accompanied by additional features such as reduced

variability. Further research is needed.

Features of the inter-deceleration FHR

Inter-deceleration FHR and variability

In the fetal sheep experiments described above, the decelerations progressively became deeper as the umbilical cord occlusion was continued. This change was partly due to a fall in the nadir but also to the development of inter-occlusion fetal tachycardia.[11, 50] This tachycardia is due to increased catecholamine activity and is not seen in less frequent, well compensated occlusions (Figure 2a).[50]

In addition to the absolute FHR, the FHR variability (FHRV) in the inter-contraction period is one of the classic indices of fetal well being. As recently reviewed, there is good clinical evidence that moderate levels of FHRV are a strong indicator that the fetus is coping well with labor and is unlikely to have significant acidosis (umbilical pH <7.15) or a low Apgar score.[15] A reduction in FHRV, particularly when it is combined with other fetal heart rate abnormalities, is reported to be an important indicator of fetal hypoxia and developing acidemia both in the term [66, 67] and preterm fetus.[68] Overall, a systematic review has suggested that undetectable or minimal FHR variability in the presence of late or variable decelerations is the most consistent predictor of newborn acidemia, though the association was relatively low (only 23%).[15]

Perhaps surprisingly, however, some clinical studies have suggested there is either a weak or no relationship between FHRV and Apgar scores or cord acid-base measures during labor.[69, 70] Indeed, the initial response to acute experimental hypoxemia or repeated asphyxia in the term fetus is an increase in FHRV rather than a decrease (Figure 3; for a clinical example see Figure 4);[71-75] typically FHRV then becomes suppressed if the insult is chronic or repeated.[71, 72, 76, 77]

Consistent with these data, during repeated brief umbilical cord occlusions in term-equivalent fetal sheep FHR variation increased with the onset of occlusions.[71] Following this transient increase, the onset of severe acidosis and hypotension during repeated umbilical cord occlusions was associated with a fall in FHR variation in two thirds of fetuses but by a terminal increase in the remaining third.[71] The significance of this finding of terminal increased FHR variability remains unclear, however, this feature may well be related to the

presence of overshoot-instability (i.e. to a pattern of tachycardia followed by a secondary fall in FHR between decelerations). Clinical examples of this phenomenon can be commonly seen (e.g. as shown by Figure 4) but further studies, perhaps of existing databases of fetal FHR surveillance, will be required to demonstrate their significance.

Summary, fetal heart rate variability: The combination of progressive intercurrent tachycardia and loss of variability between recurrent deep decelerations suggests that the fetal ability to continue to compensate for repeated hypoxia may be limited.

FHR Overshoot

It is not unusual to see FHR accelerations or 'shoulders' immediately before or after a variable deceleration, perhaps due to different degrees or rate of occlusion in the cord vein compared to the arteries. A variable FHR deceleration which has a transient shoulder only after the deceleration is referred to as an 'overshoot' deceleration pattern. This pattern was described soon after the introduction of clinical fetal heart rate recording [78] and was noted to follow umbilical cord occlusion in both the pre-term human [79] and animal experiments.[80] Several authors have attempted to ascribe clinical significance to this pattern. Goodlin and Lowe [79] reported that a deceleration-overshoot pattern was associated with newborns requiring resuscitation and suggested that the pattern may be caused by an acute fetal hypoxic insult. Shields and Schifrin [81] described overshoot after a deceleration as one component of a 'chronic fetal distress' pattern which was associated with subsequent cerebral palsy. They suggested that the combination of a normal baseline heart rate, but absent variability and mild variable decelerations with overshoot, was due to attenuation of vagal control of heart rate, possibly caused by previous cerebral ischemia in the fetus.

In the present discussions of FHR overshoot we will refer only the occurrence of a FHR shoulder after a variable deceleration. In experimental studies in fetal sheep, the overshoot pattern has been related to the development of fetal acidosis and a fall in cerebral glucose metabolic rate during recurrent umbilical cord occlusions.[82, 83] However, there is currently no definitive evidence for the prognostic importance of the overshoot FHR pattern in human labor.[84]

The relationship between the appearance of overshoot fetal heart rate after decelerations and the duration of individual umbilical cord occlusions and the development of fetal compromise,

with hypotension and acidosis has been examined during brief repeated occlusions in fetal sheep. Overshoot accelerations following the decelerations were seen only in longer occlusions (2-minute duration of occlusions; an example is shown in Figure 3), or in association with developing fetal acidosis and hypotension during 1-minute occlusions in normoxic fetuses.[48] The overshoot pattern occurred after the very first occlusion in a group exposed to one 2-minute occlusion repeated every five minutes, when by definition the fetuses were neither acidotic nor hypotensive. In contrast, overshoot was never seen during the initial stages of 1 minute occlusion series groups. When 1-minute occlusions were repeated every five min overshoot never appeared despite continuing occlusions for 4 hours. The fetuses remained normotensive, with minimal acidosis throughout. When the frequency of occlusions was increased to 1 every 2.5 minutes, progressive hypotension and acidosis developed. Under these conditions, overshoot appeared in all fetuses in association with worsening acidosis and a variable degree of hypotension. In these experiments the mean pH associated with the onset of overshoot was 7.17, consistent with the pH of approximately 7.15 reported by Saito *et al* in four fetal sheep subjected to 1 minute cord occlusions.[82]

The mechanisms involved are unclear, but may include two factors: reduced vagal stimulation during the occlusion and beta-adrenergic myocardial stimulation immediately after the occlusion ends.[81] The initial component of a FHR deceleration caused by umbilical cord occlusion is vagal, mediated by the carotid chemoreflex. However, as the occlusion is continued, decelerations are maintained by direct hypoxic myocardial depression.[35] Consistent with a role of reduced myocardial vagal tone in the overshoot pattern, atropine produces overshoot tachycardia both in the human [7, 85] and the fetal sheep.[36] Catecholamine stimulation must also be required, since the FHR overshoot induced by atropine can be abolished by concurrent administration of propranolol.[82] This suggests that overshoot is caused by beta-adrenergic stimulation which is unopposed because vagal tone has become relatively attenuated during decelerations.

We propose that 2 minute periods of occlusion are sufficient to trigger FHR overshoot from the beginning, because the insult is long enough to result in complete loss of vagal tone by the end of the first occlusion. In contrast, after only 1 minute of occlusion there is likely to be some persisting vagal stimulation, combined with markedly less catecholamine release compared with 2 minute occlusions,[33] preventing subsequent tachycardia. The later development of overshoot with 1-minute occlusions is likely to reflect greater catecholamine

release due to worsening systemic compromise.[86] In conclusion, these data suggest that although it is a reflex mechanism, fetal heart rate overshoot has been under appreciated as a potential marker of fetal compromise; further experimental data are essential to elucidate how its appearance is modulated by other factors such as fetal condition. It was striking that the overshoot events associated with profound hypoxia and acidosis were followed by marked instability of the FHR between occlusion, strongly suggesting that in this very specific setting it may reflect near end stage fetal decompensation.

Summary, FHR overshoot: The clinical significance of the FHR deceleration-overshoot pattern is not yet established and requires further research; in some situations it may be a useful marker of developing fetal acidosis and hypotension.

The impact of fetal condition

The studies addressed so far have examined the responses of healthy, well-oxygenated fetuses to hypoxia. Naturally the pre-labor condition of the fetus, which is seldom easy to ascertain, must have a considerable impact. Cordocentesis has shown that antenatal hypoxia,[87-89] for example due to growth retardation and multiple pregnancy, is associated with an increased incidence of stillbirth, metabolic acidosis during labor and with subsequent abnormal neurodevelopment.[89] Although this clinical experience strongly suggests that such infants are likely to be compromised by otherwise well tolerated labor, intriguingly, experimental studies seem to suggest improved or greater cardiovascular adaptation to moderate induced hypoxemia. When chronically hypoxic fetal sheep were exposed to a further episode of acute hypoxia, they exhibited more pronounced centralization of circulation,[57] with enhanced femoral vasoconstriction.[58] This was associated with greater increases in plasma noradrenaline and vasopressin.[58] It is important to note, however, that these studies tested the response to mild to moderate hypoxia only rather than to labor-like or profound hypoxic insults. Thus it may be speculated that these greater reflex responses reflect reduced fetal reserve that would be exposed during a more severe insult.[57]

We tested the response of chronically hypoxic fetuses from multiple pregnancies to one minute occlusions of the umbilical cord repeated every five minutes, a rate that is well tolerated by normoxic fetuses. Strikingly, whereas the normoxic fetuses were able to tolerate this occlusion series for four hours, the fetuses with pre-existing hypoxia developed severe,

progressive metabolic acidosis (pH 7.07 ± 0.14 *vs* 7.34 ± 0.07) and hypotension (a nadir of 24 ± 2 mm Hg *vs* 45.5 ± 3 mm Hg after 4 hours of occlusion).[13] In experimental studies the presence and severity of hypotension is one of the major factors associated with neural injury.[12, 90, 91]

Summary, the impact of fetal condition: these data support the clinical concept that fetuses with pre-existing hypoxia are vulnerable even to relatively infrequent periods of additional hypoxia in early labor.

The effect of previous neural injury

The viability of intrapartum FHR monitoring to improve outcomes is largely based on the concept that fetuses have not experienced prolonged antenatal hypoxia and consequent neuronal damage before labor. Although this is correct for the large majority of fetuses, there is strong evidence that severe hypoxia is not uncommon before labor,[92, 93] and that consequent neurological injury can lead to abnormal FHR patterns both in the short and long-term.[94] Several studies have reported that near-term or preterm fetal lambs exposed to a prolonged asphyxial insult developed epileptiform brain activity accompanied by abnormal fetal breathing movements and rapid fluctuations in fetal blood pressure and FHR shortly after the insult.[77, 95] These rapid fluctuations in FHR caused an apparent increase in FHR variability. Clinically, Cruikshank *et al* have described a similar FHR pattern with frequent small accelerations, the so-called 'checkmark' pattern.[96] A subsequent case report associated this pattern with regular, repetitive movements seen on ultrasound. Because the movements continued for over 40 min and involved the whole fetus rather than just the diaphragm and the chest wall it was speculated that they represented fetal seizure activity.[97]

In contrast, by 24 to 72 h after severe hypoxia FHR variability was dramatically suppressed in both term and preterm fetal lambs who developed severe injury.[77, 95] This is consistent with the clinical association of absent FHR variability with severe antenatal neural injury.[81, 98] Postnatal studies in infants with congenital brain lesions suggest that mechanism of the long term loss of variability is damage to the medulla oblongata and midbrain.[99]

Summary, the effect of previous neural injury: fetal neural injury is associated with significant acute and chronic changes in FHR pattern. Although it is tempting to speculate that such injury may compromise fetal responses to further hypoxia, there is no direct evidence of this at

present.

Overall summary of FHR changes in labor

Our understanding of the pathophysiological mechanisms involved in labor has been derived almost entirely from studies in the near-term fetal sheep. Many predictions from this work, for example FHR variation changes during repeated decelerations, have been supported by findings in humans. It would be premature to propose specific criteria for intervention as, for example, further research is essential on the utility of overshoot. However, many key principles are clear.

The central, unique aspect of labor is the repetitive hypoxia associated with contractions. As highlighted in this review, in one manner or another, typical short decelerations are mediated by the fetal chemoreflex, in the great majority of cases in response to falls in systemic fetal oxygen tensions. Shallow decelerations reflect a corresponding mild fall in oxygen tension, although if they are seen in early labor they should raise concerns about the fetus's ability to tolerate labor, especially second stage. Once deep decelerations are present, however, no deceleration pattern is necessarily benign. If the fetus is healthy, with a normal placental reserve, it may be able to stably adapt to even deep brief decelerations for prolonged periods; indeed essentially indefinitely at rates consistent with early labor. In contrast, those with limited placental reserve such as twins or growth retarded fetuses may rapidly decompensate even in early labor.

Critically, experimental evidence suggests that when it occurs, the progressive development of metabolic acidosis and impaired blood pressure responses indicating deterioration during repeated deep decelerations are accompanied by changes in baseline rate and variability and perhaps overshoot. As the fetus deteriorates the sequence of events includes increasing amplitude of decelerations, more rapid rate of initial deceleration, a rising baseline, an initial increase and then loss of baseline variability, and finally brief overshoot immediately after the deceleration. Given the progressive, evolving nature of these FHR changes continuous monitoring is important to allow comprehensive assessment of fetal progress compared with the limited data provided by a single snapshot in time.

Conclusion

This review illustrates that whilst our understanding of the pathophysiology of fetal responses to hypoxia is incomplete, considerable useful information is already available to support assessment of fetal wellbeing in labor. Given the consistent confusion over many decades around the terminology of FHR decelerations, the authors believe that simplifying this terminology is vital. We propose that rather than focus on descriptive labels, clinicians should be trained to understand the physiological mechanisms of FHR decelerations and the patterns of FHR change which indicate progressive loss of fetal compensation.

There is already some evidence that significant improvements in the quality of intrapartum fetal assessment can be made by using existing knowledge more effectively.[14, 16] For example, a prospective study showed that a majority of a group of 17 ‘experts’ did in fact agree when assessing cardiotocographic patterns and could accurately identify the majority of cases that did and did not require intervention.[14] More recently, a retrospective assessment of a compulsory fetal monitoring education programme at a single institution suggested that education was associated with an approximate halving of the incidence of babies born with low Apgars and with neonatal encephalopathy.[16] Thus these data support the potential for a simplified physiological approach to improve intrapartum fetal monitoring.

Figure Legends

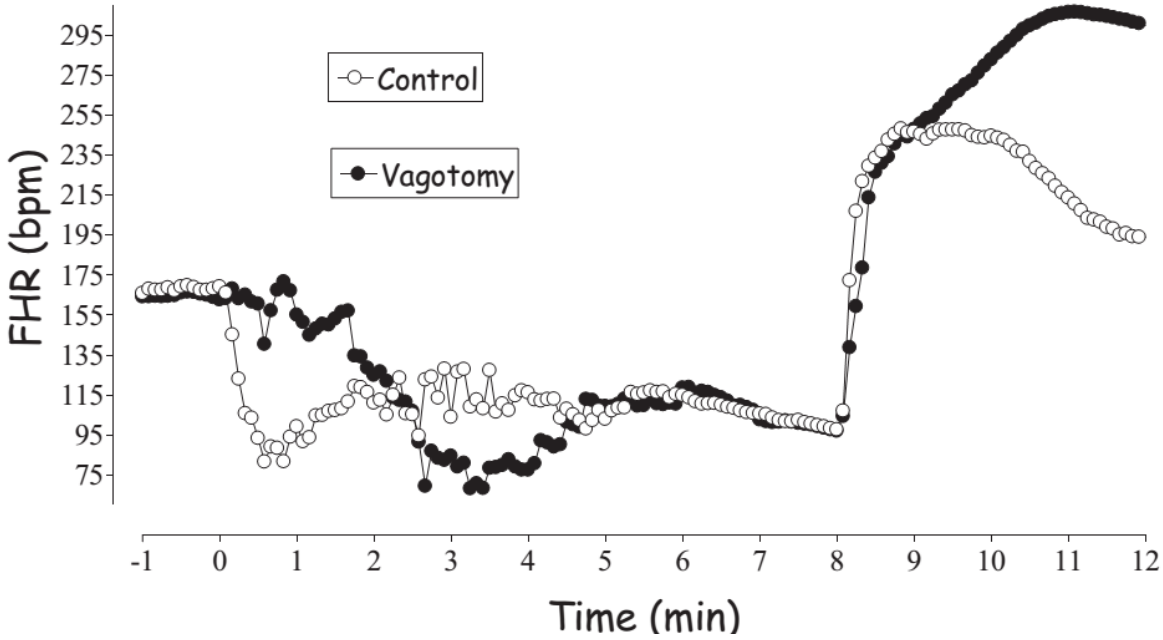

Figure 1. Examples showing the contribution of the parasympathetic system to bradycardia during 8 minutes of severe asphyxia induced by complete occlusion of the umbilical cord in near-term sheep fetuses. Consistent with observations by Barcroft,[35] whereas an immediate bradycardia is seen in the control fetus, vagotomy was associated with a delayed fall in heart rate until the 3rd minute after the start of umbilical occlusion. These data demonstrate that the typical variable deceleration which lasts for approximately one minute is entirely chemoreflex-mediated, whereas prolonged decelerations involve an increasing proportion of hypoxic myocardial depression.

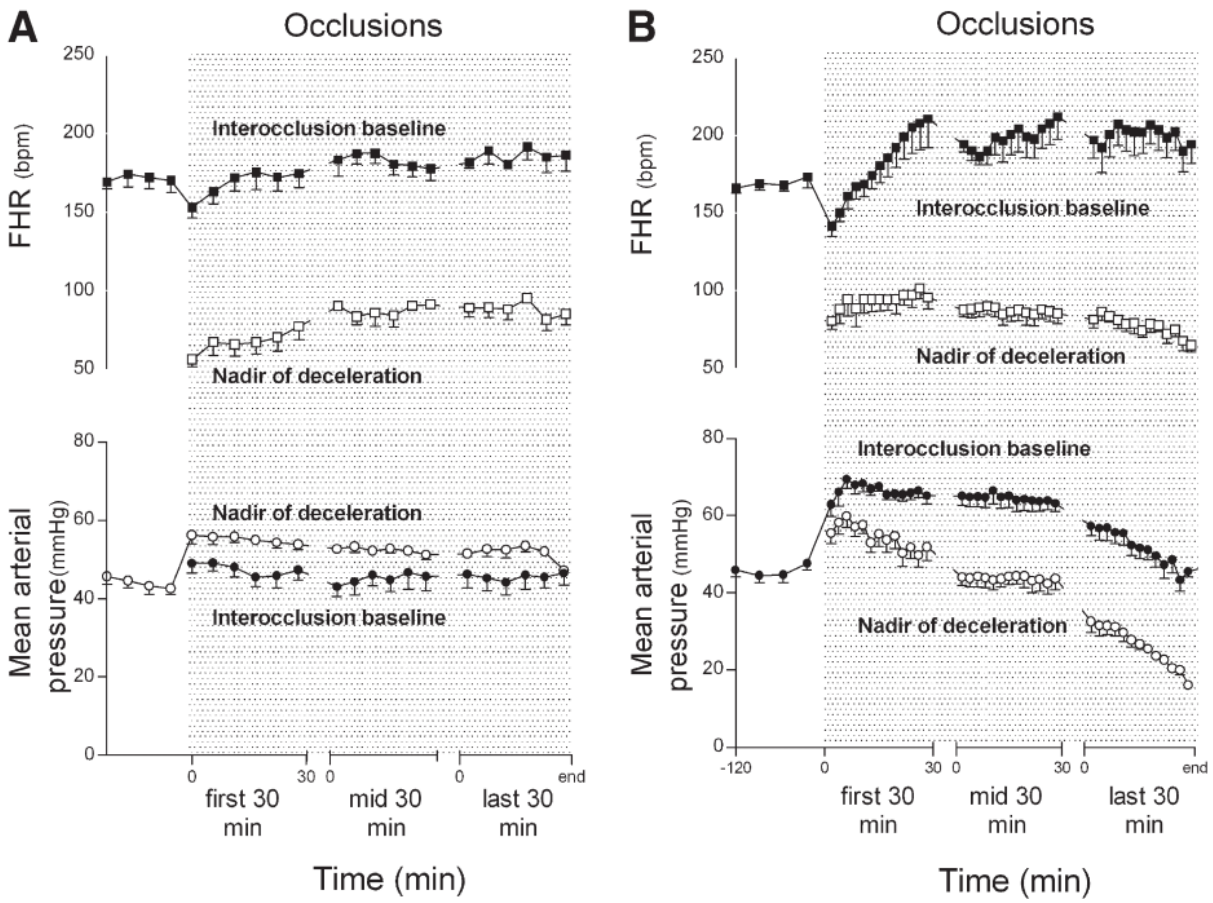

Figure 2. Fetal heart rate (FHR) and mean arterial pressure (MAP) changes occurring in near term fetal sheep exposed to (a) one min umbilical cord occlusion repeated every five min for four hours (1:5 group) and (b) one min occlusions repeated every 2.5 min (1:2.5 group) until fetal MAP fell <20 mmHg. The minimum (i.e. nadir of deceleration) FHR and MAP during each occlusion and the interocclusion baseline FHR and MAP are shown. As the individual experiments in the 1 in 2.5 group were of unequal duration, the data in both groups are presented for three time intervals: the first 30 min, the middle 30 min (defined as the median ± 15 min) and the final 30 min of occlusions.

2a. In the 1:5 group, note that there was no significant change in interocclusion baseline FHR and MAP was higher during occlusions. The FHR decelerations were uniform in size.

2b. In the 1:2.5 group, note that interocclusion baseline FHR was higher in the first and mid 30 min. In the first 30 min minimum MAP transiently rose to greater than baseline values, but fell progressively in the last 30 min. The FHR decelerations appeared to become much larger due to both a small fall in the nadir and a rise in the interocclusion baseline FHR. Data modified from Westgate *et al*.[47, 49, 71]

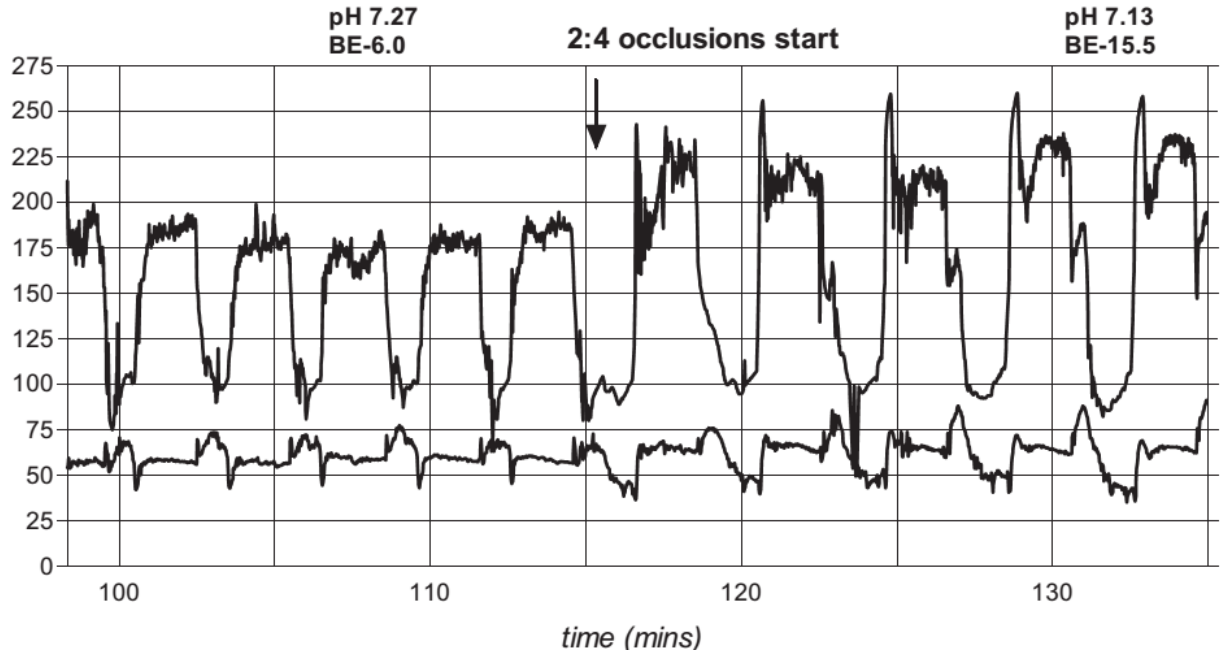

Figure 3. An example of fetal heart rate (FHR) and mean arterial pressure (MAP) from a near term fetal sheep undergoing intermittent cord occlusion at a rate of 1 minute of occlusion every 3 minutes (1:3 protocol) from 0 min to 115 min, followed by occlusions at a rate of 2 min, repeated every 4 min (2:4 protocol; unpublished data). The figure shows the FHR and MAP from 109 minutes to 135 minutes in the experiment. The 1:3 occlusion protocol resulted in a stable baseline with a variable FHR deceleration pattern, no significant hypotension and a slow fall in pH from 7.42 to 7.27 and a rise in BD from 0 to 6 mmol/ over 115 minutes. When the 2:4 protocol begins at 115 minutes there is an immediate change in FHR with overshoot and an increase in interocclusion baseline FHR and FHR variability. Following the 4th two minute occlusion the interocclusion baseline variability is not so marked and there is a secondary fall in FHR after the overshoot (overshoot-instability pattern). MAP falls markedly during the first two minute occlusion and the fall gets progressively more marked with additional occlusions. pH and BE fall rapidly to 7.13 and -15.5 mmol/l after 4 occlusions.

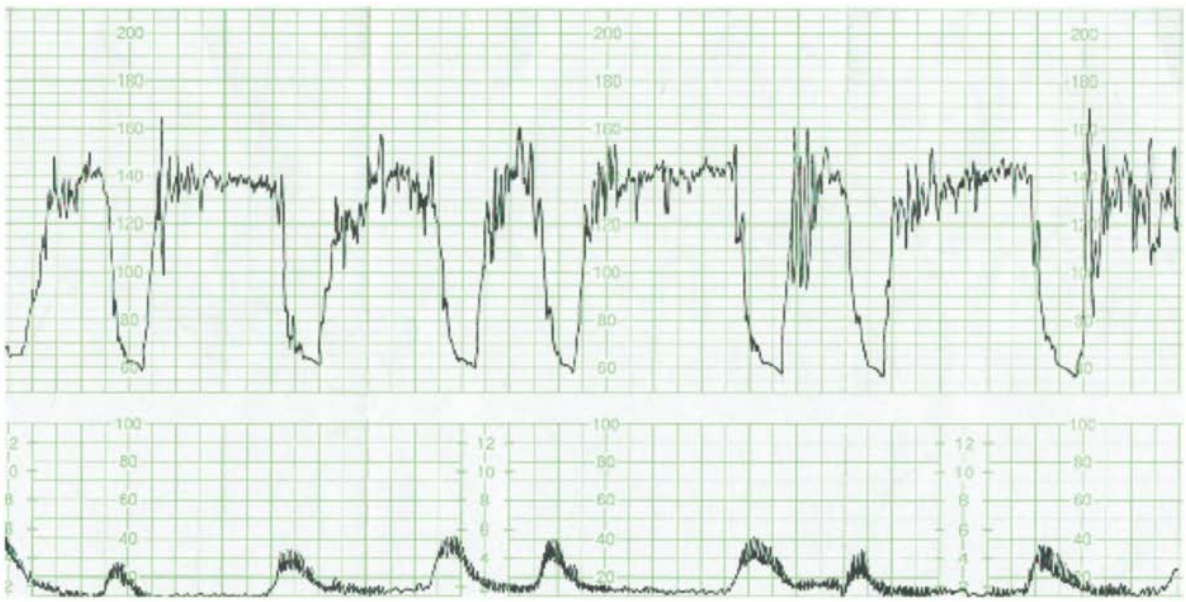

Figure 4. Cardiotocogram recording of fetal heart rate and contractions from a term human fetus who had a cord prolapse in early labor. The FHR pattern shows large variable decelerations with mild contractions every 3 minutes, a stable baseline but increased heart rate variability in between decelerations, consistent with acute hypoxia.

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