Fetal Behavior Assessed in All Three Trimesters of Normal Pregnancy by Four-dimensional Ultrasonography

Asim Kurjak, Milan Stanojević, Wiku Andonoto1, Elena Scazzocchio-Duenas2, Guillermo Azumendi3, Jose Maria Carrera2

Department of Obstetrics and Gynecology, Zagreb School of Medicine, Holy Ghost General Hospital, Zagreb, Croatia; 1Department of Health, Ministry of Health, Republic of Indonesia, Jakarta, Indonesia; 2Department of Obstetrics and Gynecology, Institut Universitat Dexeus, Barcelona; and 3Clinica Centro Ecographia Gutenberg, Malaga, Spain

Aim
To assess fetal behavior in all three trimesters of normal pregnancy and to investigate the continuation of behavior from fetal to neonatal period.

Methods
One hundred out of 130 pregnant women in all trimesters with singleton pregnancy were assigned for the investigation. All recordings were performed in the morning, after two hours of fasting. Video recordings of newborns were made while the newborns were in bed, separated from other infants in the nursery, dressed, and lying on their backs in a supine position with unrestrained hands. Recording was not performed during prolonged episodes of fussing and crying, during drowsiness, and episodes of hiccupping. All observed facial expressions and movement patterns were presented collectively with maximum, minimum, and median frequencies during 30-minute observation period.

Results
We noted a tendency towards decreased frequency of facial expressions and movement patterns with increasing gestational age. In the first trimester, we observed the highest incidence of general movements ranging between 5 and 147, and with a median value of 47. In the second trimester, the number of head and hand movements decreased gradually, compared with the first trimester. The highest range was registered for head retroflexion pattern, ranging from 15 to 42 with a median of 25. The most frequent facial pattern in the second trimester was sucking (3 and 30 movements per infant with a median value of 9). Wilcoxon rank-sum test showed statistically significant differences between the fetuses in the third trimester and the newborns ($P<0.05$) in hand to head, head to mouth, hand to eye, hand to ear movement, tongue expulsion, and smiling, whereas the differences between the rest of the movements were not statistically significant. Spearman rank order correlation reached statistical significance ($P<0.05$) in isolated eye blinking, smiling, grimacing, hand to head, hand to mouth, hand to eye, hand to face, and in hand to ear movement, whereas the differences between the rest of the facial expressions were not statistically significant.

Conclusion
Fetal behavioral patterns directly reflect the developmental and maturational processes of the central nervous system. 4D observation of fetal and early neonatal period may add to better understanding of the neurological development of the fetus.
normal and abnormal fetal neurological function in utero, so that we can better predict which fetuses are at risk for adverse neurological outcomes antenatally, irrespective of intrapartum management. As we learned from postnatal studies of neonatal behavior, assessment of behavior is a better predictor of neurodevelopmental disability than neurological examination (4,5).

Innovations in ultrasonic technology have created new possibilities in the study of fetal behavior (4). Although the first fetal movements are registered in the 7th week of gestation, pregnant women begin feel tremulous excitements in the abdomen caused by fetal movements as late as in the second trimester of pregnancy (6-9). Pregnant women's awareness of fetal movements increases with increasing movement intensity. Although two-dimensional (2D) ultrasonography documents the origin, occurrence, and developmental course of specific fetal movements, simultaneous imaging of complex facial movements was impossible only by means of a 2D real-time technique (6,7,9,10).

The development of three-dimensional (3D) and four-dimensional ultrasound (4D-US) provides new opportunities for the study of fetal behavior. Four-dimensional sonography enables simultaneous spatial imaging of the entire fetus and its movements (4,6,7,11-13).

Recently, a few multicentric studies of fetal brain function have been carried out (6,12,14-17). The aim of this study was to establish the standards of fetal peripheral and body movements, and facial expressions, by means of 30-minute 4D-US recordings, as additional diagnostic criteria for prenatal brain impairment.

Patients and Methods

Patients

From November 2003 to November 2004, a multicentric study was performed in three centers: Holy Ghost General Hospital, Department of Obstetrics and Gynecology, Zagreb University School of Medicine, Croatia; Department of Obstetrics and Gynecology, Institut Universitari Dexeus, Barcelona, Spain; and in Centre Gutenberg, Malaga, Spain. Hundred and thirty pregnant women regardless of parity (from the 1st to the end of 3rd trimester of pregnancy) with singleton pregnancies were referred for a routine 2D ultrasound check-up in the outpatient clinic of the three centers. The patients were assigned to the study if they met the inclusion criteria, which left 100 women in the final sample. The fetus and the mother were considered “term and normal” if 2D ultrasound and clinical assessment were uneventful, if the newborn was delivered at term, and had normal 1- and 5-min Apgar scores. Pregnancies subsequently complicated by congenital abnormalities, gestational diabetes, hypertensive disorders in pregnancy, and preterm deliveries were excluded. Fetuses from the second and the third trimester whose examined parts of the body could not be visualized in a region of interest, were also excluded from the study.

The patients were offered 4D ultrasonography and signed informed consent for the investigation. There were 90 patients selected in the first and second trimester, 70 of whom fulfilled the inclusion criteria (35 patients in the first, 35 patients in the second trimester), whereas 7 patients from the second and 13 patients from the third trimester were excluded from the study. Thirty out of 40 patients in the third trimester, who gave birth to 30 healthy term newborns, fulfilled the inclusion criteria. The newborns were included in the analysis if they appeared at the first and at least two subsequent check-ups by neonatologist and if they demonstrated normal spontaneous activity, normal posture and tone, and the presence of some primitive reflexes. Subjects were randomly assigned to the investigation and pregnant women were fasting for two hours before the beginning of the investigation. All 4D examinations were performed in the morning and by an experienced sonographer.

4D Ultrasound

All 4D examinations were performed by a single experienced operator using Voluson 730 (Kretztechnik, Zipf, Austria) and Sonoline Antares (Siemens AG, Issaquah, WA, USA) with transabdominal 5 MHz transducer. After standard assessment in 2D B-mode ultrasound, a 4D mode was turned on and a live 3D image was built by selecting the ideal representative 2D image placed in the region of interest (ROI). The crystal array of the transducer moved mechanically over the defined ROI. The volume was automatically scanned every two seconds, and 4D images were displayed on the screen and recorded on the videotape during the 30-minute observation period. This proce-
dure was used for the observation of fetal facial expressions and hand movements.

**Video Recording of Neonatal Behavioral Patterns**

The recordings were created on Sony P-612 OHMPL videotape by video camera (Sony camcorder CC DTRV 318 Hv8, Tokyo, Japan) and reviewed on the videocassette recorder (Sony VHS SLV-N 900, Tokyo, Japan). During the examination, newborns were in bed, separated from other infants in the nursery, dressed, and lying on their backs in a supine position with unrestrained hands. The temperature in the room was 22 to 24°C. The video recording was performed mainly while children were actively awake or during alert inactivity. Video recording was not performed during prolonged episodes of fussing and crying, drowsiness, and episodes of hiccuppying. During the videotaping there were no items or other persons in the newborn’s proximity that could distract or disturb the child.

**Definitions**

Fetal behavior can be defined as any observable action or reaction to an external stimulus by the fetus (8,11,18). Behavior may be spontaneous, endogenously generated by the fetus itself. This may be recorded by maternal perception of movement or real time ultrasound imaging which by means of which fetal behavior can be observed in the clearest and most detailed way. Fetal body movements provide important information on the condition of the fetus. Spontaneous movement patterns emerge between 7 and 15 weeks of gestation (Table 1, ref. 8). These movements, once observed, remain present and unchanged throughout the whole pregnancy. With 4D ultrasound, it is now possible to study a full range of facial expressions including smiling, crying, scowling, and eyelid movements (11-13,16,17; Figs. 1-5). The definitions of eight types of analyzed movement patterns were given by de Vries and Prechtl (Table 1 and 2, refs. 8,14,15).

<table>
<thead>
<tr>
<th>Type of movements</th>
<th>Onset of specific movement patterns (gestational weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sideway bending</td>
<td>+</td>
</tr>
<tr>
<td>General movement</td>
<td>+</td>
</tr>
<tr>
<td>Startle</td>
<td>+</td>
</tr>
<tr>
<td>Isolated arm movement</td>
<td>+</td>
</tr>
<tr>
<td>Isolated leg movements</td>
<td>+</td>
</tr>
<tr>
<td>Hiccup</td>
<td>+</td>
</tr>
<tr>
<td>Sucking</td>
<td>+</td>
</tr>
<tr>
<td>Swallowing</td>
<td>+</td>
</tr>
<tr>
<td>Hand to face contact</td>
<td>+</td>
</tr>
<tr>
<td>Head retroflexion</td>
<td>+</td>
</tr>
<tr>
<td>Head antiflexion</td>
<td>+</td>
</tr>
<tr>
<td>Head rotation</td>
<td>+</td>
</tr>
<tr>
<td>Breathing movement</td>
<td>+</td>
</tr>
<tr>
<td>Stretching</td>
<td>+</td>
</tr>
<tr>
<td>Jaw opening</td>
<td>+</td>
</tr>
<tr>
<td>Yawning</td>
<td>+</td>
</tr>
</tbody>
</table>

*Adapted from ref. 8, with permission.*

**Statistical Analysis**

The number of fetal and neonatal movements in a 30-minute time period was analyzed in all trimesters of pregnancy and postnatally in the first three days of life. All observed movement patterns were presented as maximum, minimum, median frequencies, and inter-quartile range during the 30-minute observation period.

As the data distribution was not normal, the non-parametric Wilcoxon rank-sum test was
used for comparison of the frequency of movements between the fetuses of different gestational ages and neonates. Spearman rank order correlation was used for the correlation of movement frequency in fetuses and in neonates. All tests were for dependent samples. The computer program Statistica 5.0 for Windows (Statsoft, 1995, Tulsa, OK, USA) was used for computing. The differences were considered significant if the \( P \) value was <0.05.

**Results**

**Fetal Movements and Facial Expressions**

The incidence of fetal movement patterns in the first trimester of pregnancy between 8-14 weeks of gestation is presented in Figure 6. We noted a tendency towards decreased frequency of facial expressions and movement patterns with increasing gestational age. The highest incidence of general movements, which ranged between 5 and 147, with a median value of 47, was found in the first trimester. In the second trimester, the number of head and hand movements decreased gradually compared with the first trimester. The highest incidence was registered for head retroflexion pattern, with range of 15 to 42 and median of 25. Among facial expressions, the highest incidence was found for sucking, with the range between 3 and 30 and median of 9.

**Fetal and Neonatal Movements**

The comparison of facial expressions and hand movements in the third trimester of pregnancy and in neonatal period is presented in Figures 9 and 10. The observed movements are shown in Table 2. Wilcoxon rank-sum test showed statistically significant differences between the fetuses in the third trimester and the newborns in the frequency of the following movements: hand to head \( (t=0.001; z=-4.457; P<0.001) \), hand to mouth \( (t=31; z=-3.400; P<0.001) \), hand to eye \( (t=18; z=-3.388; P<0.001) \), hand to ear \( (t=54; z=2.919; P<0.001) \), tongue expulsion \( (t=-84; z=-2.323; P=0.02) \), and smiling \( (t=0.01; P=0.97) \).
All movements observed in fetal life, especially in the third trimester, that were also present in neonatal life. The most frequent fetal and neonatal movements were isolated eye blinking, mouthing, grimacing, hand to mouth, and hand to face movements. Isolated blinking and mouthing appeared more frequently in neonates than in fetuses, although the difference was not statistically significant. Hand to mouth and hand to face movements were more frequent in fetal than in neonatal life, whereas all other hand movements were less frequent in neonates than in fetuses. Spearman rank order correlation reached statistical significance between the fetuses in the third trimester and the newborns in isolated eye blinking ($r = 0.36; t = 2.06; P = 0.048$), smiling ($r = 0.78; t = 6.74; P < 0.001$), grimacing ($r = 0.71; t = 5.35; P < 0.001$), hand to head ($r = 0.45; t = 2.67; P = 0.012$), hand to mouth ($r = 0.76; t = 6.22; P < 0.001$), hand to eye ($r = 0.55; t = 3.57; P < 0.001$), hand to face ($r = 0.82; t = 7.82; P < 0.001$), and in hand to ear movement ($r = 0.68; t = 4.95; P < 0.001$). There were no differences in the repertoire of smiling expression in the same individual pre- and postnatally (Fig. 5).
Our previous report on fetal 4D sonographic examination set out to determine whether dynamic observations of the fetus were possible in the first and second trimester (6,12,16,17). The aim of this study was to establish the standards of normal fetal behavioral patterns after 30 minutes recording. To the best of our knowledge, there has been no report on 4D sonographic examination of the fetus in all trimesters of pregnancy, followed by neonatal examination. Using 4D-US technique, it was possible to perform dynamic 3D observations of the fetal behavior. Moreover, it was possible to obtain a finer image quality since the whole fetus could be visualized (7,11,13).

Functional development of the fetal brain begins as early as the late embryonic period. During the 9 months of gestation, a repertoire of fetal activities constantly expands, correlating precisely with the structural development of the CNS (19-21). Major developmental events, such as the establishment of neural connections in the different regions of the brain, are accompanied by the occurrence of new patterns of fetal activity or with the transformation of the existing patterns. The organization of behavioral states during the last weeks of pregnancy shows that the connection between cerebral cortex and periphery is established, and that cerebral cortex takes control over fetal activity. This also indicates the ability of the fetus to perceive and to process external signals. Furthermore, the latest results indicate that even higher brain functions, such as learning, develop in utero during the last weeks of gestation (19,20).

There have been many descriptions of conventional two-dimensional (2D) sonographic assessment of fetal movements with respect to the assessment of fetal behavior (22-24). Many studies of fetal movements were performed in the first and in the second trimester of pregnancy, but most of them were in the third trimester (25,26). Recently, a new faster 4D-US system acquiring up to 16 volumes per second or around 25 frames per second has become available, which solved the problem of dynamic 3D sonographic fetal imaging.

In our previous study, a proper analysis was possible for seven hand movement patterns and the highest incidence was registered in isolated arm movements during 15-minute interval which decreased gradually from 13 to 16 weeks (12). The most frequent fetal and neonatal movements registered in the third trimester and in the neonatal period were scowling, eye and mouth opening, and hand to face, hand to eye, and hand to head movements. Isolated blinking, mouth to eyelid movement, yawning, tongue expulsion, and scowling were more frequent in neonates than in fetuses, although the difference was not statistically significant (16). Hand to mouth movements appeared more frequently in neonatal than in fetal life, whereas all other hand movements were less
frequent in neonates than in fetuses, although the differences did not reach statistical significance. The correlation reached statistical significance in smiling and in hand to ear movement, and was almost statistically significant in isolated eye blinking.

Although not all observations in the first through the third trimester of pregnancy fulfilled the criteria of optimal visualization, we noted a tendency towards a decrease in frequencies of observed facial expressions (isolated eye blinking, mouthing) and some hand movement patterns (hand to head, hand to mouth, hand to face, hand to eye, hand to ear) with increasing gestational age, whereas the medians were quite the same (Fig. 6-10). This was not in concordance with the findings of other authors, probably due to a small sample size in our study and different study samples in all trimesters of pregnancy. The duration of resting periods between fetal movements increases, whereas the frequency of movements decreases with an increase in the gestational age due to maturational of fetal brain (27,28).

Some of the movement patterns could not be observed through all trimesters. For example, startle and stretch, which were observed only in the first trimester, disappear with the progression of pregnancy. Other hand movement patterns and facial expressions, like sucking and swallowing, could be better observed in the second and the third trimester due to a better visualization by 4D-US.

Some movement patterns occurred more frequently than others in the studied gestational ages (8 to 35 weeks). Large fluctuations in incidence per week and per fetus were noted even in the case of these more frequent movements. Still, we had the impression that a 30-minute observation in the morning was representative for the rest of the day. This was confirmed by observations performed in different periods of the day, as has been described earlier (14,15,23).

It was assumed that reflex activities present before 20 weeks of gestation are executed through the mesencephalon, lower brain stem, and spinal cord (1,2). A decrease in movements such as startles at about 20 weeks gives a false impression that at this age the fetus moves in a more coordinated fashion than earlier. We know now that general movements maintain a stable incidence from 10 weeks onwards (8,9). We confirmed an orderly developmental progression of fetal activity beginning with beating of the fetal heart (7 weeks), progressing to fetal trunk movement (8 weeks), and culminating in individual fetal limb movement (9 weeks) (22).

Between 9 and 12 weeks, fetal movements were characterized by brisk changes of position and posture. From 13 to 16 weeks, there were prolonged changes of position, as well as flexion and extension of the limbs. Fetuses from 17 to 20 weeks made slow flexion and extension movements of the trunk, sometimes accompanied by the movement of a single limb (29). At 18 to 20 weeks, fetuses performed slow, supple, and harmonious movements with isolated leg movements, in contrast to the synchronized movements of the whole body with twitches and kicking, as frequently found at 12 to 13 weeks (30).

De Vries et al (8) described the developmental pathway of fetal movements in longitudinal study of 12 fetuses using 2D ultrasound. They reported not only how to describe a particular movement but also how these movements were performed in terms of speed and amplitude. With 4D-US, we found body movements at 7 weeks of pregnancy (6). De Vries found isolated arm and leg movement at 8 weeks of pregnancy (8), whereas with 4D-US we found limb movements at 8-9 weeks (6,12). Isolated arm and leg movements are clearly visible and they consisted of changes in position of the extremities towards the body. It seems that fetal arms explore the surrounding environment and cross the midline, with the palmar surface oriented towards the uterine wall. The fetal legs are extended to the uterine wall (12).

Postnatal observation of movement patterns was introduced by Roodenburg et al (23,31). The method is based on the observation of spontaneous movements of the infant using video typing and “off-line” analysis of movement quantity and quality (23,31). It has been proved that assessment of general movements in high-risk newborns has significantly better predictive value for later neurological development than classical neurological examination (5,32,33).

Neonatal behavior is a continuation of the activities shown in fetal period (16). One of mysterious behavioral pattern observed pre- and postnatally is yawning. There is no explanation why human fetus would yawn. The yawn appears to have at best an obscure purpose (10,34,35).
literature fails to define yawning in a fetus, which results in accepting far too many interpretations of open mouths as yawns. The range of variation includes, for example, a single, continuous opening of the mouth lasting three minutes and a set of five repetitive openings of the mouth for four to six seconds each (35). It has been proposed that yawning is a complex arousal defense mechanism, the center of which is located in the reticular brainstem, and its function is to reverse brain hypoxia and improve brain oxygenation. However, its role for only primary respiratory purposes has been questioned (10).

Before the introduction of ultrasound, some investigators were convinced that fetal movements were similar to those of newborn infants, but detailed investigation was prevented by the inability to visualize the fetus. The introduction of 4D ultrasound enabled the determination of milestones in fetal development, and led to very important conclusions about fetal behavior (7,12,16,17,36). During the first postnatal weeks, i.e. after suspension of intra-uterine movement restriction, the slow speed and small amplitude of general movements is still observed, suggesting a carryover effect from prenatal to postnatal period (37). Newborns can produce both head and eye movements and show clear vestibulococular reflexes. However, the communication between visual, vestibular, head movement, and eye movement systems shows a marked shift between the second and the third month of life, and the addition of coordination between the vestibular system and the head and eye movement systems does not appear until the third month of life (38).

It is still unclear whether there are any changes specific for cerebral palsy in the developing brain, and whether they can be detected early enough either by sophisticated methods of basic sciences or by simple methods of clinical sciences to predict the developmental outcome (39). It is still questionable whether assessing the continuity of fetal to neonatal behavior can improve our ability to detect brain pathology early enough to intervene and prevent the damage (21).

Recently, there have been many advances in a wide variety of scientific areas associated with cerebral palsy (18-20). Furthermore, there was strong evidence that most examples of perinatal asphyxial events in full term infants, but of prenatal intrauterine problems (2,21). Therefore, classic causal relationship between birth asphyxia and cerebral palsy should be questioned. Indeed, an evolving challenge for the medical profession is to better define normal and abnormal fetal neurological function in utero so that we can better predict antenatally which fetuses are at risk for adverse neurological outcomes irrespective of intrapartum management. The introduction of 4D sonography could be helpful in reaching our goal. However, we are aware of the disadvantages of 4D technology which should be improved in order to enable the visualization of real-time fetal behavior to study the quality of movements.

Preliminary results from our previous 15-minute observations of fetal behavior by 4D ultrasound proved that 4D technique is better than 2D technique in the assessment of fetal behavior (12,16,17). Short period of observation was the main limitation of those investigations compared with 2D studies (8,9). This conclusion prompted us to extend observation time and to investigate fetal behavior throughout the whole gestation. Our study will be continued with the assessment of fetal behavior in high-risk pregnancies.

References

Kurjak et al: Fetal Behavior Assessed by 4D Ultrasound

Croat Med J 2005;46(5):772-780


14 Prechtl HF. Qualitative changes of spontaneous movements in fetuses and preterm infant are a marker of neurological dysfunction. Early Hum Dev. 1990;23:151-8.


