CHAPTER 17: Fetal Assessment

The rate of the foetal heart is subject to considerable variations, which affords us a fairly reliable means of judging as to the well-being of the child. As a general rule, its life should be considered in danger when the heart-beats fall below 100 or exceed 160.

—J. Whitridge Williams (1903)

INTRODUCTION

More than 100 years ago, the approach to fetal assessment was rather primitive. Since that time, and especially since the 1970s, technology to evaluate the health of the fetus has advanced remarkably. Techniques employed today to forecast fetal well-being focus on fetal biophysical findings that include heart rate, movement, breathing, and amnionic fluid production. These findings aid antepartum fetal surveillance to prevent fetal death and avoid unnecessary interventions, which are stated goals of the American College of Obstetricians and Gynecologists and the American Academy of Pediatrics (2017).

Most fetuses will be healthy, and usually a negative—that is, normal—antepartum test result is highly reassuring, because fetal deaths within 1 week of a normal test are rare. Indeed, negative-predictive values—a true negative test—for most of the tests described are 99.8 percent or higher. In contrast, estimates of the positive-predictive values—a true positive test—for abnormal test results are low and range between 10 and 40 percent. Importantly, fetal surveillance is primarily based on circumstantial evidence. No definitive randomized clinical trials have been conducted for obvious ethical reasons (American College of Obstetricians and Gynecologists, 2016).

FETAL MOVEMENTS

Physiology

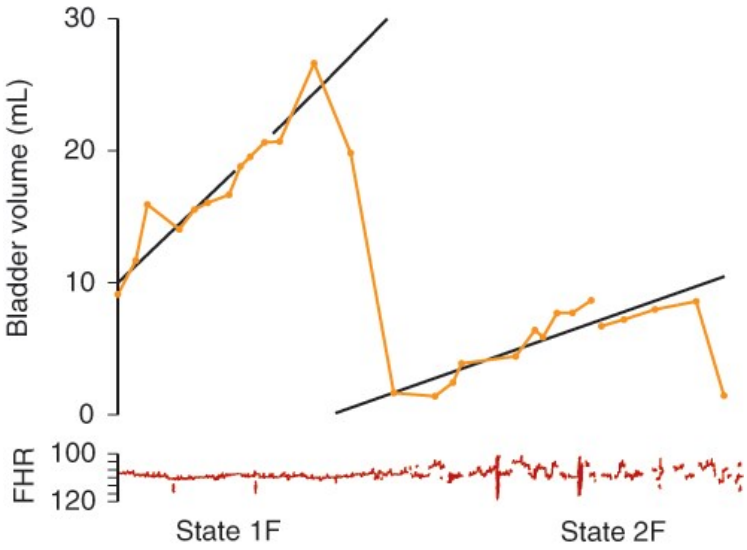
Passive unstimulated fetal activity commences as early as 7 weeks' gestation and becomes more sophisticated and coordinated by the end of pregnancy (Sajapala, 2017; Vindla, 1995). Indeed, beyond 8 menstrual weeks, fetal body movements are never absent for periods exceeding 13 minutes (DeVries, 1985). Between 20 and 30 weeks' gestation, general body movements become organized, and the fetus starts to show rest-activity cycles (Sorokin, 1982). Fetal movement maturation continues until approximately 36 weeks, when behavioral states are established in most normal fetuses. Nijhuis and colleagues (1982) described four fetal behavioral states:

- State 1F is a quiescent state—quiet sleep—with a narrow oscillatory bandwidth of the fetal heart rate.
- State 2F includes frequent gross body movements, continuous eye movements, and wider oscillation of the fetal heart rate. This state is analogous to rapid eye movement (REM) or active sleep in the neonate.
- State 3F includes continuous eye movements in the absence of body movements and no heart rate accelerations. The existence of this state is disputed (Pillai, 1990a).
- State 4F is one of vigorous body movement with continuous eye movements and heart rate accelerations. This state corresponds to the awake state in newborns.

Fetuses spend most of their time in states 1F and 2F. For example, at 38 weeks, 75 percent of time is spent in these two states. These behavioral states—particularly 1F and 2F, which correspond to quiet sleep and active sleep—have been used to develop an increasingly sophisticated understanding of fetal behavior. In a study of fetal urine production, bladder volumes increased during state 1F quiet sleep (Fig. 17-1). During state 2F, the fetal heart rate baseline bandwidth increased appreciably, and bladder volume was significantly diminished due to decreased urine production and infrequent fetal voiding. These phenomena were interpreted to represent reduced renal blood flow during active sleep.

FIGURE 17-1

Fetal bladder volume measurements together with fetal heart rate (FHR) variation recorded in relation to 1F or 2F behavior states. State 1F fetal heart rate has a narrow bandwidth consistent with quiet sleep. State 2F heart rate shows wide oscillation of the baseline consistent with active sleep. (Modified with permission from Oosterhof H, vd Stege JG, Lander M, et al: Urine production rate is related to behavioural states in the near term human fetus, Br J Obstet Gynaecol. 1993 Oct;100(10):920–922.)

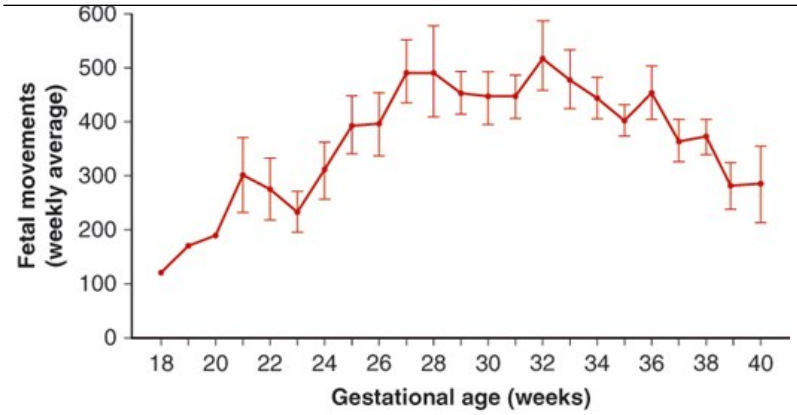


An important determinant of fetal activity appears to be sleep-awake cycles, which are independent of maternal ones. Fetal sleep cyclicity varies from approximately 20 minutes to as much as 75 minutes. In one study, the mean length of the quiet or inactive state for term fetuses was 23 minutes (Timor-Tritsch, 1978). Patrick and associates (1982) measured gross fetal body movements with real-time sonography for 24-hour periods in 31 normal pregnancies and found the longest period of inactivity to be 75 minutes. *Amnionic fluid volume* is another important determinant of fetal activity. Sherer and colleagues (1996) assessed the number of fetal movements in 465 pregnancies during biophysical profile testing in relation to amnionic fluid volume. They observed decreased fetal activity with diminished amnionic volumes and suggested that a restricted uterine space might physically limit fetal movements.

Sadovsky and coworkers (1979b) classified fetal movements into three categories according to both maternal perceptions and independent recordings using piezoelectric sensors. Weak, strong, and rolling movements were described, and their relative contributions to total weekly movements throughout the last half of pregnancy were quantified. As pregnancy advances, the rate of weak movements decreases, more vigorous movements increase for several weeks, and then rates of these subside at term. Presumably, declining amnionic fluid and space account for diminished activity at term. Figure 17-2 shows fetal movements during the last half of gestation in 127 pregnancies with normal outcomes. The mean number of weekly movements calculated from 12-hour daily recording periods rose from approximately 200 at 20 weeks' gestation to a maximum of 575 movements at 32 weeks. Fetal movements then declined to an average of 282 at 40 weeks. Normal weekly maternal counts of fetal movements ranged between 50 and 950. Count showed large daily variations, with included counts as low as 4 to 10 per 12-hour period in normal pregnancies.

FIGURE 17-2

Graph depicts averages of fetal movements counted during 12-hour periods (mean ± SEM). (Data from Sadovsky, 1979a.)



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Clinical Application

Diminished fetal activity may be a harbinger of impending fetal death (Sadovsky, 1973). To quantify fetal movement, clinical methods include use of a uterine contraction tocodynamometer, visualization with sonography, and maternal subjective perceptions.

Most, but not all, investigators report excellent correlation between maternally perceived fetal motion and movements documented by instrumentation. For example, Rayburn (1980) found that 80 percent of all movements observed during sonographic monitoring were perceived by the mother. In contrast, Johnson and colleagues (1992) reported that beyond 36 weeks, mothers perceived only 16 percent of fetal body movements. Fetal motions lasting more than 20 seconds were more likely to be identified than shorter episodes. Although several fetal-movement counting protocols have been used, neither the optimal number of movements nor the ideal duration for counting them has been defined. For example, in one method, perception of 10 fetal movements in up to 2 hours is considered normal (Moore, 1989). Commonly, women may present in the third trimester complaining of subjectively reduced fetal movement. Harrington and associates (1998) reported that 7 percent of nearly 6800 women presented with a complaint of decreased fetal movement. Fetal heart rate monitoring tests were employed if sonographic scans for fetal growth or Doppler velocimetry were abnormal. Pregnancy outcomes for women who complained of decreased fetal movement were not significantly different from those for women without this complaint. Scala and colleagues (2015) reported that 6 percent of women at term reported decreased fetal movements at 36 weeks or more. Women with two or more episodes of reduced fetal movements had greater risks of growth-restricted newborns and abnormal Doppler uterine artery flow studies. However, stillbirth rates were not increased. Measurement of the myocardial performance index did not improve accuracy (Ho, 2017).

Grant and coworkers (1989) performed an unparalleled investigation of maternally perceived fetal movements and pregnancy outcome. More than 68,000 pregnancies were randomly assigned between 28 and 32 weeks' gestation. Women in the fetal movement arm of the study were instructed by specially employed midwives to record the time needed to feel 10 movements each day. This required an average of 2.7 hours each day. Women in the control group were informally asked about movements during prenatal visits. Reports of decreased fetal motion were evaluated with tests of fetal well-being. Antepartum death rates for otherwise normal singleton fetuses were similar in the two study groups. Despite the counting policy, most stillborn fetuses were dead by the time the mothers reported for medical attention. Importantly, rather than concluding that maternal perceptions of fetal activity were meaningless, these investigators concluded that informal maternal perceptions were as valuable as formally recorded fetal movement.

Saastad and associates (2011) reported a total of 1076 women who were randomly assigned to standardized fetal movement counting from gestational week 28 versus no counting. Growth-restricted fetuses were identified before birth significantly more often when fetal movement counting was used. The rate of 1-minute Apgar scores ≤3 was significant reduced (0.4 versus 2.3 percent) when counting was used. Also, Warrander and coworkers (2012) described placental pathology in pregnancies complicated by diminished fetal movements. Decreased movement was associated with various placental abnormalities including infarction.

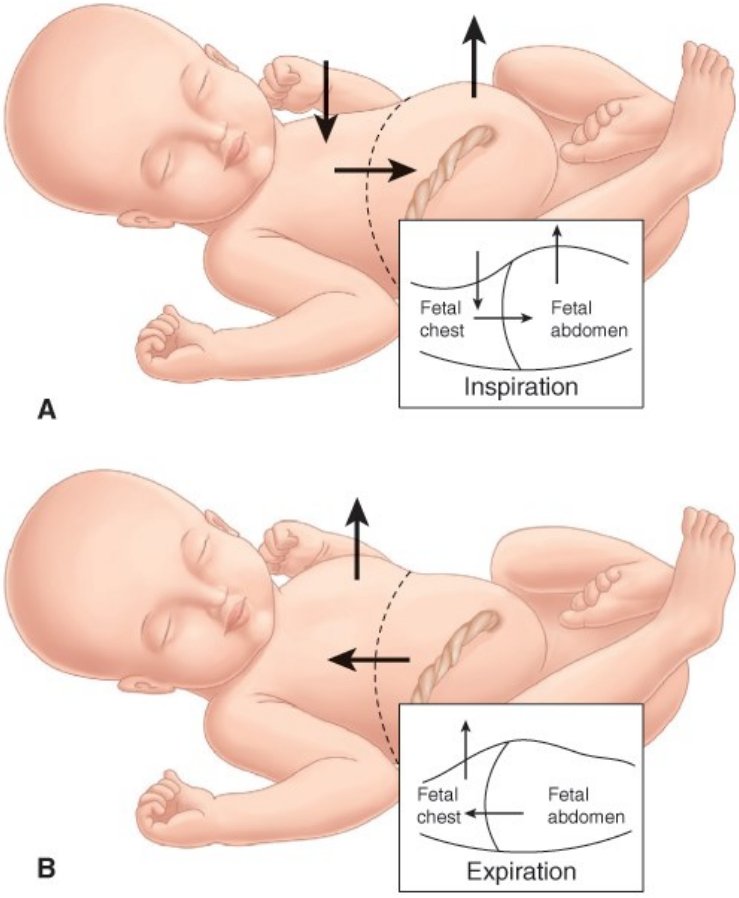
FETAL BREATHING

After decades of uncertainty as to whether the fetus normally breathes, Dawes and coworkers (1972) showed small inward and outward flows of tracheal fluid in fetal sheep, indicating thoracic movement. These chest wall movements differed from those following birth in that they were

discontinuous. Another interesting feature of fetal respiration was *paradoxical chest wall movement* (Fig. 17-3). In the newborn or adult, the opposite occurs. One interpretation of the paradoxical respiratory motion might be coughing to clear amnionic fluid debris. Although the physiological basis for the breathing reflex is not completely understood, such exchange of amnionic fluid appears to be essential for normal lung development (Chap. 7, Respiratory System). Dawes (1974) identified two types of respiratory movements. The first are *gasps* or *sighs,* which occurred at a frequency of 1 to 4 per minute. The second, *irregular bursts of breathing,* occurred at rates up to 240 cycles per minute. These latter rapid respiratory movements were associated with rapid eye movement. Badalian and associates (1993) studied the maturation of normal fetal breathing using color flow and spectral Doppler analysis of nasal fluid flow as an index of lung function. They suggested that fetal respiratory rate declined in conjunction with increased respiratory volume at 33 to 36 weeks and coincidental with lung maturation.

FIGURE 17-3

Paradoxical chest movement with fetal respiration. During inspiration **(A)**, the chest wall paradoxically *collapses* and the abdomen protrudes, whereas during expiration **(B)**, the chest wall *expands*. (Adapted from Johnson, 1988.)



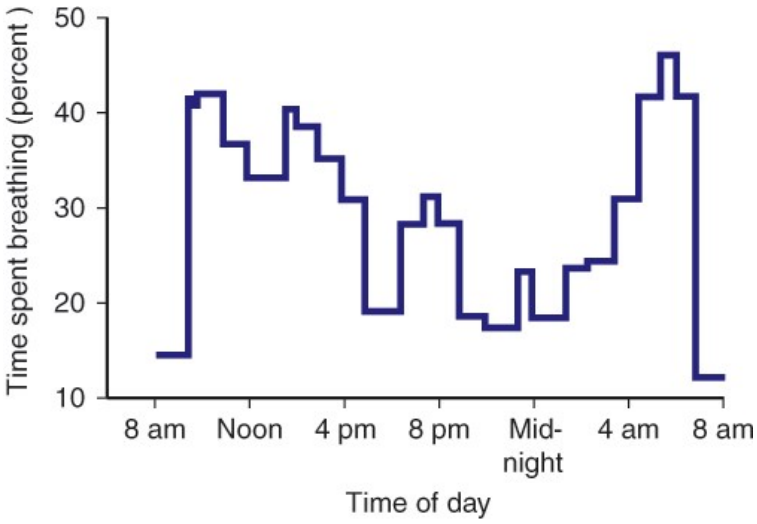
Many investigators have examined fetal breathing movements using sonography to determine whether chest wall movements might reflect fetal health. Several variables in addition to hypoxia were found to affect fetal respiratory movements. These included hypoglycemia, sound stimuli, cigarette smoking, amniocentesis, impending preterm labor, gestational age, the fetal heart rate itself, and labor—during which it is normal for respiration to cease.

Because fetal breathing movements are episodic, interpretation of fetal health when respirations are absent may be tenuous. Patrick and associates (1980) performed continuous 24-hour observation using sonography to characterize fetal breathing patterns during the last 10 weeks of pregnancy. A total of 1224 hours of fetal observation in 51 pregnancies were collected, and Figure 17-4 displays the percentages of time spent breathing near term. Clearly, there is diurnal variation, because breathing substantively diminishes during the night. In addition, breathing activity increases somewhat

following maternal meals. Total absence of breathing was observed in some of these normal fetuses for up to 122 minutes, indicating that fetal evaluation to diagnose absent respiratory motion may require long periods of observation.

FIGURE 17-4

The percentage of time spent breathing by 11 fetuses at 38 to 39 weeks. There is a significant increase in fetal breathing activity after breakfast. Breathing activity diminished during the day and reached its minimum between 20:00 and 24:00 hours. There was a significant increase in the percentage of time spent breathing between 04:00 and 07:00 hours, when mothers were asleep. (Adapted with permission from Patrick J, Campbell K, Carmichael L, et al: Patterns of human fetal breathing during the last 10 weeks of pregnancy, Obstet Gynecol. 1980 Jul;56(1):24–30.)



The potential for breathing activity to be an important marker of fetal health is unfulfilled because of the multiplicity of factors that normally affect breathing. Most clinical applications have included assessment of other fetal biophysical indices, such as heart rate. As discussed subsequently, fetal breathing has become a component of the *biophysical profile.*

CONTRACTION STRESS TESTING

As amnionic fluid pressure rises with uterine contractions, myometrial pressure exceeds collapsing pressure for vessels coursing through uterine muscle. This ultimately lowers blood flow to the intervillous space. Brief periods of impaired oxygen exchange result, and if uteroplacental pathology is present, these elicit late fetal heart rate decelerations (Chap. 24, Late Deceleration). Contractions also may produce a pattern of variable decelerations as a result of cord compression, suggesting oligohydramnios, which is often a concomitant of placental insufficiency.

Ray and colleagues (1972) used this concept in 66 complicated pregnancies and developed the *oxytocin challenge test,* which was later called the *contraction stress test.* Intravenous oxytocin is used to stimulate contractions, and the criterion for a positive test result, that is, an abnormal result, is uniform repetitive late fetal heart rate decelerations. These reflected the uterine contraction waveform and had an onset at or beyond the contraction acme. Such late decelerations could be the result of uteroplacental insufficiency. In their study, the tests were generally repeated on a weekly basis, and the investigators concluded that negative contraction stress test results, that is, normal results, forecasted fetal health. A major disadvantage is that the average contraction stress test requires 90 minutes to complete.

To perform the test, the fetal heart rate and uterine contractions are recorded simultaneously with an external monitor. If at least three spontaneous contractions of 40 seconds or longer are present in 10 minutes, no uterine stimulation is necessary (American College of Obstetricians and Gynecologists, 2016). Contractions are induced with either oxytocin or nipple stimulation if there are fewer than three in 10 minutes. For oxytocin use, a dilute intravenous infusion is initiated at a rate of 0.5 mU/min and doubled every 20 minutes until a satisfactory contraction pattern is established (Freeman, 1975). The results of the contraction stress test are interpreted according to the criteria shown in Table 17-1.

Nipple stimulation to induce uterine contractions is usually successful for contraction stress testing (Huddleston, 1984). One method involves a woman rubbing one nipple through her clothing for 2 minutes or until a contraction begins. This 2-minute nipple stimulation ideally will induce a pattern of three contractions per 10 minutes. If not, after a 5-minute interval, she is instructed to retry nipple stimulation to achieve the desired pattern. If this is unsuccessful, then dilute oxytocin may be used. Advantages include reduced cost and shortened testing times. Some have reported unpredictable uterine hyperstimulation and fetal distress, whereas others did not find excessive activity to be harmful (Frager, 1987; Schellpfeffer, 1985).

TABLE 17-1

Criteria for Interpretation of the Contraction Stress Test

Negative: no late or significant variable decelerations
Positive: late decelerations following 50% or more of contractions (even if the contraction frequency is fewer than three in 10 minutes)
Equivocal-suspicious: intermittent late decelerations or significant variable decelerations
Equivocal-hyperstimulatory: fetal heart rate decelerations that occur in the presence of contractions more frequent than every 2 minutes or lasting longer than 90 seconds
Unsatisfactory: fewer than three contractions in 10 minutes or an uninterpretable tracing

NONSTRESS TESTS

Freeman (1975) and Lee and colleagues (1975) introduced the *nonstress test* to describe fetal heart rate acceleration in response to fetal movement as a sign of fetal health. This test involved the use of Doppler-detected fetal heart rate acceleration coincident with fetal movements perceived by the mother. By the end of the 1970s, the nonstress test had become the primary method of testing fetal health. The nonstress test was easier to perform, and normal results were used to further discriminate false-positive contraction stress tests. Simplistically, the nonstress test is primarily a test of *fetal condition,* and it differs from the contraction stress test, which is considered a test of *uteroplacental function.* Currently, nonstress testing is the most widely used primary testing method for assessment of fetal well-being. It has also been incorporated into the biophysical profile testing system, subsequently discussed.

Fetal Heart Rate Acceleration

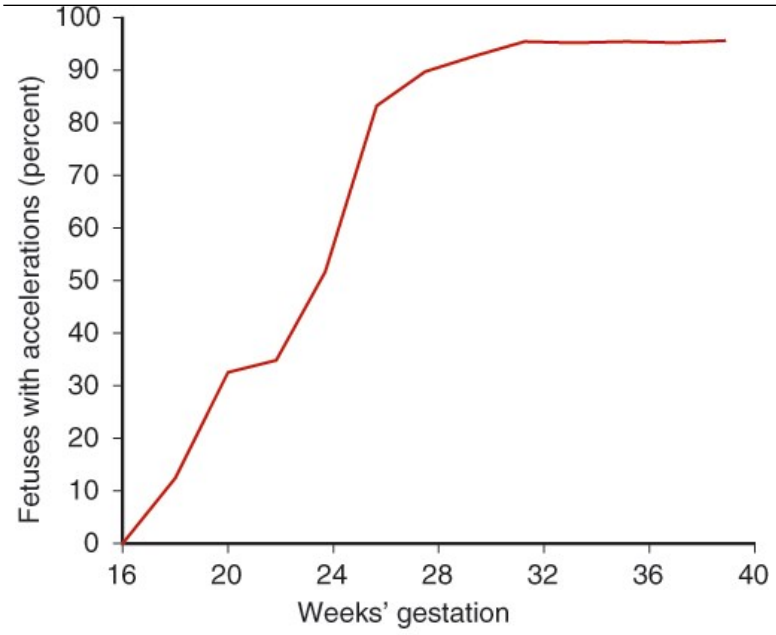
Autonomic influences are mediated by sympathetic or parasympathetic impulses from brainstem centers to normally raise or slow the fetal heart rate. *Beat-to-beat variability* is also under the control of the autonomic nervous system (Matsuura, 1996). Consequently, pathological loss of fetal heart rate acceleration may be seen in conjunction with significantly decreased beat-to-beat variability (Chap. 24, Cardiac Arrhythmia). Loss of such reactivity, however, is most commonly associated with sleep cycles. It also may be caused by central depression from medications or cigarette smoking (Jansson, 2005).

The nonstress test is based on the hypothesis that the heart rate of a fetus that is not acidemic as a result of hypoxia or neurological depression will temporarily accelerate in response to fetal movement. Fetal movements during testing are identified by maternal perception and recorded. As hypoxia develops, these fetal heart rate accelerations diminish (Smith, 1988).

Gestational age influences acceleration or reactivity of the fetal heart rate. Pillai and James (1990b) studied the development of fetal heart rate acceleration patterns during normal pregnancy. The percentage of body movements that is accompanied by accelerations and the amplitude of these accelerations both increase with gestational age (Fig. 17-5). Guinn and colleagues (1998) studied nonstress test results between 25 and 28 weeks' gestation in 188 normal fetuses. Only 70 percent of these normal fetuses demonstrated the required 15 beats per minute (bpm) or more of heart rate acceleration. Lesser degrees of acceleration, that is, 10 bpm, occurred in 90 percent of the fetuses.

FIGURE 17-5

Percentage of fetuses with at least one acceleration of 15 bpm sustained for 15 seconds concurrent with fetal movement. (Redrawn from Pillai M, James D: The development of fetal heart rate patterns during normal pregnancy, Obstet Gynecol. 1990 Nov;76(5 Pt 1):812–816.)



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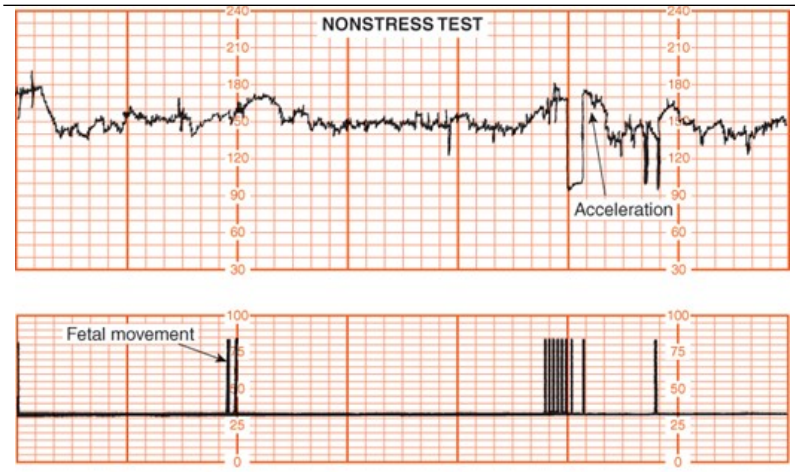
The National Institute of Child Health and Human Development Fetal Monitoring Workshop defined normal acceleration based on gestational age (Macones, 2008). In fetuses at or beyond 32 weeks' gestation, the acceleration acme is 15 bpm or more above the baseline rate, and the acceleration lasts 15 seconds or longer but less than 2 minutes. Before 32 weeks, normal accelerations are defined as having an acme that is 10 bpm or more above baseline for 10 seconds or longer. Cousins and associates (2012) compared the Workshop criteria recommended before 32 weeks, that is, 10 bpm/10 seconds, with standard 15 bpm/15 seconds criteria in a randomized trial of 143 women. They found no differences in perinatal outcomes.

Normal Nonstress Tests

Criteria to define normal nonstress test results differ. They vary regarding the number, amplitude, and duration of accelerations and the test duration. The definition recommended by the American College of Obstetricians and Gynecologists (2016) requires two or more accelerations peaking at 15 bpm or more above baseline, each lasting 15 seconds or more, and all occurring within 20 minutes of beginning the test (Fig. 17-6). It is also recommended that accelerations with or without fetal movements be accepted, and that a 40-minute or longer tracing—to account for fetal sleep cycles—should be performed before concluding that fetal reactivity is insufficient. Miller and coworkers (1996b) reviewed outcomes in fetuses with nonstress tests considered as nonreactive because there was only one acceleration. They concluded that one acceleration was just as reliable as two in predicting healthy fetal status.

FIGURE 17-6

Reactive nonstress test. In the upper panel, notice the increase of fetal heart rate by more than 15 beats/min for longer than 15 seconds following fetal movements, which are indicated by the vertical marks (*lower panel*).



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Although a normal number and amplitude of accelerations seems to reflect fetal well-being, their absence does not invariably predict fetal compromise. Indeed, some investigators have reported 90-percent or higher false-positive rates (Devoe, 1986). Because healthy fetuses may not move for periods of up to 75 minutes, some have considered that a longer duration of nonstress testing might increase the positive-predictive value of an abnormal, that is, nonreactive, test (Brown, 1981). In this scheme, either the test became reactive during a period up to 80 minutes or the test remained nonreactive for 120 minutes, which indicated that the fetus was very ill.

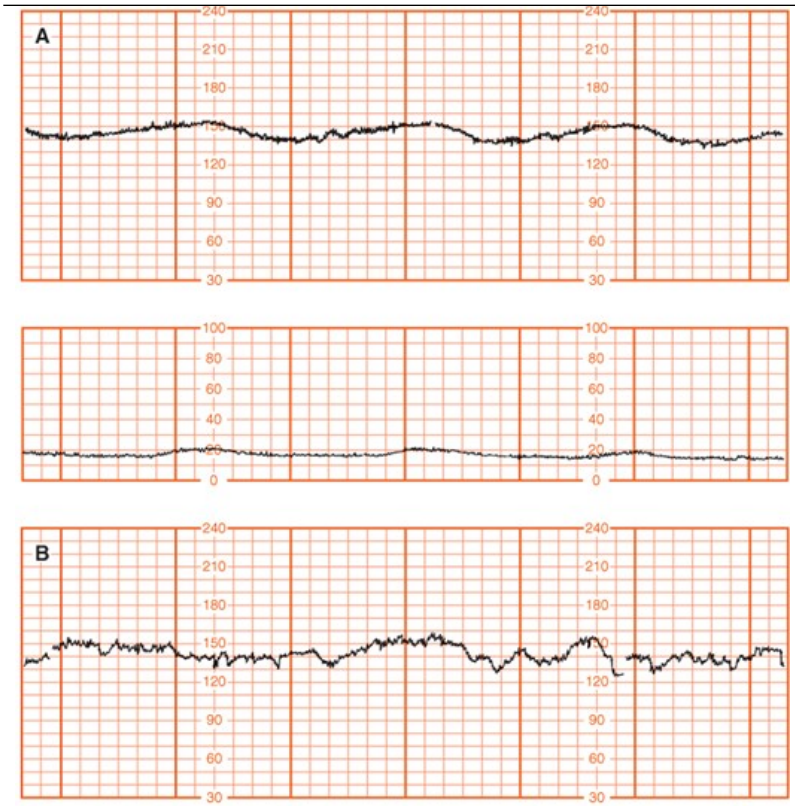
Not only do definitions of normal nonstress test results differ, but the reproducibility of interpretations is problematic (Hage, 1985). Thus, although nonstress testing is popular, the reliability of test interpretation needs improvement.

Abnormal Nonstress Tests

Based on the foregoing, an abnormal nonstress test is not always ominous and can be seen with a sleeping fetus. Also, an abnormal test can revert to normal as the fetal condition changes, such as the example shown in Figure 17-7. Importantly, a normal nonstress test can become abnormal if the fetal condition deteriorates.

FIGURE 17-7

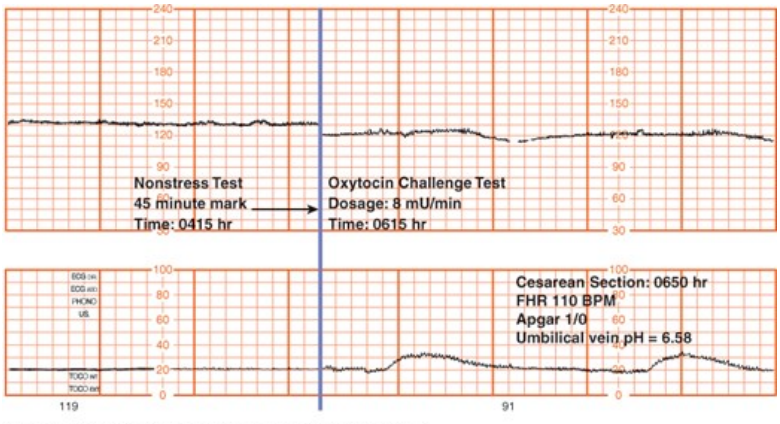
Two antepartum fetal heart rate (FHR) tracings in a 28-week pregnant woman with diabetic ketoacidosis. **A.** FHR tracing (*upper panel*) and accompanying contraction tracing (*second panel*). Tracing, obtained during maternal and fetal acidemia, shows absence of accelerations, diminished variability, and late decelerations with weak spontaneous contractions. **B.** Fetal heart rate tracing shows return of normal accelerations and variability of the fetal heart rate following correction of maternal acidemia.



There are abnormal patterns that reliably forecast severe fetal jeopardy (Fig. 17-8). Devoe and coworkers (1985) concluded that nonstress tests that were nonreactive for 90 minutes were almost invariably—93 percent—associated with significant perinatal pathology. Hammacher and coworkers (1968) described tracings with what they termed a *silent oscillatory pattern* that he considered dangerous. This pattern consisted of a fetal heart rate baseline that oscillated less than 5 bpm and presumably indicated absent acceleration and beat-to-beat variability.

FIGURE 17-8

Nonreactive nonstress test (*left side of tracing*) followed by contraction stress test showing mild, late decelerations (*right side of tracing*). Cesarean delivery was performed, and the severely acidemic fetus could not be resuscitated.



Visser and associates (1980) described a *terminal cardiotocogram,* which included: (1) baseline oscillation of less than 5 bpm, (2) absent accelerations, and (3) late decelerations with spontaneous uterine contractions. These results were similar to experiences from Parkland Hospital in which absence of accelerations during an 80-minute recording period in 27 fetuses was associated consistently with evidence of uteroplacental pathology (Leveno,

1983). The latter included fetal-growth restriction in 75 percent, oligohydramnios in 80 percent, fetal acidemia in 40 percent, meconium in 30 percent, and placental infarction in 93 percent.

Interval between Testing

Set originally rather arbitrarily at 7 days, the interval between tests appears to have been shortened as experience evolved with nonstress testing. According to the American College of Obstetricians and Gynecologists (2016), more frequent testing is advocated by some investigators for women with postterm pregnancy, multifetal gestation, pregestational diabetes, fetal-growth restriction, or pregnancy hypertension. In these circumstances, some investigators perform twice-weekly tests, with additional testing completed for maternal or fetal deterioration regardless of the time elapsed since the last test. Others perform nonstress tests daily or even more frequently, such as with severe preeclampsia remote from term.

Decelerations During Nonstress Testing

Fetal movements commonly produce heart rate decelerations. Timor-Tritsch and associates (1978) reported this during nonstress testing in half to two thirds of tracings, depending on the vigor of the fetal motion. This high incidence of decelerations inevitably makes interpretation of their significance problematic. Indeed, Meis and coworkers (1986) reported that variable fetal heart rate decelerations during nonstress tests were not a sign of fetal compromise. The American College of Obstetricians and Gynecologists (2016) has concluded that variable decelerations, if nonrepetitive and brief—less than 30 seconds—do not indicate fetal compromise or the need for obstetrical intervention. In contrast, repetitive variable decelerations—at least three in 20 minutes—even if mild, have been associated with a greater risk of cesarean delivery for fetal distress. Decelerations lasting 1 minute or longer have been reported to have an even worse prognosis (Bourgeois, 1984; Druzin, 1981; Pazos, 1982).

Hoskins and associates (1991) attempted to refine interpretation of testing that shows variable decelerations by adding sonographic estimation of amnionic fluid volume. The incidence of cesarean delivery for intrapartum fetal distress progressively rose concurrently with the severity of variable decelerations and decline of amnionic fluid volume. Severe variable decelerations during a nonstress test plus an amnionic fluid index (AFI) ≤5 cm resulted in a 75-percent cesarean delivery rate. Fetal distress in labor, however, also frequently developed in those pregnancies with variable decelerations but with normal amounts of amnionic fluid. Similar results were reported by Grubb and Paul (1992).

False-Normal Nonstress Tests

Smith and associates (1987) performed a detailed analysis of the causes of fetal death within 7 days of normal nonstress tests. The most common indication for testing was postterm pregnancy. The mean interval between testing and death was 4 days, with a range of 1 to 7 days. The single most common autopsy finding was meconium aspiration, often associated with some type of umbilical cord abnormality. They concluded that an acute asphyxial insult had provoked fetal gasping. They also concluded that nonstress testing was inadequate to preclude such an acute asphyxial event and that other biophysical characteristics might be beneficial. Importantly, assessment of amnionic fluid volume was considered valuable. Other ascribed frequent causes of fetal death included intrauterine infection, abnormal cord position, malformations, and placental abruption.

ACOUSTIC STIMULATION TESTS

Loud external sounds have been used to startle the fetus and thereby provoke heart rate acceleration—an *acoustic stimulation nonstress test*. A commercially available acoustic stimulator is positioned on the maternal abdomen, and a stimulus of 1 to 2 seconds is applied (Eller, 1995). This may be repeated up to three times for up to 3 seconds (American College of Obstetricians and Gynecologists, 2016). A positive response is defined as the rapid appearance of a qualifying acceleration following stimulation (Devoe, 2008). In a randomized trial of 113 women undergoing nonstress testing, vibroacoustic stimulation shortened the average time of testing from 24 to 15 minutes (Perez-Delboy, 2002). Similar results were reported by Turitz and coworkers (2012). Laventhal and colleagues (2003) reported that fetal tachyarrhythmia could be provoked with vibroacoustic stimulation.

BIOPHYSICAL PROFILE

Manning and colleagues (1980) proposed the combined use of five fetal biophysical variables as a more accurate means of assessing fetal health than a single element. Typically, these tests require 30 to 60 minutes of examiner time. Shown in Table 17-2 are the five fetal biophysical components assessed: (1) heart rate acceleration, (2) breathing, (3) movements, (4) tone, and (5) amnionic fluid volume. Normal variables were assigned a score of 2 each, and abnormal variables were given a score of 0. Thus, the highest score possible for a normal fetus is 10. Maternal medications such as narcotics

and sedatives can significantly lower the score (Kopecky, 2000). Ozkaya and associates (2012) found that biophysical test scores were higher if a test was performed in late evening—20:00 to 22:00 hours—compared with 08:00 to 10:00 hours.

TABLE 17-2

Components and Scores for the Biophysical Profile

Component	Score 2	Score 0
Nonstress test[a]	≥2 accelerations of ≥15 beats/min for ≥15 sec within 20–40 min	0 or 1 acceleration within 20–40 min
Fetal breathing	≥1 episode of rhythmic breathing lasting ≥30 sec within 30 min	<30 sec of breathing within 30 min
Fetal movement	≥3 discrete body or limb movements within 30 min	<3 discrete movements
Fetal tone	≥1 episode of extremity extension and subsequent return to flexion	0 extension/flexion events
Amnionic fluid volume[b]	A pocket of amnionic fluid that measures at least 2 cm in two planes perpendicular to each other (2 × 2 cm pocket)	Largest single vertical pocket ≤2 cm

[a]May be omitted if all four sonographic components are normal.

[b]Further evaluation warranted, regardless of biophysical composite score, if largest vertical amnionic fluid pocket ≤2 cm.

Manning and colleagues (1987) tested more than 19,000 pregnancies using the biophysical profile interpretation and management shown in Table 17-3. More than 97 percent of the pregnancies tested had normal test results. They reported a false-normal test rate—defined by an antepartum death of a structurally normal fetus—of approximately 1 per 1000. The most common identifiable causes of fetal death after a normal biophysical profile include fetomaternal hemorrhage, umbilical cord accidents, and placental abruption (Dayal, 1999).

TABLE 17-3

Interpretation of Biophysical Profile Score

Biophysical Profile Score	Interpretation	Recommended Management
10	Normal, nonasphyxiated fetus	No fetal indication for intervention; repeat test weekly except in diabetic patients and postterm pregnancy (twice weekly)
8/10 (Normal AFV)	Normal, nonasphyxiated fetus	No fetal indication for intervention; repeat testing per protocol
8/8 (NST not done)		
8/10 (Decreased AFV)	Chronic fetal asphyxia suspected	Deliver
6	Possible fetal asphyxia	If amnionic fluid volume abnormal, deliver
		If normal fluid at >36 weeks with favorable cervix, deliver
		If repeat test ≤6, deliver
		If repeat test >6, observe and repeat per protocol
4	Probable fetal asphyxia	Repeat testing same day; if biophysical profile score ≤6, deliver
0 to 2	Almost certain fetal asphyxia	Deliver

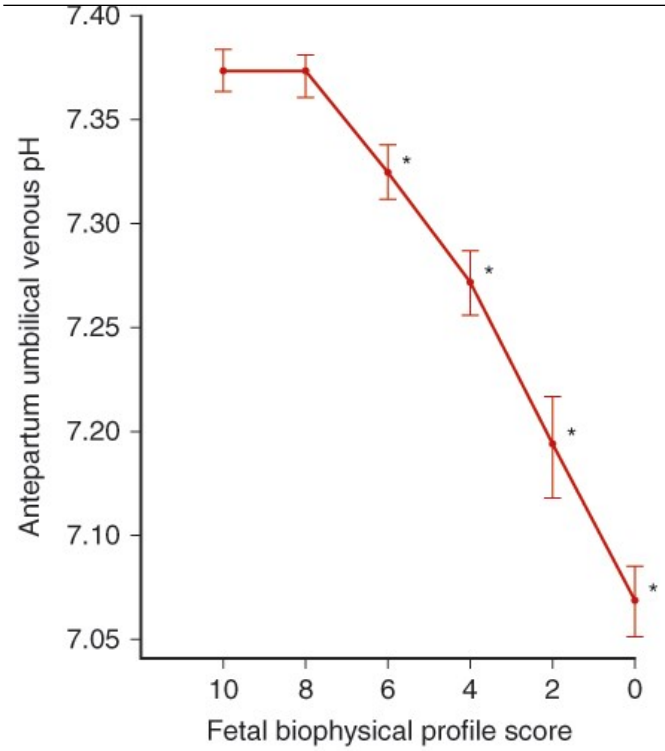
AFV = amnionic fluid volume; NST = nonstress test.

Reproduced with permission from Manning FA, Morrison I, Harman CR, et al: Fetal assessment based on fetal biophysical profile scoring: experience in 19,221 referred high-risk pregnancies. II. An analysis of false-negative fetal deaths, Am J Obstet Gynecol. 1987 Oct;157(4 Pt 1):880–884.

Manning and coworkers (1993) published a remarkable description of 493 fetuses in which biophysical scores were performed immediately before measurement of umbilical venous blood pH values obtained via antepartum cordocentesis. Approximately 20 percent of tested fetuses had growth restriction, and the remainder had alloimmune hemolytic anemia. As shown in Figure 17-9, a biophysical score of 0 was almost invariably associated with significant fetal acidemia, whereas a normal score of 8 or 10 was associated with normal pH. An equivocal test result—a score of 6—was a poor predictor of abnormal outcome. As the abnormal score dropped from 2 or 4 down to 0, this decline was a more accurate predictor of abnormal fetal outcome. Thus overall, these scores provide poor sensitivity to predict cord blood pH.

FIGURE 17-9

Mean umbilical vein pH (±2 SD) obtained by cordocentesis in relation to fetal biophysical profile score category. (Data from Manning, 1993.)



Source: F. Gary Cunningham, Kenneth J. Leveno, Steven L. Bloom, Catherine Y. Spong, Jodi S. Dashe, Barbara L. Hoffman, Brian M. Casey, Jeanne S. Sheffield: *Williams Obstetrics*, 25th Edition

Similar studies have substantiated these findings. Salvesen and associates (1993) concluded that the biophysical profile was of limited value in the prediction of fetal pH. Weiner and coworkers (1996) assessed 135 overtly growth-restricted fetuses and came to a similar conclusion. Kaur and colleagues (2008) performed daily biophysical profiles to ascertain the optimal delivery time in 48 growth-restricted preterm fetuses that weighed less than 1000 g. Despite scores of 8 in 27 fetuses and 6 in 13, there were six deaths and 21 acidemic fetuses. Lalor and associates (2008) performed a Cochrane review and concluded that there is insufficient evidence to support the use of the biophysical profile as a fetal well-being test in high-risk pregnancies.

Modified Biophysical Profile

Because the biophysical profile is labor intensive and requires a person trained in sonography, Clark and coworkers (1989) used an abbreviated biophysical profile as a first-line screening test in 2628 singleton pregnancies. Specifically, a vibroacoustic nonstress test was performed twice weekly and combined with AFI determination for which ≤5 cm was considered abnormal (Chap. 11, Oligohydramnios). This abbreviated biophysical profile required approximately 10 minutes to perform, and they concluded that it was a superb antepartum surveillance method because there were no unexpected fetal deaths.

Nageotte and colleagues (1994) also combined biweekly nonstress tests with the AFI and considered measures ≤5 cm to be abnormal. They performed 17,429 modified biophysical profiles in 2774 women and concluded that such testing was an excellent fetal surveillance tool. Miller and associates (1996a) reported results with more than 54,000 modified biophysical profiles performed in 15,400 high-risk pregnancies. They described a false-negative rate of 0.8 per 1000 and a false-positive rate of 1.5 percent.

The American College of Obstetricians and Gynecologists (2016) has concluded that the modified biophysical profile test is as predictive of fetal well-being as other approaches to biophysical fetal surveillance.

AMNIONIC FLUID VOLUME

The importance of amnionic fluid volume estimation is indicated by its inclusion into virtually all schemes in which fetal health is assessed (Frøen, 2008). This is based on the rationale that diminished uteroplacental perfusion may lead to lower fetal renal blood flow, decreased urine production,

and ultimately, oligohydramnios (Chap. 11, Pregnancy Outcomes). The American College of Obstetricians and Gynecologists (2016) concludes that data available from randomized trials indicate that the use of the deepest vertical pocket measurement, as opposed to the AFI, to diagnose oligohydramnios is associated with a reduction in unnecessary interventions without an increase in adverse perinatal outcomes (Nabhan, 2008; Reddy, 2014).

DOPPLER VELOCIMETRY

Blood flow velocity measured by Doppler ultrasound reflects downstream impedance (Chap. 10, Doppler). For growth-restricted fetuses, several fetal vascular circuits including the umbilical artery, middle cerebral artery, and ductus venosus have been evaluated as diagnostic tools for fetal well-being (Chap. 44, Prevention). Maternal uterine artery Doppler velocimetry has also been assessed as a modality to predict placental dysfunction, with the goal to balance stillbirth against the risks of preterm delivery (Ghidini, 2007). Even the effects of sildenafil in pregnant sheep have been evaluated using Doppler velocimetry (Alanne, 2017). The rationale is that sildenafil would improve placental blood flow in the presence of placental insufficiency. This proved untrue, as sildenafil was associated with detrimental effects on fetal cardiovascular dynamics.

Doppler Blood Flow Velocity

Waveforms were first studied in the umbilical arteries late in pregnancy, and abnormal waveforms correlated with placental villous hypovascularity. Of the small placental arterial channels, 60 to 70 percent need to be obliterated before the umbilical artery Doppler waveform becomes abnormal. Such extensive placental vascular pathology has a major effect on fetal circulation. According to Trudinger (2007), because more than 40 percent of the combined fetal ventricular output is directed to the placenta, obliteration of placental vascular channel increases afterload and leads to fetal hypoxemia. This in turn leads to ventricular dilation and redistribution of middle cerebral artery blood flow. Ultimately, pressure rises in the ductus venosus due to afterload in the right side of the fetal heart (Baschat, 2004). Clinically, abnormal Doppler waveforms in the ductus venosus are a late finding in the progression of fetal deterioration due to chronic hypoxemia.

Umbilical Artery Velocimetry

The umbilical artery systolic-diastolic (S/D) ratio is considered abnormal if it is >95th percentile for gestational age or if diastolic flow is either absent or reversed (Chap. 10, Doppler). Absent or reversed end-diastolic flow signifies greater impedance to umbilical artery blood flow (Fig. 44-8). It is reported to result from poorly vascularized placental villi and is seen in extreme cases of fetal-growth restriction (Todros, 1999). According to Zelop and colleagues (1996), the perinatal mortality rate for absent end-diastolic flow was about 10 percent, and for reversed end-diastolic flow, it approximated 33 percent.

Spinillo and associates (2005) studied neurodevelopmental outcome at 2 years of age in 266 growth-restricted fetuses delivered between 24 and 35 weeks' gestation. Of infants who had shown absent or reversed umbilical artery flow, 8 percent had evidence of cerebral palsy compared with 1 percent of those in whom Doppler flow had been normal.

Doppler ultrasound of the umbilical artery has been subjected to more extensive assessment with randomized controlled trials than has any previous test of fetal health. Williams and colleagues (2003) randomized 1360 high-risk women to either nonstress testing or Doppler velocimetry. They found a significantly higher incidence of cesarean delivery for fetal distress in the nonstress test group compared with that for those tested with Doppler velocimetry—8.7 versus 4.6 percent, respectively. One interpretation of this finding is that the nonstress test more frequently identified fetuses in jeopardy. Conversely, Gonzalez and associates (2007) found that abnormal umbilical artery Doppler findings in a cohort of growth-restricted fetuses were the best predictors of perinatal outcomes.

The utility of umbilical artery Doppler velocimetry was reviewed by the American College of Obstetricians and Gynecologists (2016). They concluded that no benefit has been demonstrated other than in pregnancies with suspected fetal-growth restriction. Similarly, velocimetry has not proved valuable as a screening test for fetal compromise in the general obstetrical population.

Various other fetal-maternal Doppler indices have been studied, including the fetal middle cerebral artery and ductus venosus and the uterine arteries. The American College of Obstetricians and Gynecologists (2016) concluded that Doppler investigations of other blood vessels besides the umbilical artery have not been shown to improve perinatal outcome.

Middle Cerebral Artery

As discussed, at this time, Doppler velocimetry interrogation of the middle cerebral artery (MCA) to detect fetal compromise is not recommended. Still, the technology has received particular attention because of observations that the hypoxic fetus attempts *brain sparing* by reducing cerebrovascular impedance and thus increasing blood flow. Such brain sparing in growth-restricted fetuses has been documented to undergo reversal (Konje, 2001). Investigators reported that 8 of 17 fetuses with this reversal died. Ott and coworkers (1998) randomized 665 women undergoing modified biophysical profile evaluation to either the profile alone or combined with middle cerebral and umbilical artery velocity flow assessment. Pregnancy outcomes between these two study groups did not differ significantly.

Middle cerebral artery Doppler velocimetry has proven valuable to detect severe fetal anemia in 165 fetuses with d-antigen alloimmunization. Oepkes and colleagues (2006) prospectively compared serial amniocentesis for measurement of bilirubin levels with Doppler measurement of peak systolic velocity in the middle cerebral artery. These investigators concluded that Doppler could safely replace amniocentesis in the management of alloimmunized pregnancies. And as discussed in Chapter 15 (Management of the Alloimmunized Pregnancy), this technique has been reported to be useful for detection and management of fetal anemia of any cause (Moise, 2008).

Ductus Venosus

Doppler ultrasound has also been used to assess the fetal venous circulation. Bilardo and colleagues (2004) prospectively studied umbilical artery and ductus venosus Doppler velocimetry in 70 growth-restricted fetuses at 26 to 33 weeks' gestation. They concluded that ductus venosus velocimetry was the best predictor of perinatal outcome. Importantly, negative or reversed flow in the ductus venosus was a late finding because these fetuses had already sustained irreversible multiorgan damage due to hypoxemia. Also, gestational age at delivery was a major determinant of perinatal outcome independent of ductus venosus flow. Specifically, 36 percent of growth-restricted fetuses delivered between 26 and 29 weeks' gestation succumbed compared with only 5 percent delivered from 30 to 33 weeks.

Baschat and coworkers (2007) studied 604 growth-restricted fetuses using umbilical artery, middle cerebral artery, and ductus venosus Doppler velocimetry and reached similar conclusions. Specifically, absent or reversed flow in the ductus venosus was associated with profound generalized fetal metabolic collapse. They too reported that gestational age was a powerful cofactor in ultimate perinatal outcome for growth-restricted fetuses delivered before 30 weeks. Put another way, by the time severely abnormal flow is seen in the ductus venosus, it is too late because the fetus is already near death. Conversely, earlier delivery puts the fetus at risk for death due to preterm delivery. Ghidini (2007) concluded that these reports do not support routine use of ductus venosus Doppler in the monitoring of growth-restricted fetuses and recommended further study.

Uterine Artery

Vascular resistance in the uterine circulation normally decreases in the first half of pregnancy due to invasion of maternal uterine vessels by trophoblastic tissue (Chap. 5, Endometrial Cycle). This process can be detected using Doppler flow velocimetry, and uterine artery Doppler may be most helpful in assessing pregnancies at high risk of uteroplacental insufficiency (Abramowicz, 2008). Persistence or development of high-resistance patterns has been linked to various pregnancy complications (Lees, 2001; Yu, 2005). In a study of 30,519 unselected British women, Smith and colleagues (2007) assessed uterine artery velocimetry at 22 to 24 weeks' gestation. The risk of fetal death before 32 weeks, when associated with abruption, preeclampsia, or fetal-growth restriction, was significantly linked to high-resistance flow. This has led to suggestions for continued research of uterine artery Doppler velocimetry as a screening tool to detect pregnancies at risk for stillbirth (Reddy, 2008). Sciscione and Hayes (2009) reviewed the use of uterine artery Doppler flow studies in obstetrical practice. Because standards for the study technique and criteria for an abnormal test are lacking, they noted that uterine artery Doppler studies should not be considered standard practice in either low- or high-risk populations.

ANTENATAL TESTING SUMMARY

Antenatal forecasts of fetal health have clearly been the focus of intense interest, and several themes emerge. First, despite a continuous evolution of testing options, the precision or efficacy of any given method is limited. Second, the wide range of normal biological fetal variation makes interpretation of test results challenging. Last, despite the invention of increasingly complex testing methods, abnormal results are seldom reliable, prompting many clinicians to use antenatal testing to forecast fetal *wellness* rather than *illness.*

Platt and coworkers (1987) reviewed the efficacy of antenatal testing between 1971 and 1985 at Los Angeles County Hospital. During this 15-year period, more than 200,000 pregnancies were managed, and nearly 17,000 of these women underwent antepartum testing of various types. Fetal

surveillance rose from <1 percent of pregnancies in the early 1970s to 15 percent in the mid-1980s. These authors concluded that such testing was clearly beneficial because the fetal death rate was significantly less in the tested high-risk pregnancies compared with the rate in those not tested. The study, however, did not consider other innovations incorporated into practice during those 15 years. Preliminary results from Ghana suggest that nonstress testing may be beneficial in low-resource countries (Lawrence, 2016). In an observational study of 316 pregnancies complicated by gestational hypertension, women undergoing nonstress testing had a nonsignificant decreased risk for stillbirth compared with those not tested—3.6 versus 9.2 percent, respectively.

The benefits of antenatal fetal testing have not been sufficiently evaluated in randomized controlled trials according to Thacker and Berkelman (1986). This was concluded after reviewing 600 reports, which included only four randomized trials that were not powered to permit detection of important benefits. From their review, Enkin and colleagues (2000) concluded that "despite their widespread use, most tests of fetal well-being should be considered of experimental value only rather than validated clinical tools."

Another important and unanswered question is whether antepartum fetal surveillance identifies fetal asphyxia early enough to prevent brain damage. Manning and coworkers (1998) studied the incidence of cerebral palsy in 26,290 high-risk pregnancies managed with serial biophysical profile testing. These outcomes were compared with those of 58,657 low-risk pregnancies in which antepartum testing was not performed. The rate of cerebral palsy was 1.3 per 1000 in tested pregnancies compared with 4.7 per 1000 in untested women. Todd and coworkers (1992) attempted to correlate cognitive development in infants up to age 2 years following either abnormal umbilical artery Doppler velocimetry or nonstress test results. Only abnormal nonstress tests were associated with marginally poorer cognitive outcomes. These investigators concluded that by the time fetal compromise is diagnosed with antenatal testing, fetal damage has already been sustained. Low and associates (2003) reached a similar conclusion.

According to the American College of Obstetricians and Gynecologists (2016), a *normal* antepartum fetal test result is highly reassuring that a stillbirth will not occur within 1 week. This conclusion was reached after an analysis of reports of stillbirth rates associated with the various antepartum fetal heart rate tests (Table 17-4). Note that these results are corrected to remove lethal anomalies and unpredictable catastrophes such as placental abruption or cord accidents. The most important consideration in deciding when to begin antepartum testing is the prognosis for neonatal survival.

The severity of maternal disease is another. In general, with most high-risk pregnancies, testing begins by 32 to 34 weeks' gestation. Pregnancies with severe complications might require testing as early as 26 to 28 weeks. The frequency for repeating tests has been arbitrarily set at 7 days, but more frequent testing is often done.

TABLE 17-4

Stillbirth Rates within 1 Week of a Normal Antepartum Fetal Surveillance Test

Antepartum Fetal Test	Stillbirth[a] Rate/1000	Number
Nonstress test	1.9	5861
Contraction stress test	0.3	12,656
Biophysical profile	0.8	44,828
Modified biophysical profile	0.8	54,617

[a]Corrected for lethal anomalies and unpredictable causes of fetal death such as abruption or cord accident.

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