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REVIEW

Human Fetal Behaviour

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Studies in fetal behaviour have been of interest for centuries. Philosophers and scientists have speculated about the behavioural abilities of the fetus. Since the existence of behavioural states in the newborn were described in the 1960s, workers have been interested in the behaviour of the human fetus. The existence of fetal behavioural states was first demonstrated in 1982 by Nijhuis *et al.*[1] These were defined as physiological and behavioural variables which characterise an organism at a given moment. The fetus is not just a passive organism feeding on its mother but is a neurologically complex organism. Before the development of high resolution ultrasound, knowledge about the fetus was rather limited. Despite limited knowledge, aspects of fetal behaviour have play a role in clinical practice for centuries. Fetal movement was thought to be the first aspect of fetal behaviour to have any clinical relevance. Prolonged absence of fetal movements in late pregnancy was associated with fetal jeopardy or even fetal death.[2] Ultrasound provides the opportunity for the first time to study the ontogeny, development and integration of many aspects of fetal behaviour. Normal behaviour may reflect normal neuronal integrity of the individual. Many aspects of fetal behaviour, such as fetal movements, rest activity cycles, cardiotocography and fetal breathing movements have been used either individually or in combination as a biophysical profile. These have been shown to be useful as measures of fetal well-being in the last trimester of pregnancy which may be compromised as a result of a number of pathological factors.[2,3] In addition, by giving an insight to the neurodevelopmental status of the fetus, behaviour may elucidate antenatal causes of childhood disability.[3]

Definition of the fetal behaviour

Behaviour is the interaction of an organism with its environment. Fetal behaviour can be studied in three ways.[3]

1. By passive observation of activity[1]
2. By recording the reaction of a fetus to a stimulus[4]
3. By documenting fetal habituation, the cessation of the response to a repeated stimulus[5]

Studies of fetal behaviour initially began with observation, followed by recording the

quantity and variation of the activity between individuals[2]

Fetal biophysical activities can be studied by real-time and Doppler ultrasound. They include the following[6]

1. Generalised biophysical activities, such as gross body movement, breathing movement and fetal tone

2. Specific activities, such as sucking, swallowing, micturition and reflex activities

3. Recognition of sleep states by monitoring the lens motion of the fetal eye

4. Recording of fetal heart rate

5. Complex measurement of flow in umbilical, uterine and fetal vessels

6. Assessment of the intrauterine environment including quantitative amniotic fluid volume determination, placental architecture, grade and pathology and cord position

7. Peristaltic patterns, purposeful movement and evoked fetal reflex responses, like the fetal startle response using an artificial larynx

Development of the fetal behaviour

The development of fetal behaviour has been observed since the first trimestes. All movement present in full term fetus has been seen in the first trimester, but becomes more sophisticated and co-ordinated towards the end of pregnancy.[3]

Fetal behavioural characteristics continue to mature as pregnancy progresses. The period of quiescence seems to be longer as the gestational age advances. For example, 95% of normal fetuses between 24 and 28 weeks' gestation have period of quiescence for less than 6 minutes, but this extends to 10 minutes when the gestational age is 28 to 32 weeks.[7] This feature is thought to reflect behavioural maturation.

Similarly, fetal body movements become more sophisticated and co-ordinated as pregnancy progresses. Most women begin to perceive fetal movement by midpregnancy. However, the first movement can be observed from 6-7 weeks of gestation.[3,8]

In the second trimester, fetal movement becomes more co-ordinated. Fine movement of the limbs increases and early attempts at co-ordinating movement are seen. As pregnancy progresses, the movements become more complex and more forceful. Sucking and swallowing are seen at 18-19 weeks. Breathing movement with diaphragm displacement may be seen at 20 weeks. Fetal extension movements are characteristic of the second trimester.[8]

Third trimester is characterised by the development of the cyclicity of fetal movement, association of fetal heart rate patterns and fetal movement and higher central nervous system control function, including modulation of movement and habituation of responses.[3,8] Maturation continues throughout the gestation.

Fetal behavioural states

Behavioural states are period of behaviour and physiologic variables that tend to occur together and repeat themselves over time.[8] Originally four fetal behavioural states were described, denoted as 1F to 4F, characterised by fetal rate pattern, presence or absence of general body movements and presence or absence of eye movements.[1]

State 1F : is a quiescent state with the fetal heart rate pattern showing a narrow oscillatory bandwidth.

State 2F : is characterised by frequent gross body movements, continuous eye movements and fetal heart rate pattern showing a wider oscillatory bandwidth and accelerations.

State 3F : is one of co-ordination ; body

movements are absent, eye movements, though, are present continuously. The fetal heart rate pattern shows a more regular wide oscillatory frequency than in state 2F with no accelerations.

State 4F : is one of vigorous body movement with continuous eye movements ; fetal heart rate exhibits long lasting accelerations and even sustained tachycardias.

Indeterminate behaviour

Fetal behaviour was defined as indeterminate when the variables not conforming to any one of the recognised states for a least three consecutive minutes. About half of these episodes occurred at the time of transition between different states.[9]

State transitions

It has been suggested that before a fetus can be considered to have behavioural states, the transitions from one state to the next should not take longer than three minutes.[1] Individual fetuses showed considerable variation in transition times between states (5 to 520 seconds). A high percentage of linkage between the variables as behavioural states and a low incidence of indeterminate behaviour were found when ignoring the 3 minute transition rule.[9]

Pillai and James[9] found no existence of state 3F when they observed a group of eighty normal term fetuses for the total duration of 138.2 hours. Cycling of quiescent and active states occurred in 96% of the fetuses within 100 minutes of starting the recording. The 2F was the commonest behavioural state being seen 58% of the time. 1F was seen 30% and 4F was 9%. The remaining 3% was indeterminate.[9]

Behavioural states were also established at earlier gestations. For example, Visser *et al*[10] studied the fetal behaviour at 30 to 32 weeks of gestation and found that heart rate variation and eye and gross body movements are not independent variables and that co-ordination among the cyclic patterns of these variables starts well before 36 weeks.

Fetal breathing movement

In human fetus, breathing movements are episodic with bursts of fetal breathing interspersed among period of apnea.[6] The presence or absence of breathing is used as part of assessment of fetal well being. The presence of fetal breathing movement is reassuring, but when abnormal they are poor predictor of outcome.[6] Pillai and James[11] found that fetal breathing was positively correlated with gestational age. The greatest increase in breathing occurred between 26 and 32 weeks' gestation and it occurred predominantly during active episodes.[11]

Fetal eye movements

The development of eye movement is observed at 16 to 17 weeks beginning with single eye deviation. Rapid eye movement may be detected as early as 19 weeks, but it is not commonly seen until 24 weeks.[8] The mean duration of a rapid eye movement (REM) phase was positively correlated with gestational age. Complex rotational eye movements have been seen in compromised or abnormal fetuses developing after 26 weeks. Absent or unusual eye movements have been seen in compromised or abnormal human fetuses.[12] An excessive nystagmoid-like eye activity was observed in a fetus with high pressure hydrocephalus after placement of ventriculoamniotic shunt in utero.[8] Abnormal body and eye movements have been used to assist detection of Trisomy 18.[13] Periods of absent fetal eye movement are seldom longer than 5 minutes, except in mature fetus in deep

sleep. Relation of eye movement to other behaviours may provide information about integration of the central nervous system.

Fetal response to external stimuli

Studies of the response of a normal fetus to a single stimulus have been documented extensively. Both fetal movement and acceleration of fetal heart rate have been elicited with sound stimulation. Gagnon *et al.*[4] found that there was an intermediate fetal heart rate response following stimulus, characterised by an increase in duration of fetal heart rate acceleration from 26 weeks to term with an increase in basal fetal heart rate after 30 weeks. In addition, a delayed response after 33 weeks' gestation was observed, which consisted of an increase in the number of fetal heart rate acceleration and the incidence of gross fetal body movements for up to 1 hour after a 5-second stimulus with the electronic artificial larynx. Term fetuses made breathing movements more irregularly after vibratory acoustic stimulation. It was suggested that human fetal response to stimulation with an electronic artificial larynx may reflect a functional maturation of the fetal central nervous system.[4]

Fetal responsiveness to stimulation did not depend on fetal state, but fetal responses are increased as the intensity and frequency of stimulus are increased.[14] Vibroacoustic stimulation also affects human fetal behaviour. Devoe *et al.*[15] showed that after vibroacoustic stimulation, the total time spent in state 1F decreased significantly, that spent in state 4F increased significantly and times spent in state 2F and indeterminate state were unchanged.

The clinical implication of fetal response to vibroacoustic stimulation has been used extensively. For example, Gagnon *et al*[16] studied small for gestational age fetuses from 26 to 32 weeks and found that fetal heart rate and fetal activity patterns were not significantly altered after stimulation with an electronic artificial larynx. It was suggested that severe early onset (32 weeks' gestation) chronic nutritional deprivation of human fetuses was associated with a delayed in functional maturation of fetal sensory receptors.[16] Anencephalic fetuses do not show a response to vibroacoustic stimulation nor do they habituate although they may have normal movement.[5]

Fetal habituation

Habituation is widely accepted as a basic form of learning. It is the cessation of the response to a repeated stimulus. Habituation presumably reflects an organism's central nervous system function including aspects of sensory capacity, neurophysiologic functioning and learning.[8]

Leader *et al.*[5] found that 93% of normal fetuses habituated within 10 to 50 stimuli when subjected to a broad frequency vibroacoustic stimulus of 5-second duration repeated every 20 seconds.

Hydrocephalic fetuses have different patterns of response compared with normal fetuses. Fetuses who failed to demonstrate startle responses died in utero or within several months after birth and had the severest central nervous system defects. These fetuses that demonstrated a response decrement before delivery had the best outcome.[8]

The studies of habituation in the group of small for gestational age, with meconium staining of the amniotic fluid or reduced rate of growth determined by serial ultrasound measurement demonstrated that only 34% of fetuses habituated after 10 to 50 stimuli.[5,17] Thus, normal habituation pattern is dependent on an intact and fully

functioning central nervous system.[18]

Factors affecting fetal behaviour

Fetal behaviour may be altered by many factors.

Hypoxemia

Hypoxemia obviously affects fetal behaviour. A higher oxygen level is required for developing central nervous system centres during fetal neurodevelopment. The biophysical activities that appear first in fetal development seem to be the last to disappear under the influence of progressive asphyxia. All biophysical activities will cease if asphyxia is severe enough. Fetal tone centre, that is the earliest to function (7.5-8.5 weeks) is the last one to disappear during progressively worsening asphyxia. In contrast, the fetal heart rate reactivity which begins to mature about 28 weeks is more sensitive to asphyxia and is the first biophysical activity to be affected by asphyxia.[8] Biophysical activity affected by hypoxia disappeared in sequences as shown in figure 1.[8] Arduini *et al*[19] found that in growth retarded fetuses secondary to uteroplacental insufficiency, the speed of development of behavioural state is slower than normal control.

Diabetic mothers

Fetuses of insulin-dependent diabetic mothers have development of behavioural state different from that of fetuses of normal controls. Mulder *et al.*[20] have studied the effects of tightly controlled maternal (type 1) diabetes mellitus on the development of fetal behavioural states. Findings in seventeen fetuses of diabetic women were compared with those obtained from 28 low risk fetuses. The criteria of states were met in only 3 of 8 fetuses studied at 38 weeks and in one of two studied at 40 weeks whereas in low risk fetuses studied at 38 and 40 weeks, the states were present in 70% and 90% of cases, respectively. This poorly developed state organisation exhibited by the near term fetuses of the diabetic group, was related to maternal parity, but not to pre-or postconceptional onset of continuous subcutaneous insulin infusion treatment. Fetuses of nulliparous diabetic women showed more often asynchrony of transitions (greater than 3 minutes) and interruption of periods of concordant association. This resulted in significantly higher percentages of "no-coincidence" and in low incidence of behavioural states as compared with control fetuses of nulliparous women. In the few multiparous diabetic cases studied near term the development of fetal behavioural states was normal. They conclude that despite tight control of maternal diabetes, the development of behavioural states is disturbed in fetuses of nulliparous diabetic women.

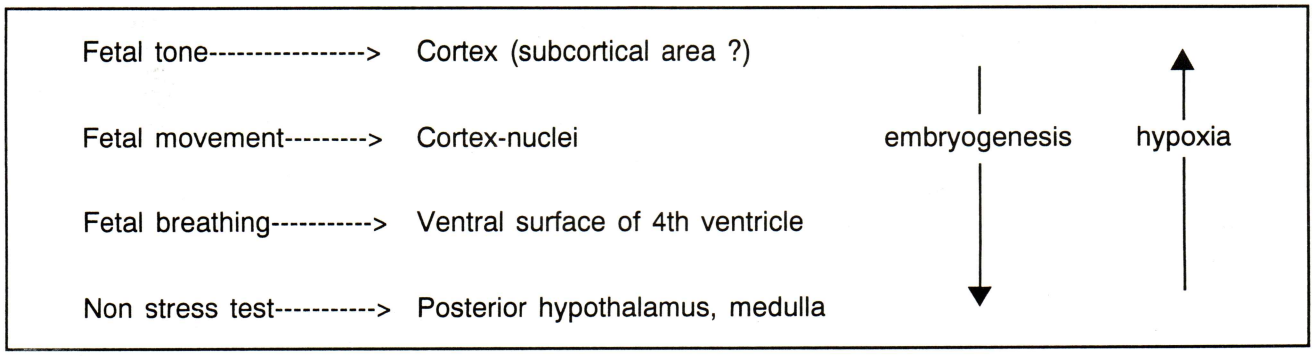


Fig. 1. Biophysical activities and sensitivity to hypoxia

Brain impairment and congenital anomalies

Both brain impairment and congenital anomalies can be detected by studying behaviour in utero. According to the study of Horimoto *et al.*,[21] it was demonstrated that the behaviour of fetuses with brain impairment was different from normal controls. Hepper & Shahidullah[22] reported that Down syndrome fetuses took significantly longer to habituate to stimuli compared with normal controls.

Drugs

Drugs that depress central nervous system activity, such as sedatives (barbiturates, benzodiazepines), analgesics (morphine, meperidine) and anaesthetics (halothane) usually abolish fetal biophysical activity. In contrast, central nervous system stimulants, such as amphetamine and hyperglycaemia often result in increased fetal biophysical activities.[6]

Clinical applications

Fetal behavioural analysis can be used as a tool of predicting the neurodevelopmental status of fetuses with central nervous system anomalies.[3] It could be a part of screening programme to identify high risk fetus of evaluate fetus suspected to be at risk. Currently, it is used as a part of assessment of fetal well being in the form of biophysical profile. However the main limitation of behavioural analysis are labour intensive, time consuming and subjective, so it still remains a research tool.

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