OBSERVATION OF FETAL BEHAVIOUR

Historical conjectures and studies
Probably the first written account of human fetal movements is to be found in the Bible, where Rebecca, Isaac’s wife, describes how ‘the children struggled within her’ (Genesis 25:22). In fact, women have always sensed fetal movements to be a sign of life. The term ‘quickening’, which refers to the moment in pregnancy when the woman first feels the fetus move, has historically been attributed to the beginning of individual life and has, therefore, been regarded as a criterion to determine the point in time at which a fetus is conceded the right to life (de Bracton 1250, Blackstone 1765). Interestingly enough, Hippocrates (460–370 bc) already suspected that fetal movements might in fact set in a few weeks earlier than the expectant mother feels them. More precisely, he suggested that the fetus could actually start moving as soon as 70–90 days after conception, which corresponds to a gestational age of 12–15 weeks (Needham 1959). Leonardo da Vinci, too, made a contribution to embryology: with his famous drawings of a fetus in a womb (1510–1512), he illustrated that embryos and fetuses could actually be measured and assessed, with regard not only to their dimension at a particular moment but also to their development (O’Rahilly 1988).

The first steps in the clinical evaluation of fetal well-being
In the second century, the Greek physician Soranus of Ephesus, who practised in Alexandria and subsequently in Rome, was very clear about the presence of fetal movements, which, in his view, indicated that the course of pregnancy was normal. After that, however, it was not until the 16th century that this issue was brought up again. Eucharius Rösslin (1470–1526), a physician in Worms, Germany, regarded the midwives’ practice as being careless and substandard. Animated by his observations, he wrote a handbook on childbirth called Der Rosengarten (The Rose Garden). The book was an immediate success and was translated into English by Thomas Raynalde (1545) with the title Byrth of Mankynde. Crucial to the work was the realisation that a decrease of fetal movements and their subsequent absence indicated intrauterine death.

In 1869, the German obstetrician Johann F Ahlfeld came to realise that maternal perception of lively fetal movements was a valuable indicator of fetal well-being (Ahlfeld 1869). At around the same time, Charles Pajot (1876) found another sign of good fetal
health, namely audible sounds produced by the fetus, which he believed were caused by movements of the fetal extremities. On this, Ahlfeld disagreed, for he deemed it incredible that movements of fetal extremities could possibly be perceived acoustically, even though he did agree on the presence of sounds, interpreting them as spasmodic contractions of the fetal diaphragm (Ahlfeld 1888). It was also during these years that James Whitehead (1867) observed an increase of fetal movements elicited by maternal emotional stress – an observation that would only be proven a long time later (see Chapter 7).

**Knowledge of spontaneous fetal movements dates back to 1885**
The English–German physiologist William T Preyer (1841–1897) placed a stethoscope on a mother’s abdomen and thus ‘heard’ the fetal movements. He concluded that the movements were definitely present by a gestational age of 12 weeks, but most probably earlier (Preyer 1885). Furthermore, Preyer was convinced that those early movements were spontaneously generated (Preyer 1885). Strassmann (1903) and Yanase (1907) took the same line, as they speculated in their early reports that fetal movements might resemble the movements of a newborn. Ahlfeld, who recorded fetal breathing movements by means of a kymograph, also considered those movements to be spontaneously generated (Ahlfeld 1888, 1905). In spite of all the speculation, the phenomenon of spontaneous movements was not yet pursued, since, at that time, scientists were convinced that such movements had to be evoked.

**The Fels Institute carries out the first non-invasive study of fetal behaviour**
The Fels Research Institute was founded in 1929 with a single, albeit complex, research project known as the Fels Longitudinal Study, which was originally designed to analyse the effects of the Great Depression on child development. Arthur Morgan, then President of the Antioch College in Yellow Springs, Ohio, posed the question: ‘what makes people different?’. He approached Samuel Fels, a Philadelphia businessman and philanthropist, and so the idea was born to study individuals from prenatal life to adulthood, in order to shed some light on the issue. Lester Sontag, a physician, was appointed as the first Director for the Fels Longitudinal Study in 1929 (http://www.med.wright.edu/lhr/fels.html). The first participants were enrolled prenatally by their parents; examinations began in 1930, applying the following equipment and procedure (Sontag and Wallace 1934): the fetal heart rate was measured by means of a stethoscope and a stop watch, while fetal movements were recorded with an apparatus consisting of four rubber bags sewn into a cloth container, each connected with a tambour and a recording drum. Over this group of rubber bags, which corresponded to the four quadrants of the abdomen, the examiner placed a plaster of Paris cast, which had been made especially for the participant and was replaced with a new one each week as the fetus grew. This combination of four bags and four tambours allowed the constantly present respiratory movements of the mother to be ruled out. The recordings were made in 260 fetuses for 2
hours a week. Sontag and Wallace (1934) were thus able to differentiate between (1) slow squirming or writhing movements, which increased until about 28 weeks’ gestation and then decreased; (2) sharp kicking or punching movements of the extremities, which increased with age; and (3) rare, small rhythmic movements, possibly hiccups. Even more interesting is the description of ‘a great deal of variability’ among fetuses as well as of the daily change in individual fetuses (Sontag 1941).

The Fels study confirmed what Whitehead (1867) had observed some 70 years before, namely that maternal emotional stress is linked to an increase in fetal movements. The study went further in claiming that those infants remained irritable and hyperactive for weeks. They cried a great deal and only slept for short periods at a stretch (Sontag 1941).

Fetal activity was also observed to increase during pre-eclampsia. And, finally, fetal movements and the fetal heart rate increased after a vibratory stimulus was applied to the maternal abdomen (Sontag and Wallace 1934). It was rightly observed that, after a sudden increase, the movements and heart rate elicited in such a way remained high for some time, before eventually returning to normal. In this context, habituation was also observed: an unstimulated fetus responded violently with movements when a vibratory stimulus was applied 15 times at 1 minute intervals, whereas a fetus that underwent daily stimulation stopped responding after five or six stimuli.

STUDIES ON EXTERIORISED FETUSES
Other systematic studies on human fetal motility were carried out in the form of examinations of embryos and fetuses after spontaneous miscarriages (Hooker 1938, 1952) or after Caesarean sections in early pregnancy (Minkowsky 1928). However, this work was done through the perspective of the reflexology doctrine, that is, the view that motility was merely a response to exogeneous stimuli. On the same theme, studies were carried out that applied tactile stimulations of embryos and fetuses of amphibians (Coghill 1929), sheep (Barcroft and Barron 1939) or cats (Windle and Becker 1940). Coghill’s (1929) thesis was that reflex mass movements preceded individual reflex movements, while Windle (1940) suggested that complex coordinated movements developed by the integration of local reflex circuits. This reflex-integration approach ultimately contributed to a ‘reflexology’ that was in line with the radical zeitgeist of the 1930s and 1940s.

Davenport Hooker had been carrying out studies on fetal activity in humans since 1932, mostly at the University of Pittsburgh. In his book *The Prenatal Origin of Behavior* (1952), he summarised the results of his studies as well as the animal studies of George E Coghill, who preceded and influenced his work. Hooker had examined 149 human fetuses, spontaneously delivered at 6–45 weeks’ gestational age. The fetuses had been given specific tactile stimuli with von Frey hairs immediately upon delivery to obviate the effects of anoxia. The appearance of reflexes (Figure 1.1) was taken as evidence of early central nervous system function (Hooker 1938, 1952; Humphrey and Hooker 1959, 1961; Humphrey 1964).
Since motility was considered to be evoked, little attention was given to spontaneous movements. In some cases, movements were indeed observed without any evidence of prior stimulation, but they were either not classified as important or described as a ‘spontaneous reflex for which the stimulus was not yet known’ (Hooker 1952). Furthermore, we must always bear in mind that these observations were essentially made in dying fetuses. By the time of examination, the fetal nervous system was presumably in a depressed state and spontaneous activity may already have ceased, even though responses could still be triggered by way of stimulation (de Vries et al 1982; Prechtl 1989).

**The first ultrasound recordings of fetal movements**

The first sonar studies of fetal movements, although not yet real time, were reported by the Viennese obstetrician Emil Reinold in 1971. He described the following two types of movements: (1) a lively movement beginning with a short impulse and ending with a motionless or almost motionless phase. Here, the impression was that the body was kicked away from the wall of the amniotic cavity and then continued to swim, before eventually resettling in its original position; and (2) a slow and lazy movement, generally followed by a pause of 1–5 minutes (Reinold 1971a). In the same year, Reinold got the impression that fetal movements were actually comparable to the darting movements of fish (Reinold 1971b). He further stated that fetal movements were not forceful enough to alter the position of the fetal body before the 10th week of gestation (Reinold 1973). And, lastly, he came to the conclusion that the observed movements of the fetus were spontaneous rather than caused by external influences.

The use of B-mode linear scanners to obtain two-dimensional images of cross-sections through the uterus soon proved a major advance in the documentation of fetal anatomy.
(Tuck 1986). In addition, a rapid succession of linear scans on a video screen in real-time allowed comprehensive observation of fetal movements. From these earliest reports, most of which were by Jouppila and Piironen (1975) and Reinold (1976), a categorisation scheme of fetal motion emerged (Birnholz et al 1978). Influenced by Hooker (1952) and Humphrey (1964), Birnholz drew particular attention to the extension of the head or limbs relative to the trunk; to the rotation or displacement of the torso; and to individual phenomena related to specific limb, regional or organ activity. He thus categorised twitches; independent limb movements; combined/repetitive movements; quasi-startles; limb–joint movements; hand–face contacts; diaphragm movements; and respiratory movements (Birnholz et al 1978).

With the advent of real-time ultrasound scanners, an attempt was made to determine the age at which fetal movements first occur. Van Dongen and Goudie (1980) observed embryos with a crown–rump length of 5–12mm, and saw the heart pulsating at 6 weeks' gestation, with tiny movements occurring in one pole of the embryo at 7.5 weeks of age.

At that time, the number of images that could be recorded per second became sufficiently high to provide real-time recordings. From that point on, examinations were mainly carried out by obstetricians, some of whom evaluated the onset of motility and behaviour (Ianniruberto and Tajani 1981, de Vries et al 1982) in collaboration with the neuropaediatrician Adriano Milani Comparetti and the developmental neurologist Heinz Prechtl.

Fetal movements as reported by the mother
Expectant mothers sense the first quickening between 14 and 22 weeks' gestation, when fetal movements are forceful enough to press against the maternal abdominal wall (Tuffnell et al 1991, Hijazi and East 2009). Quickening is noticed earlier (1) by multigravidae, at an average gestational age of 17 weeks, as opposed to 19 weeks in primigravidae (O’Dowd and O’Dowd 1985); and (2) if the placental site is on the posterior instead of the anterior uterine wall (Gillieson et al 1984, Hijazi and East 2009). At first, fetal movements are infrequent, weak, and sometimes indistinguishable from other abdominal sensations, but they gradually become stronger, more frequent and easily distinguishable from other types of movement. They reach a maximum between 30 and 38 weeks and then decrease somewhat until delivery (Sadovsky and Yaffe 1973, Sadovsky and Polishuk 1977).

What mothers describe are kicks (quick jerks and thrusts of the extremities); squirms (slow stretching, pushing and turning movements); hiccups (rhythmic series of quick convulsive movements); ripples (light, rapid, constant-intensity movements consisting of a back-and-forth and up-and-down movement); and rolling or rotating movements (Walters 1964, Sadovsky et al 1979, Rayburn and Mc Kean 1980). Most fetal movements are noticed by the mother when she is lying; fewer are felt when she is sitting, and hardly any when standing (Minors and Waterhouse 1979).
Charting the mother’s perception of fetal motion is the oldest and simplest method of monitoring fetal well-being during the second half of pregnancy (Figure 1.2). However, the agreement between maternally perceived and ultrasonographically recorded fetal movements is between 33% and 82% (Gettinger et al 1978, Hertogs et al 1979, Rayburn 1980, Schmidt et al 1984, Valentin and Maršál 1987, Kisilevsky et al 1991, Nishihara et al 2008). Quite often – in 30% of all cases – mothers perceive movements that cannot be sonographically confirmed (Schmidt et al 1984).

The Groningen fetal ultrasound studies
The use of real-time ultrasound has opened the door to both behavioural and neurological assessment of the human fetus. High-resolution, real-time ultrasound scanning has become an indispensable tool in the longitudinal investigation of the emergence and differentiation of an individual’s prenatal movement repertoire (de Vries et al 1982, 1985, 1988, Nijhuis et al 1982, Roodenburg et al 1991). From a methodological point of view, this comes very close to the approach of developmental neurology, where the observation of movement patterns, of their quantity and, above all, their quality, serves as a basis for the investigation of neural development and for assessment of the condition of the nervous system. Aiming to acquire a sound knowledge of normal development, the first questions posed in the Groningen studies were the following:

• How should fetal movement patterns be classified?
• At what age do they appear for the first time?
• Do they change in the course of intrauterine development?
• Are there any age-related preferences with regard to the fetal position?
• Are there any specific motor patterns which are responsible for changes in the fetal position?

The attempts to answer these questions were based on many years of experience in infant observation (Prechtl and Schleidt 1950, Prechtl 1953, 1958, 1977, Prechtl et al 1979). At the beginning of the ultrasound studies, Heinz Prechtl, the founder and leading figure of the Groningen studies, was hoping that familiarity with motor patterns in preterm and term infants would help with recognition of similar patterns in the fetuses. It came as somewhat of a surprise that the repertoire of fetal movements exclusively comprised motor patterns that could also be observed postnatally (Prechtl 1984, 1985, 1989, 2001). This striking coherence greatly facilitated a consistent and comprehensive descriptive classification and terminology.

Three- and four-dimensional ultrasonography: what do they add?
Whereas three-dimensional (3D) ultrasound is a static display of the various reformattting techniques based upon the acquisition of a static volume, 4D ultrasound displays a continuously updated and newly acquired volume in any rendering modality, creating the
impression of a moving structure (Campbell 2002, Timor-Tritsch and Platt 2002). A high
acquisition speed (volume per second) makes the perceivable transition between images
more fluid; real-time, however, is yet to be realised. Hence, movements are of staggering
appearance, and the quality of movements is especially difficult to assess from 4D
ultrasound images. During the first trimester of gestation, the 4D technique may not
provide a clear picture of specific movement patterns, such as hiccups, fetal breathing
movements or jaw opening (Andonotopo et al 2005); but apart from the better
detectability of malformations and anomalies, this technique clearly serves as a novel
means for the evaluation of fetal facial expressions, especially during the last trimester
(DiPietro 2005, Gonçalves et al 2005). Nevertheless, 4D is no alternative to 2D ultrasound
recordings (Campbell 2002).
The effects of ultrasound examination on the parents and the fetus

Maternal–fetal attachment or bonding is literally kick-started by the onset of fetal movements. It is further intensified during the third trimester of gestation, as the mother responds to her unborn baby’s distinct patterns of rest and activity. Visualisation of the fetus by the parents may arouse emotions that are capable of triggering the parental–fetal bonding much earlier, or of improving it. This, in turn, may lead to changes in behaviour and lifestyle that promote maternal and fetal health (Arabin et al 1996, Gonçalves et al 2005, Campbell 2006, Sedgmen et al 2006). Mothers who undergo 3D ultrasound show their ultrasound images to other people more often than mothers with 2D ultrasound examinations do (Ji et al 2005). The quality or intensity of the maternal–fetal attachment, however, is independent of the type of ultrasound – 2D, 3D or 4D – that the expectant mothers choose (Rustico et al 2005).

Obviously, ultrasound is a form of energy that has both thermal and mechanical effects on the tissues it runs through. Some 30 years ago, conjectures were made as to whether ultrasound could enhance fetal motion (David et al 1975), but subsequent studies did not corroborate these ideas (Powell Phillips and Towell 1979, Weinstein et al 1981, Murrils et al 1983). In a more recent study, on the other hand, fetuses moved more frequently when exposed to pulsed ultrasound in pulsed Doppler and B modes than they did in continuous wave Doppler mode (Fatemi et al 2001).

After a number of studies had shown that there was no adverse outcome associated with fetal ultrasound recording (Stark et al 1984, Reece et al 1990, Visser et al 1993), a study by Newnham and associates (1993) caused quite a stir, as it documented a higher number of intrauterine growth restrictions in an intensive ultrasound examination group than in fetuses that had only been exposed to a single sonographic examination. The same 3000 children of the study were re-examined when aged 8 years: their physical size, language, behaviour and neurological outcome bore no relationship to the number of ultrasound examinations during fetal life (Newnham et al 2004). It must, however, be stressed that there is no epidemiological study published on populations scanned after 1992, when regulations were altered and the acoustic output of ultrasound instruments was permitted to reach levels that were many times higher than previously allowed (Abramovicz et al 2008, Torloni et al 2009).

In 2006, Ang and colleagues from Pasko Rakic’s well-known laboratory at Yale University published results on neuronal migration in the embryonic mouse brain and on the effects of prenatal exposure to ultrasound. The authors of the study exposed immobilised, unanaesthetised, pregnant mice to ultrasound on days 16.5–19.5 of gestation, which is the time of neuronal migration from the proliferative zone towards the brain surface. Exposure time varied from 5 to 420 minutes. Their conclusion, based on the examination of more than 335 animals, was that ultrasound exposure of 30 minutes or more caused a derangement in the migration of neurones from the deep to the more superficial layers of the brain. The authors postulated that, because of the device’s low output, a non-thermal mechanism, radiation force or microstreaming was probably operating. In his comment on this study, Abramovicz (2007) questioned whether a
relatively small misplacement in a relatively small number of cells could be of clinical consequence. At the same time, he supported ultrasound scanning in principle, but argued that it should be carried out for the shortest possible time and with the lowest possible output in order to achieve high diagnostic acuity.

There may be some issues if ultrasound examinations are not performed by trained experts but in commercial settings with no physicians present. In the United States (US) in particular, ultrasound scanners are operated in shopping malls and similar public places, offering non-diagnostic ‘baby pictures’. Obviously, such boutique-like fetal imaging is clinically and ethically deficient, if only for the lack of counselling that some women may need (Bly and van den Hof 2005, Chervenak and McCullough 2005, Gorincour et al 2006, Abramovicz 2007, Sheiner et al 2007).

**Other methods of assessing fetal behaviour**

Lindsey (1942) claimed to have obtained a fetal electroencephalogram (EEG) by means of electrodes placed on the abdominal wall of a pregnant woman. Borkowski and Bernardine (1955), who applied abdominal and cervical electrodes, also produced positive EEG recordings of irregular slow-wave activity with superimposed fast waves in two fetuses. Garcia-Austt (1969) inserted hook-shaped platinum needles into the fetal vertex to study term fetuses during labour. He recorded a deceleration in all leads of the fetal EEG during a uterine contraction – apparently a consequence of the fetal head moulding.

While these EEG recordings are mainly of historical interest, various other methods have been applied to record fetal activity, employing strain gauges (Timor-Tritsch et al 1976, Wood et al 1977); electromagnetic devices, which created an electromagnetic field around the maternal abdomen and thus recorded movements inside it (Sadovsky et al 1973); impedance plethysmography (Ehrström 1979); or piezo-electric sensors, which are sensitive to rapid strained forces like fetal movements but relatively insensitive to steady or slowly changing movements such as uterine contractions or maternal respiratory movements (Sadovsky and Polishuk 1977).

A number of fetal behaviour studies by DiPietro and associates are based on the actocardiocytograph (Maeda et al 1991), which records both the fetal heart rate and body movements by means of a single wide-array Doppler transducer positioned on the maternal abdomen. It filters out the highest-frequency signal, which represents the fetal heart motion, and the lowest-frequency signals, representing maternal movements and respiration. The signals are generated by a change in the returned Doppler waveform; if there is no movement, the returned signal will retain the same frequency as the emitted signal. If the fetus moves, the echo will be returned at a different frequency, which is commensurate with the velocity with which the fetal body part moves towards or away from the transducer (Maeda et al 1991, 2009, DiPietro et al 1999, Witter et al 2007). Thus, the method is accurate in detecting periods of quiescence and activity (Maeda et al 1999); it achieves an overall kappa of 0.88 for agreement with ultrasonography (DiPietro et al 1999).
Fetal magnetoencephalography (MEG) is a new promising technique of studying the development of neuronal processing properties directly and non-invasively. It has an excellent temporal resolution but does not provide anatomical information. The current technology makes it possible to record fetal auditory and visual evoked fields, spontaneous brain activity, and, as a by-product, fetal heart rate parameters (Blum et al. 1985, Wakai et al. 1996, Schleussner et al. 2001, Sheridan et al. 2010). Most researchers have been working in the acoustic mode. The general approach is to search for an evoked component around 200ms, which is interpreted as a delayed component corresponding to the adult N100. As several factors, such as the variable position of the fetal head to the probe and differences in fetal behavioural states in different sessions of measurement, may limit detection, the detection rate is between 30% and 50% (Schleussner et al. 2001, Preissl et al. 2004, Eswaran et al. 2007, Sheridan et al. 2008).

Finally, fetal magnetocardiography (MCG) enables an accurate assessment of fetal heart rate variability. Owing to the high sensitivity of the signal to the position and orientation of the fetal heart, fetal MCG also allows an indirect assessment of fetal activity, especially of trunk movements (Wakai 2004).

**Magnetic resonance imaging: spotlight on fetal behaviour**

The limitations of fetal ultrasonography include the non-specific appearance of some abnormalities, and problems when there is associated maternal obesity (Pistorius et al. 2008, Parkar et al. 2010). Therefore, magnetic resonance imaging (MRI) has primarily been utilised as a complementary device in fetal imaging (Prayer 2006, Glenn and Coakley 2009, Limperopoulos and Clouchoux 2009, Weston 2010).

Naturally, safety is a major issue when scanning a fetus (Leithner et al. 2009, Baysinger 2010, Hand et al. 2010, Kikuchi et al. 2010). In the UK, for instance, health authorities advise against scanning pregnant women above 3T (Gowland and Fulford 2004). The fetus can only lose heat via conduction and convection processes within the placenta and amniotic fluid; and, certainly, a greater fractional volume of the fetus is irradiated compared with the adult. A real issue of concern is that of acoustic noise. So far, there is no evidence of alterations in the short-term heart rate variability or the number of fetal movements that can be attributed to the exposure to noise (Michel et al. 2003, Gowland and Fulford 2004).

**Dynamic magnetic resonance imaging: a revolutionary approach**

At present, dynamic MRI allows detailed behavioural studies of the fetus (Prayer 2006, Chung et al. 2009). These dynamic studies are based on a so-called steady-state sequence with free precession (SSFP-sequence). A slice thickness of up to 50mm and a large field of view create a 3D-like impression of the whole fetus. Five to six images per second are sufficient to visualise fetal movements in a real-time fashion (Prayer and Brugger 2007). The images are not confined to gross body movements but also comprise swallowing,
yawning, breathing excursions of the diaphragm and cardiac activity. Usually, a series of 30–60 second episodes of fetal movements is recorded during a 30–40 minute magnetic resonance (MR) examination. It is possible to make an assessment of movement patterns, but interpretation has to be made cautiously: if the fetus does not move during the MR examination, this should not be interpreted as pathological, especially if the morphological findings are normal.

**FUNCTIONAL MAGNETIC RESONANCE IMAGING**

Functional magnetic resonance imaging (fMRI) is a method of measuring the change in the MRI signal in response to a stimulus. Although single-trial fMRI is possible at very high field, it is usually necessary to repeat the stimulus up to 30 times, at 1 minute intervals. Blocked paradigms use extended stimuli of approximately 10 seconds, whereas event-related paradigms use short stimuli (<5 seconds). When stimulating a fetus, it is crucial to choose a stimulus that does not elicit a gross movement response (Gowland and Fulford 2004, Fulford and Gowland 2009). When averaged over the first three studies (Moore et al 2001, Fulford et al 2003, 2004), activation was found in 45% of the fetuses scanned, with 21% unsuccessful data sets because of susceptibility artefacts from the bowel or excessive fetal motion.

**REFERENCES**


Prechtl HFR. (1953) [Coupling of suction and the grasp reflex in infants]. Naturwissenschaft 12: 347–348. (In German)


Prechtl HFR, Schleidt WM. (1950) [Initiating and controlling mechanisms of the act of sucking]. Z Zschr Vergl Physiol 32: 257–262. (In German)


