CHAPTER 33: Diseases and Injuries of the Term Newborn

In a small number of cases fractures of the skull are met with. This accident usually follows violent attempts at delivery, though occasionally it may occur spontaneously.

—J. Whitridge Williams (1903)

INTRODUCTION

In the first edition of this book, Williams wrote very little of the disorders of the term newborn. That said, it is well known that these neonates are susceptible to a wide variety of illnesses and injuries. In many instances, clinical manifestations of these disorders are extensions of pathological effects already incurred by the fetus. A common example is the newborn who is depressed and acidotic because of intrapartum septicemia. Because many of these disorders manifest differently, those more common in term newborns are considered here. Those more frequent in preterm neonates are discussed in Chapter 34. Specific disorders that are the direct consequence of maternal diseases are discussed in pertinent chapters.

RESPIRATORY DISTRESS

At the time of delivery, the newborn must convert rapidly to air breathing as described in Chapter 32 (Transition to Air Breathing). With inspiration, there is alveolar expansion, fluid clearance, and surfactant secretion by type II pneumocytes to prevent alveolar collapse. Interference with these functions can create respiratory insufficiency with hypoxemia and compensatory tachypnea, nasal flaring, retractions, and grunting (Reuter, 2014). In preterm infants, this is caused by lung immaturity and insufficient surfactant—*respiratory distress syndrome (RDS)*—and variants may be seen in severely ill older children and adults (Chap. 47, Acute Respiratory Distress Syndrome). All of these have some element of surfactant deficiency because the inciting agent damages alveolar epithelium. As fetuses approach term, surfactant deficiency as a cause of respiratory distress diminishes. The leading causes in term newborns are transient tachypnea of the newborn, RDS, meconium aspiration syndrome, pneumonia, persistent pulmonary hypertension, and hypoxic-ischemic encephalopathy (Lin, 2015).

Respiratory Distress Syndrome

In a report from Beijing that described 125 term infants with RDS, the most frequent causes were perinatal infection with sepsis syndrome in 50 percent, elective cesarean delivery in 27 percent, severe asphyxia in 10 percent, and meconium aspiration in 7 percent (Liu, 2010). Notably, even with a low incidence in term infants, RDS from surfactant deficiency is not rare (Berthelot-Ricou, 2012). Chorioamnionitis, male gender, and white race are independent risks (Anadkat, 2012; Higgins, 2016). Also, mutations of genes that encode for surfactant protein synthesis may augment the deficiency (Wambach, 2012). Regardless of etiology, when surfactant secretion is diminished, the pulmonary pathophysiology, clinical course, and management are similar to that for preterm infants. Treatment includes mechanical ventilation and replacement of surfactant (Chap. 34, Clinical Course). Evidence now supports that antenatal maternal corticosteroid treatment will enhance surfactant synthesis in late-preterm fetuses, that is, those 34 to 37 weeks' gestation (Gyamfi-Bannerman, 2016). At Parkland Hospital, corticosteroids are not given for this indication in the late-preterm period. Neonatal hypoglycemia is a concern with such treatment, and long-term effects are unknown. However, data indicate that hypoglycemia, if promptly treated, creates no adverse sequelae (McKinlay, 2015). The prognosis in term newborns with RDS largely depends on the cause, severity, and response to treatment.

Meconium Aspiration Syndrome

The physiology of meconium passage and amnionic fluid contamination is considered in Chapter 24 (Meconium in the Amnionic Fluid). In some instances, inhalation of meconium-stained fluid at or near delivery causes acute airway obstruction, chemical pneumonitis, surfactant dysfunction or inactivation, and pulmonary hypertension (Lee, 2016; Lindenskov, 2015). If severe, hypoxemia may lead to neonatal death or long-term neurological

sequelae in survivors.

Given the high incidence—10 to 20 percent—of meconium-stained amnionic fluid in laboring women at term, one may reasonably assume that meconium aspiration must be relatively common. Fortunately, severe aspiration leading to overt respiratory failure is much less frequent. And although the exact incidence of meconium aspiration syndrome is unknown, Singh and associates (2009) reported it to complicate 1.8 percent of all deliveries. In a French study of nearly 133,000 term newborns, the prevalence of severe aspiration syndrome was 0.07 percent, and this rose progressively from 37 to 43 weeks' gestation (Fischer, 2012). Mortality rates depend on severity.

Fetal morbidity is more often associated with thicker meconium content. Presumably, in most cases, amnionic fluid is ample to dilute the meconium to permit prompt clearance by normal fetal physiological mechanisms. Meconium aspiration syndrome still occasionally develops with light staining. Many newborns are affected after a normal labor and uncomplicated delivery. However, some associated obstetrical factors include postterm pregnancy and fetal-growth restriction. These fetuses are at highest risk because diminished amnionic fluid and labor with cord compression or uteroplacental insufficiency are often comorbid. These can enhance the likelihood of meconium passage that is thick and undiluted (Leveno, 1984).

Prevention

Previously, aspiration was thought to be stimulated by fetal hypoxic episodes, and fetal heart rate tracing abnormalities were used to identify fetuses at greatest risk during labor. Unfortunately, this was found to be an unreliable predictor (Dooley, 1985). As another potential prevention, oropharyngeal suctioning was standard care for a time. However, this was abandoned when evidence failed to support a reduction in syndrome incidence or severity (Davis, 1985; Wiswell, 1990). At the same time, reports described that pulmonary hypertension caused by aspirated meconium was characterized by abnormal arterial muscularization beginning well before birth. These findings led some to conclude that only chronically asphyxiated fetuses developed meconium aspiration syndrome (Katz, 1992). But, correlation was not found between meconium aspiration and markers of *acute* asphyxia—for example, umbilical artery acidosis (Bloom, 1996; Richey, 1995). Others, however, have reported that thick meconium is an independent risk factor for neonatal acidosis (Maisonneuve, 2011).

In response to conflicting results regarding suctioning, an 11-center randomized trial was designed to compare suctioning with no suctioning (Vain, 2004). There was an identical 4-percent incidence of meconium aspiration syndrome in both groups. Subsequently, a committee that represented the American Heart Association updated its guidelines (Wyckoff, 2015). Adopted by the American College of Obstetricians and Gynecologists (2017c) and the World Health Organization (2012), these recommend *against* routine intrapartum oro- and nasopharyngeal suctioning at delivery. For vigorous newborns, no treatment is required. For depressed newborns, management includes intervention to support ventilation and oxygenation, and intubation is used as indicated (Chap. 32, Chest Compressions).

Intrapartum amnioinfusion has been used successfully in laboring women with diminished amnionic fluid volume and frequent variable fetal heart rate decelerations (Chap. 24, Management Options). Earlier, it was studied as a preventive measure in labors complicated by meconium staining. This practice failed to lower meconium aspiration syndrome rates because fetuses usually inhaled meconium before labor (Bryne, 1987; Wenstrom, 1995). To further settle this issue, a trial was conducted with almost 2000 women at 36 weeks' gestation or later and in whom labor was complicated by thick meconium (Fraser, 2005). The perinatal death rate with and without amnioinfusion was 0.05 percent in both groups. Rates of moderate or severe meconium aspiration were also not significantly different—4.4 percent with and 3.1 percent without amnioinfusion. Finally, cesarean delivery rates were similar—32 versus 29 percent, respectively. Currently, the American College of Obstetrics and Gynecologists (2016a) does not recommend amnioinfusion to reduce meconium aspiration syndrome.

Treatment

Ventilatory support and intubation are carried out as needed (Wyckoff, 2015). Because some aspects of meconium aspiration syndrome are caused by surfactant deficiency, replacement therapy is beneficial (Natarajan, 2016a). Also, inhaled corticosteroids may ameliorate the severity (Garg, 2016). *Extracorporeal membrane oxygenation—ECMO*—therapy is reserved for neonates who remain poorly oxygenated despite maximal ventilatory assistance (Hirakawa, 2017). In their review of randomized trials, El Shahed and colleagues (2014) found that surfactant replacement may reduce the need for ECMO but did not lower the mortality rate. The proportion that requires ECMO treatment varies. In a report by Singh and coworkers (2009), 1.4 percent of 7518 term newborns with the syndrome required such treatment, and these had a 5-percent mortality rate. Ramachandrappa and associates (2011) reported a higher mortality rate in late-preterm neonates with meconium aspiration compared with affected term newborns. Finally, pulmonary lavage with surfactant is being evaluated (Choi, 2012).

NEONATAL ENCEPHALOPATHY AND CEREBRAL PALSY

Few events evoke more apprehension in parents and obstetricians than the specter of "brain injury," which immediately prompts concerns for disabling cerebral palsy and intellectual disability. Although most brain disorders or injuries are less profound, history has helped to perpetuate the more dismal outlook. In his first edition of this textbook, Williams (1903) limited discussions of brain injury to those sustained from birth trauma. When later editions introduced the concept that *asphyxia neonatorum* was another cause of cerebral palsy, this too was linked to traumatic birth. Even as brain damage caused by traumatic delivery became uncommon during the ensuing decades, the belief—albeit erroneous—was that intrapartum events caused most neurological disability. This was a major reason for the escalating cesarean delivery rate beginning in the 1970s. Unfortunately, because in most cases the genesis of cerebral palsy occurs long before labor, this did little to mitigate risks for cerebral palsy (O'Callaghan, 2013).

These realizations stimulated scientific investigations to determine the etiopathogenesis of fetal brain disorders, including those leading to cerebral palsy. Seminal observations include those of Nelson and Ellenberg (1984, 1985, 1986a), discussed subsequently. These investigators are appropriately credited with proving that these neurological disorders are due to complex multifactorial processes caused by a combination of genetic, physiological, environmental, and obstetrical factors. Importantly, these studies showed that few neurological disorders were associated with peripartum events. Continuing international interest was garnered to codify the potential role of intrapartum events. In 2000, a task force of the American College of Obstetricians and Gynecologists was appointed to study the vicissitudes of neonatal encephalopathy and cerebral palsy. The multispecialty coalition reviewed contemporaneous data and provided criteria to define various neonatal brain disorders. Their findings were promulgated by the American Academy of Pediatrics and American College of Obstetricians and Gynecologists (2003).

Ten years later, a second task force of these organizations updated the findings (American College of Obstetricians and Gynecologists, 2014c). The 2014 Task Force findings are more circumspect in contrast to the earlier ones. Specifically, more limitations are cited in identifying cause(s) of peripartum *hypoxic-ischemic encephalopathy (HIE)* compared with other etiologies of neonatal encephalopathy. The 2014 Task Force recommends multidimensional assessment of each affected infant. They add the caveat that no one strategy is infallible, and thus, no single strategy will achieve 100-percent certainty in attributing a cause to neonatal encephalopathy.

Neonatal Encephalopathy

The 2014 Task Force defined neonatal encephalopathy as a syndrome of neurological dysfunction identified in the earliest days of life in neonates born at ≥35 weeks' gestation. It is manifested by subnormal levels of consciousness or seizures and often accompanied by difficulty with initiating and maintaining respiration and by depressed tone and reflexes. The incidence of encephalopathy has been cited to be 0.27 to 1.1 per 1000 term liveborn neonates, and it is much more frequent in preterm newborns (Ensing, 2013; Plevani, 2013; Takenouchi, 2012; Wu, 2011). Although the 2014 Task Force concluded that there are many causes of encephalopathy and cerebral palsy, it focused on HIE and those that were thought to be incurred intrapartum. To identify affected infants, a thorough evaluation is necessary and includes maternal history, obstetrical antecedents, intrapartum factors, placental pathology, and newborn course. These are complemented by laboratory and neuroimaging findings.

There are three clinically defined levels. *Mild encephalopathy* is characterized by hyperalertness, irritability, jitteriness, and hypertonia and hypotonia. *Moderate encephalopathy* is manifest by lethargy, severe hypertonia, and occasional seizures. S*evere encephalopathy* is manifest by coma, multiple seizures, and recurrent apnea.

The 2014 Task Force also concluded that of the several forms of cerebral palsy, only the *spastic quadriplegic* type can result from acute peripartum ischemia. Other forms—*hemiparetic* or *hemiplegic cerebral palsy, spastic diplegia,* and *ataxia*—are unlikely to result from an intrapartum event. Purely dyskinetic or ataxic cerebral palsy, especially when accompanied by a learning disorder, usually has a genetic origin (Nelson, 1998).

Criteria for Hypoxic-Ischemic Encephalopathy

The 2014 Task Force radically revised its 2003 criteria used to define an acute peripartum event that is consistent with an HIE and neonatal encephalopathy. These are outlined in Table 33-1 and are considered with the following caveats.

TABLE 33-1

Findings Consistent with an Acute Peripartum or Intrapartum Event Leading to Hypoxic-Ischemic Encephalopathy

Neonatal Findings
Apgar score: <5 at 5 and 10 minutes
Umbilical arterial acidemia: pH <7.0 and/or base deficit ≥12 mmol/L
Neuroimaging evidence of acute brain injury: MR imaging or MRS consistent with HIE
Multisystem involvement consistent with HIE
Type and Timing of Contributing Factors
Sentinel hypoxic or ischemic event occurring immediately before or during delivery
Fetal heart rate monitor patterns consistent with an acute peripartum or intrapartum event

HIE = hypoxic ischemic encephalopathy; MR = magnetic resonance; MRS = magnetic resonance spectroscopy.

Summarized from the American College of Obstetricians and Gynecologists, 2014b.

First, *Apgar Scores* that are low at 5 and 10 minutes are associated with greater risk for neurological impairment. Low scores stem from many causes, and most of these infants will not develop cerebral palsy. With a 5-minute Apgar ≥7, it is unlikely that peripartum HIE caused cerebral palsy.

Acid-base study results define a second HIE criterion. Low pH and base deficit levels raise the likelihood that neonatal encephalopathy was caused by HIE. Decreasing levels form a continuum of increasing risk, but most acidemic neonates will be neurologically normal (Wayock, 2013). A cord artery pH ≥7.2 is very unlikely to be associated with HIE.

Magnetic resonance (MR) imaging or *MR spectroscopy (MRS)* is the best modality with which to visualize findings consistent with HIE. The 2014 Task Force concludes that cranial sonography and computed tomography (CT) lack sensitivity in the term newborn. Normal imaging findings after the first 24 hours of life, however, effectively exclude a hypoxic-ischemic cause of encephalopathy. MR imaging between 24 and 96 hours may be more sensitive for the timing of peripartum cerebral injury, and MR imaging at 7 to 21 days following birth is the best technique to delineate the full extent of cerebral injury.

Last, *multisystem involvement* of injury is consistent with HIE. These include renal, gastrointestinal, hepatic, or cardiac injury; hematological abnormalities; or combinations of these. The severity of neurological injury does not necessarily correlate with injuries to these other systems.

The 2014 Task Force also found that certain contributing factors may be consistent with an acute peripartum event. Of these, *sentinel events* are considered adverse obstetrical events that may lead to catastrophic clinical outcomes. Examples include ruptured uterus, severe placental abruption, cord prolapse, and amnionic fluid embolism. Martinez-Biarge and associates (2012) studied almost 58,000 deliveries and identified 192 cases with one of these sentinel events. Of these 192 fetus/newborns, 6 percent died intrapartum or in the early neonatal period, and 10 percent developed neonatal encephalopathy. Other risk factors for neonatal acidosis include prior or emergent cesarean delivery, maternal age ≥35 years, thick meconium, chorioamnionitis, and general anesthesia (Ahlin, 2016; Johnson, 2014; Nelson, 2014).

Differentiating an *abnormal fetal heart rate (FHR) tracing* on presentation versus one that develops subsequently was also emphasized by the 2014 Task Force. A category 1 or 2 FHR tracing associated with Apgar scores ≥7 at 5 minutes, normal cord gases (±1 SD), or both are not consistent with an acute HIE event (Graham, 2014). An FHR pattern at the time of presentation with persistently minimal or absent variability and lacking accelerations, with duration ≥60 minutes, and even without decelerations is suggestive of an already compromised fetus (Chap. 24, Cardiac Arrhythmia). The 2014 Task Force further recommended that if fetal well-being cannot be established with these findings present, the woman should be evaluated for the

method and timing of delivery.

Prevention

Most prophylactic measures for neonatal encephalopathy have been evaluated in preterm infants (Chap. 42, Magnesium Sulfate for Neuroprotection). One of these—postnatally induced hypothermia—may prevent death and mitigate moderate to severe neurological disability in term newborns (Garfinkle, 2015; Nelson, 2014; Shankaran, 2012). MR imaging studies have demonstrated a slowing of diffusional abnormalities and fewer infarctions with hypothermia (Bednarek, 2012; Natarajan, 2016b). Most randomized trials have shown improved outcomes with induced hypothermia in those born at 36 weeks' gestation or older (Azzopardi, 2014; Guillet, 2012; Jacobs, 2011). In a metaanalysis of more than 1200 newborns, Tagin and colleagues (2012) concluded that hypothermia improves survival rates and neurodevelopment. Clinical trials to evaluate concomitant neonatal erythropoietin therapy for neuroprophylaxis have reported conflicting results (Fauchère, 2015; Malla, 2017). Preliminary data from one multicenter trial of maternal *allopurinol* therapy indicate some mitigation of cerebral damage caused by hypoxia and ischemia (Kaandorp, 2013).

Cerebral Palsy

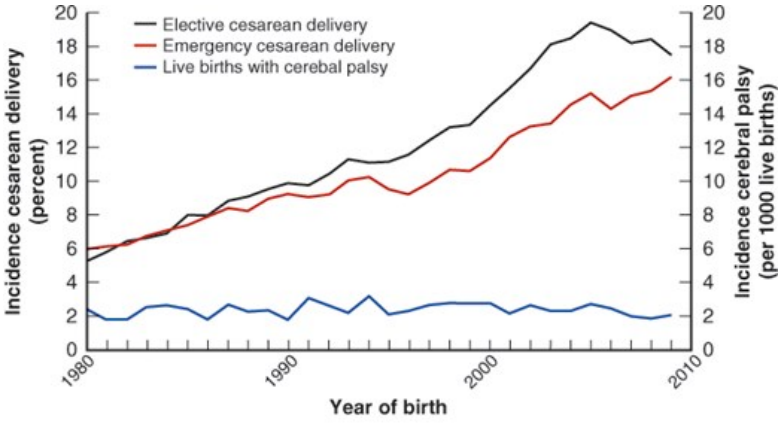
This term refers to a group of nonprogressive disorders of movement or posture caused by abnormal development or damage to brain centers for motor control. Cerebral palsy is further classified by the type of neurological dysfunction—spastic, dyskinetic, or ataxic—and by the number and distribution of limbs involved—quadriplegia, diplegia, hemiplegia, or monoplegia. Together, the major types are s*pastic quadriplegia*—the most common—which has a strong association with mental retardation and seizure disorders; *diplegia,* which is common in preterm or low-birthweight infants; *hemiplegia; choreoathetoid types;* and *mixed varieties.* Although epilepsy and mental retardation frequently accompany cerebral palsy, these two disorders seldom are associated with perinatal asphyxia in the absence of cerebral palsy.

Incidence and Epidemiological Correlates

According to Nelson and coworkers (2015), the prevalence of cerebral palsy in the United States averages 2 of every 1000 children. *It is crucial to emphasize that this rate is derived from all children—including those born preterm.* Because of the remarkably greater survival rates of the latter currently, and despite the elevated cesarean delivery rate, the overall rate of cerebral palsy has remained essentially unchanged (Fig. 33-1). For example, follow-up studies of more than 900,000 Norwegian nonanomalous term infants cite an incidence of 1 per 1000, but the incidence was 91 per 1000 for those born at 23 to 27 weeks (Moster, 2008). Similar findings have been reported for Australian births (Smithers-Sheedy, 2016). In absolute numbers, term newborns comprise half of cerebral palsy cases because there are proportionately far fewer preterm births. It is again emphasized that most studies of cerebral palsy rates have not made distinctions between term and preterm infants.

FIGURE 33-1

Elective and emergency cesarean deliveries and live births with cerebral palsy. (Reproduced with permission from Nelson KB, Blair E: Prenatal factors in singletons with cerebral palsy born at or near term, N Engl J Med. 2015 Sep 3;373(10):946–953.)



As noted earlier, Nelson and Ellenberg (1984, 1985, 1986a) made many fundamental observations concerning cerebral palsy. Their initial studies

emanated from data from the Collaborative Perinatal Project. This included children from almost 54,000 pregnancies who were followed until age 7. They found that the most frequently associated risk factors for cerebral palsy were: (1) evidence of genetic abnormalities such as maternal mental retardation or fetal congenital malformations; (2) birthweight <2000 g; (3) birth before 32 weeks; and (4) perinatal infection. They also found that obstetrical complications were not strongly predictive, and only a fifth of affected children had markers of perinatal asphyxia. *For the first time, there was solid evidence that the cause of most cases of cerebral palsy was unknown, and importantly, only a small proportion was caused by neonatal HIE.* Equally importantly, there was no foreseeable single intervention that would likely prevent a large proportion of cases.

Numerous studies have since confirmed many of these findings and identified an imposing list of other risk factors that are shown in Table 33-2. As expected, preterm birth continues to be the single most important risk factor (Nelson, 2015; Thorngren-Jerneck, 2006). Small-for-gestational-age neonates are also at higher risk. Stoknes and associates (2012) showed that in more than 90 percent of growth-restricted newborns, cerebral palsy was due to antepartum factors. Many other placental and neonatal risk factors have been correlated with neurodevelopmental abnormalities (Ahlin, 2013; Avagliano, 2010; Blair, 2011; Redline, 2008). Some placental factors are discussed further in Chapter 6 (Normal Placenta). One example is the substantively greater risk from chorioamnionitis (Gilbert, 2010; Shatrov, 2010). An example of a neonatal cause is arterial ischemic stroke, which may be associated with inherited fetal thrombophilias (Harteman, 2013; Kirton, 2011). Also, newborns with isolated congenital heart lesions have an elevated risk for microcephaly, possibly due to chronic fetal hypoxemia (Barbu, 2009). Other miscellaneous etiologies of cerebral palsy include fetal anemia, twin-twin transfusion syndrome, intrauterine transfusions, and fetal alcohol syndrome (DeJong, 2012; Lindenburg, 2013; O'Leary, 2012; Rossi, 2011; Spruijt, 2012).

TABLE 33-2

Perinatal Risk Factors Reported to Be Increased in Children with Cerebral Palsy

Risk Factors	Risk Ratio	95% CI
Hydramnios	6.9	1.0–49.3
Placental abruption	7.6	2.7–21.1
Interval between pregnancies <3 mo or >3 yr	3.7	1.0–4.4
Spontaneous preterm labor	3.4	1.7–6.7
Preterm delivery at 23–27 weeks	78.9	56.5–110
Breech or face presentation, transverse lie	3.8	1.6–9.1
Severe birth defect	5.6	8.1–30.0
Nonsevere birth defect	6.1	3.1–11.8
Time to cry >5 minutes	9.0	4.3–18.8
Obesity	1.2–2	1.1–2.8
Low placental weight	3.6	1.5–8.4
Placental infarction	2.5	1.2–5.3
Chorioamnionitis		
Clinical	2.4	1.5–3.8
Histological	1.8	1.2–2.9
Others[a]	—	—

[a]Includes respiratory distress syndrome, meconium aspiration, emergent cesarean or operative vaginal delivery, hypoglycemia, gestational hypertension, hypotension, advanced maternal age, genetic factors, twins, thrombotic states, nighttime delivery, seizures, fetal-growth restriction, male gender, and nulliparity.

CI = confidence interval.

From Ahlin, 2013; Blair, 2011; McIntyre, 2013; Moster, 2008; Nelson, 2015; O'Callaghan, 2011; Shatrov, 2010; Takenouchi, 2012; Torfs, 1990; Villamor, 2017; Wu, 2012.

Apart from these causes, intrapartum hypoxemia was linked to only a minority of cerebral palsy cases by the National Collaborative Perinatal Project. However, because the study was carried out in the 1960s, there were inconsistent criteria to accurately assign cause. The contribution of HIE to subsequent neurological disorders is discussed in detail in Neonatal Encephalopathy. The 2003 Task Force applied these criteria to more contemporaneous outcomes and determined that only 1.6 cases of cerebral palsy per 10,000 deliveries are attributable solely to intrapartum hypoxia. This finding is supported by a study from Western Australia that spanned from 1975 to 1980 (Stanley, 1991). Other studies concluded that very few cases were due to intrapartum events and therefore preventable (Phelan, 1996; Strijbis, 2006).

Intrapartum Fetal Heart Rate Monitoring

Despite persistent attempts to validate continuous intrapartum electronic fetal monitoring as effective to prevent adverse perinatal outcomes,

evidence does not support its ability to predict or reduce cerebral palsy risk (Clark, 2003; Thacker, 1995). Importantly, no specific fetal heart rate patterns predict cerebral palsy. Further, no relationship has been found between the clinician's response to abnormal patterns and neurological outcome. And, efforts using assisted computer analysis of fetal heart tracings have not enhanced predictability (Alfirevic, 2017; INFANT Collaborative Group, 2017). Indeed, an abnormal heart rate pattern in fetuses that ultimately develop cerebral palsy may reflect a preexisting neurological abnormality (Phelan, 1994). Because of these studies, the American College of Obstetricians and Gynecologists (2017a,d) has concluded that electronic fetal monitoring does not reduce the incidence of long-term neurological impairment. This is discussed further in Chapter 24 (Benefits of Electronic Fetal Heart Rate Monitoring).

Apgar Scores

In general, 1- and 5-minute Apgar scores are poor predictors of long-term neurological impairment (American College of Obstetricians and Gynecologists, 2017e). When the 5-minute Apgar score is ≤3, however, neonatal death or the risk of neurological sequelae rises substantially (Dijxhoorn, 1986; Nelson, 1984). In a Swedish study, 5 percent of such children subsequently required special schooling (Stuart, 2011). In a Norwegian study, the incidence of these low Apgar scores was 0.1 percent in more than 235,000 newborns. Almost a fourth of those with such scores died, and 10 percent of survivors developed cerebral palsy (Moster, 2001).

Persistence past 5 minutes of these extremely low scores correlates strongly with a higher risk for neurological morbidity and death (Grünebaum, 2013). This of course is not absolute, and the 2003 Task Force cited a 10-percent risk for cerebral palsy for infants with 10-minute scores of 0 to 3. For 15-minute scores ≤2, there is a 53-percent mortality rate and a 36-percent cerebral palsy rate. For 20-minute scores ≤2, mortality rate is 60 percent, and a cerebral palsy rate is 57 percent. Some outcomes in the Norwegian Study of infants with these low 5-minute Apgar scores are shown in Table 33-3. Survivors who had Apgar scores of 0 at 10 minutes have even worse outcomes. In a review of 94 such newborns, 78 died, and *all* survivors assessed had long-term disabilities (Harrington, 2007).

TABLE 33-3

Comparison of Mortality and Morbidity in Norwegian Infants Weighing >2500 g According to 5-Minute Apgar Scores

Outcome	Apgar 0–3 (%)	Apgar 7–10 (%)	Relative Risk (95% CI)
Number	292	233, 500	
Mortality rates			
Neonatal	16.5	0.05	386 (270–552)
Infant	19.2	0.3	76 (56–103)
1–8 yr	3	0.2	18 (8–39)
Morbidity rates			
Cerebral palsy	6.8	0.09	81 (48–128)
Mental retardation	1.3	0.1	9 (3–29)
Other neurological	4.2	0.5	9 (5–17)
Non-neurological	3.4	2.0	2 (0.8–5.5)

CI = confidence interval.

Data from Moster, 2001.

Umbilical Cord Blood Gas Studies

As outlined in Neonatal Encephalopathy, objective evidence for metabolic acidosis—cord arterial blood pH <7.0 and base deficit ≥12 mmol/L—is a risk factor for encephalopathy and for cerebral palsy. The risk accrues as acidosis worsens. From their review of 51 studies, Malin and coworkers (2010) found that low cord arterial pH correlates with greater risk for neonatal encephalopathy and cerebral palsy. When used alone, however, these determinations are not accurate in predicting long-term neurological sequelae (Dijxhoorn, 1986; Yeh, 2012).

Data from several studies corroborate that a pH <7.0 is the threshold for clinically significant acidemia (Gilstrap, 1989; Goldaber, 1991). The likelihood of neonatal death grows as the cord artery pH falls to 7.0 or less. Casey and colleagues (2001) reported that when the pH was ≤6.8, the neonatal mortality rate rose 1400-fold. When the cord pH was ≤7.0 *and* the 5-minute Apgar score was 0 to 3, the risk of neonatal death was increased 3200-fold.

In the study from Oxford, adverse neurological outcomes were 0.36 percent with pH <7.1 and 3 percent with pH <7.0 (Yeh, 2012). As mentioned, newborn complication rates rise coincident with increasing severity of acidemia at birth. In a Swedish study, researchers observed that cord blood lactate levels may prove to be superior to base deficit for prognostication of neurological disorders (Wiberg, 2010).

Nucleated Red Blood Cells and Lymphocytes

Both immature red cells and lymphocytes enter the circulation of term newborns in response to hypoxia or hemorrhage. During the past two decades, quantification of these cells has been proposed as a measure of hypoxia, but most studies do not support this premise (Boskabadi, 2017; Silva, 2006; Walsh, 2011, 2013).

Neuroimaging Studies in Encephalopathy and Cerebral Palsy

Various neuroimaging techniques have provided important insight into the etiology and evolution of perinatal HIE and later cerebral palsy (Neonatal Encephalopathy). Importantly, findings are highly dependent on fetal age. The preterm neonatal brain responds quite differently to an ischemic episode compared with that of a term newborn. Other factors include insult severity and duration as well as restoration of cerebrovascular hypoperfusion. *Thus, precise timing of an injury with neuroimaging studies is not a realistic goal.* Moreover, the grade of neonatal encephalopathy, that is, mild, moderate, or severe, does not correlate with MR imaging findings (Walsh, 2017).

Neuroimaging in Neonatal Period

Regarding early use, the 2014 Task Force concluded that these imaging techniques provide the following information:

1. Sonographic studies are generally normal on the day of birth. With injury, increasing echogenicity in the thalami and basal ganglia is seen beginning at approximately 24 hours. This progresses over 2 to 3 days and persists for 5 to 7 days.

2. Computed tomography scans are usually normal the first day in term infants. With injury, decreased density in the thalami or basal ganglia is seen beginning at about 24 hours and persists for 5 to 7 days.

3. Magnetic resonance imaging will detect some abnormalities on the first day. Within 24 hours, MR imaging may show restricted water diffusion that peaks at approximately 5 days and disappears within 2 weeks. Acquisitions with T1- and T2-weighted images show variable abnormalities, which have an onset from less than 24 hours to several days. In a study of 175 term neonates with acute encephalopathy, it was reported that MR imaging showing basal ganglia lesions accurately predicted motor impairment at 2 years of age (Martinez-Biarge, 2012).

The 2014 Task Force concluded that for term newborns, imaging studies are helpful in timing an injury, but they provide only a window in time that is imprecise. In one study, the optimal range was 3 to 10 days (Lee, 2017).

Neuroimaging in Older Children with Cerebral Palsy

Imaging studies performed in children diagnosed with cerebral palsy frequently show abnormal findings. Wu and associates (2006) used CT or MR imaging to study 273 children who were born after 36 weeks' gestation and who were diagnosed later in childhood with cerebral palsy. Although a third of these studies were normal, focal arterial infarction was seen in 22 percent; brain malformations in 14 percent; and periventricular white-matter injuries in 12 percent. In another study of 351 children with cerebral palsy—approximately half were born near term—MR imaging findings were abnormal in 88 percent (Bax, 2006). Similar findings were reported in an Australian study (Robinson, 2008).

CT and MR imaging techniques have also been used in older children to help define the timing of fetal or perinatal cerebral injury. Wiklund and coworkers (1991a,b) studied 83 children between ages 5 and 16 years who were born at term and who developed hemiplegic cerebral palsy. Nearly 75 percent had abnormal CT findings, and these investigators concluded that more than half had CT changes that suggested a *prenatal injury.* Approximately 20 percent were attributed to a *perinatal injury.* In a similar study, Robinson and associates (2008) used MR imaging. They reported pathological findings in 84 percent of children with spastic quadriplegia. Remember, this is the neurological lesion that the 2014 Task Force concluded correlated with neonatal encephalopathy.

Intellectual Disability and Seizure Disorders

The term *intellectual disability* describes a spectrum of disabilities and seizure disorders that frequently accompany cerebral palsy. But, when either of these manifests alone, they are seldom caused by perinatal hypoxia (Nelson, 1984, 1986a,b). Severe mental disability has a prevalence of 3 per 1000 children, and its most frequent causes are chromosomal, gene mutation, and other congenital malformations. Finally, preterm birth is a common association for these (Moster, 2008).

The major predictors of seizure disorders are fetal malformations—cerebral and noncerebral; family history of seizures; and neonatal seizures (Nelson, 1986b). Neonatal encephalopathy causes a small proportion of seizure disorders. Reports from the Neonatal Research Network and other studies concluded that increasing severity of encephalopathy correlates best with seizures (Glass, 2011; Kwon, 2011).

Autism Spectrum Disorders

According to the Centers for Disease Control and Prevention, the frequency of autism spectrum disorders is 14.6 per 1000 in 8-year-old children (Christensen, 2016). Although these may be associated with maternal metabolic conditions, none has been linked convincingly to peripartum events (Krakowiak, 2012).

NEONATAL ABSTINENCE SYNDROME

This is a drug-withdrawal syndrome that most commonly follows in utero exposure to maternal opioids. It also may complicate exposure to ethanol or benzodiazepines. The syndrome is characterized by hypertonia, autonomic instability, irritability, poor sucking reflex, and seizures (Finnegan, 1975). The incidence of abstinence syndrome has risen six- to sevenfold during the past decade, coincidental with the growing opioid use described in Chapter 1 (Family Planning Services). For example, Tolia and colleagues (2015) reported that 4 percent of all neonatal intensive care unit (NICU) days in 2013 were attributed to care of these affected newborns.

Affected neonates undergo close observation, and pharmacotherapy is usually given. In addition to morphine and methadone, other treatment may include phenobarbital, benzodiazepines, and clonidine (Tolia, 2015). More recently, buprenorphine compared with morphine was reported to result in shorter lengths of stay (Kraft, 2017). Consensus is lacking regarding the most effective regimen. The American College of Obstetricians and Gynecologists and the American Society of Addiction Medicine (2017f) have taken the lead in screening, intervention, and treatment of opioid use disorders in pregnant women (Chap. 12, Cocaine).

HEMATOLOGICAL DISORDERS

There are a few neonatal disorders of erythrocytes, platelets, and coagulation with which the obstetrician should be familiar. As is the case for most other conditions manifest by the newborn shortly after birth, many of these hematological problems were manifest by the fetus and persist in the newborn.

Anemia

After 35 weeks' gestation, the mean cord hemoglobin concentration approximates 17 g/dL, and values below 14 g/dL are considered abnormal. The American College of Obstetricians and Gynecologists (2017b) now recommends a 30- to 60-second delay in cord clamping in all healthy newborns. A review of nearly 4000 deliveries found that this delayed cord clamping was associated with a mean neonatal hemoglobin rise of 1.5 g/dL (McDonald, 2013). At the same time, this practice almost doubled the incidence of hyperbilirubinemia requiring phototherapy.

Fetal anemia results from many causes (Colombatti, 2016; Yaish, 2017). Many of these are discussed in more detail in Chapter 15 (Fetal Anemia). Acute anemia with hypovolemia is seen with deliveries in which the placenta is cut or torn, if a fetal vessel is perforated or lacerated, if there is recent fetal-maternal hemorrhage, or if the newborn is held well above the level of the placenta for some time before cord clamping. Intracranial or extracranial injury or trauma to fetal intraabdominal organs can also cause hemorrhage with acute anemia (Akin, 2011; McAdams, 2017).

Polycythemia and Hyperviscosity

Neonatal polycythemia with hyperviscosity can be associated with chronic hypoxia in utero, twin-twin transfusion syndrome, placental- and fetal-growth restriction, fetal macrosomia from maternal diabetes, and transfusion at delivery. When the hematocrit rises above 65, blood viscosity markedly increases and may cause neonatal plethora, cyanosis, or neurological aberrations. Because of the shorter life span of macrocytic fetal erythrocytes, hyperbilirubinemia commonly accompanies polycythemia. Other findings include thrombocytopenia, fragmented erythrocytes, and hypoglycemia. Cui and associates (2017) reported a case of unilateral macular hemorrhage in a newborn with polycythemia and platelets of 1 million/μL. Partial exchange transfusion may be necessary in some neonates.

Hyperbilirubinemia

Even in term fetuses, hepatic maturation is not complete, and thus some unconjugated bilirubin—either albumin bound or free—is cleared by placental transfer to be conjugated in the maternal liver (Chap. 7, Urinary System). Fetal protection from unconjugated bilirubin is lost after delivery if not cleared rapidly. Because clearance is totally dependent on neonatal hepatic function, varying degrees of neonatal hyperbilirubinemia result. Even

in the mature newborn, serum bilirubin levels usually rise for 3 to 4 days to reach up to 10 mg/dL. After this, concentrations usually fall rapidly. In one large study, 1 to 2 percent of neonates delivered at 35 weeks' gestation or later had a maximum serum bilirubin level >20 mg/dL (Eggert, 2006). Concomitant glucose-6-phosphate deficiency worsens hyperbilirubinemia (Chang, 2017). In approximately 15 percent of term newborns, bilirubin levels cause clinically visible skin yellowing termed *physiological jaundice* (Burke, 2009). As expected, in preterm neonates, the bilirubin elevation is greater and more prolonged.

Acute Bilirubin Encephalopathy and Kernicterus

Excessive serum bilirubin levels can be neurotoxic for newborns (Dijk, 2012; Watchko, 2013). The pathogenesis is complex, and toxicity has two forms. *Acute bilirubin encephalopathy* is encountered in the first days of life and is characterized by hypotonia, poor feeding, lethargy, and abnormal auditory-evoked responses (Kaplan, 2011). Immediate recognition and treatment will usually mitigate progressive neurotoxicity. The chronic form is termed *kernicterus*. With this, neurotoxicity follows bilirubin deposition and staining of the basal ganglia and hippocampus and is further characterized by profound neuronal degeneration. Survivors have spasticity, muscular incoordination, and varying degrees of mental deficiencies (Frank, 2017). Although there is a positive correlation between kernicterus and unconjugated bilirubin levels above 18 to 20 mg/dL, it can develop at much lower concentrations, especially in very preterm neonates (Sgro, 2011). Continuing hemolysis is a risk factor for kernicterus (El Houchi, 2017; Vandborg, 2012).

Prevention and Treatment

Various forms of phototherapy are used to prevent and treat neonatal hyperbilirubinemia (Ree, 2017). These "bili-lights" emit a spectrum of 460 to 490 nm, which augments bilirubin oxidation to enhance its renal clearance and lower serum levels. Sunlight filtered to remove ultraviolet light has been used in resource-poor countries (Slusher, 2015). Light that penetrates the skin also increases peripheral blood flow, which further enhances photo-oxidation. It is problematic that available devices are not standardized (Bhutani, 2011). Another advantage is that exchange transfusions are seldom required with phototherapy. Studies in both preterm and term newborns attest to phototherapy efficacy (Watchko, 2013). A Neonatal Research Network study reported that aggressive phototherapy in low-birthweight neonates reduced rates of neurodevelopmental impairment (Newman, 2006). Similar reductions were reported from Canada after implementation of 2007 guidelines (Sgro, 2016).

For term newborns, the American Academy of Pediatrics and the American College of Obstetricians and Gynecologists (2017) stress early detection and prompt phototherapy to prevent bilirubin encephalopathy. Despite these measures, bilirubin encephalopathy persists, and this is somewhat related to early hospital discharges (Gazzin, 2011; Kaplan, 2011; Sgro, 2011). According to Burke and coworkers (2009), hospitalizations for kernicterus in term newborns were 5.1 per 100,000 in 1988. Since then, however, this rate has dropped to 0.4 to 2.7 cases per 100,000 births (Watchko, 2013). This may be due in part to legislation, discussed in Chapter 36 (Immunizations), to minimize brief postpartum hospital stays.

Hemorrhagic Disease of the Newborn

This disorder is characterized by spontaneous internal or external bleeding beginning any time after birth. Most hemorrhagic disease results from abnormally low levels of the vitamin K-dependent clotting factors—V, VII, IX, X, prothrombin, and proteins C and S (Zipursky, 1999). Newborns whose mothers took anticonvulsant drugs are at higher risk because these suppress maternal hepatic synthesis of some of these factors. Classic hemorrhagic disease is usually apparent 2 to 5 days after birth in neonates not given vitamin K prophylaxis at delivery (Busfield, 2013). Delayed hemorrhage may occur at 2 to 12 weeks in exclusively breastfed infants because breast milk contains little vitamin K. Other causes of neonatal hemorrhage not related to vitamin K include hemophilia, congenital syphilis, sepsis, thrombocytopenia purpura, erythroblastosis, and intracranial hemorrhage.

The American Academy of Pediatrics and the American College of Obstetricians and Gynecologists (2017) recommend routine prophylaxis for hemorrhagic disease with a 0.5- to 1-mg dose of vitamin K_1 (phytonadione) given intramuscularly. Oral administration is not effective, and maternal vitamin K administration results in very little transport to the fetus (Sankar, 2016).

Thrombocytopenia

Abnormally low platelet concentrations in term newborns may be due to various etiologies such as immune disorders, infections, drugs, or inherited platelet defects, or they may be part of a congenital syndrome (American College of Obstetricians and Gynecologists, 2016b). In many, thrombocytopenia is an extension of a fetal disorder such as infection with B19 parvovirus, cytomegalovirus, toxoplasmosis, and others discussed in

Chapters 64 and 65. Neonatal thrombocytopenia has been reported with maternal antiretroviral therapy for human immunodeficiency virus (HIV) infection (Smith, 2016). Term newborns admitted to NICUs, especially those with sepsis, have accelerated platelet consumption (Eissa, 2013).

Immune Thrombocytopenia

In women with an autoimmune disorder such as systemic lupus erythematosus or immunological thrombocytopenia, maternal antiplatelet IgG is transferred to the fetus and can cause accelerated platelet destruction. Most cases are mild, and platelet levels usually reach a nadir at 48 to 72 hours. Maternal corticosteroid therapy generally has no effect on fetal platelets. Fetal blood sampling for platelet determination is seldom necessary, and platelets are usually adequate to prevent fetal hemorrhage during delivery (Chap. 56, Platelet Disorders).

Alloimmune Thrombocytopenia

Alloimmune thrombocytopenia (AIT) or neonatal alloimmune thrombocytopenia (NAIT) is caused by maternal-fetal platelet antigen disparity. If maternal alloimmunization is stimulated, then transplacental antiplatelet IgG antibodies cause severe fetal thrombocytopenia and severe bleeding (Winkelhorst, 2017). This is considered in detail in Chapter 15 (Fetal Thrombocytopenia).

Preeclampsia Syndrome

Maternal platelet function and destruction can be severely affected in women with severe preeclampsia. That said, fetal or neonatal thrombocytopenia is rarely caused by the preeclampsia syndrome even when the mother has severe thrombocytopenia. Findings from the large study of mother-infant pairs delivered at Parkland Hospital dispelled earlier reports of an association of neonatal thrombocytopenia with preeclampsia (Pritchard, 1987). Instead, neonatal thrombocytopenia was found to be associated with preterm delivery and its numerous complications (Chap. 34, Respiratory Distress Syndrome).

INJURIES OF THE NEWBORN

Birth injuries can potentially complicate any delivery. Thus, although some are more likely associated with operative delivery by forceps or vacuum, others are seen with otherwise uncomplicated vaginal or cesarean delivery. In this section, some injuries are discussed in general, but specific injuries are described elsewhere in connection with their associated obstetrical complications.

Incidence

In three population studies that included more than 8 million term newborns, the overall incidence of birth trauma was 20 to 26 per 1000 deliveries (Baskett, 2007; Linder, 2012; Moczygemba, 2010). Data from Nova Scotia show an overall trauma risk of 19.5 per 1000 deliveries (Table 33-4). Only 1.6 cases of major trauma per 1000 were found, and these rates were highest with failed forceps or vacuum delivery and lowest with cesarean delivery without labor. Thus, most traumatic injuries were minor, and these had an incidence of 18 per 1000 deliveries.

TABLE 33-4

Incidence of Major and Minor Birth Trauma—Nova Scotia, 1988–2001

Type of Delivery (Trauma Rate per 1000)		Birth Trauma (Rate per 1000)	
	Number	Major[a]	Minor[b]
Spontaneous (14)	88,324	1.2	13
Assisted			
Vacuum (71)	3175	3.7	67
Forceps (58)	10,478	5.2	53
Failed assisted			
Vacuum (105)	609	8.3	100
Forceps (56)	714	7.0	50
Cesarean (8.6)	16,132	0.3	8.3
Labor (12)	10,731	0.4	11.9
No labor (1.2)	5401	0.2	1.1
All (19.5)	119,432	1.6	18

[a]Major trauma = depressed skull fracture, intracranial hemorrhage, brachial plexopathy, or combination.

[b]Minor trauma = linear skull fracture, other fractures, facial palsy, cephalohematoma, or combination.

Data from Baskett, 2007.

Trauma associated with cesarean delivery from a Maternal-Fetal Medicine Units Network study was described by Alexander and coworkers (2006). There were 400 injuries identified from a total of 37,100 operations—a rate of 11 per 1000 cesarean deliveries. Although skin lacerations predominated—7 per 1000—more serious injuries in these 400 infants included 88 cephalohematomas, 11 clavicular fractures, 11 facial nerve palsies, nine brachial plexopathies, and six skull fractures.

Cranial Injuries

Traumatic head injuries that are associated with labor or delivery can be *external* and obvious, such as a skull or mandibular fracture; they can be *intracranial*; and in some, they are *covert*. The fetal head has considerable plasticity and can undergo appreciable molding. Rarely, severe molding can result in tearing of veins. These may be the bridging cortical veins that empty into the sagittal sinus, the internal cerebral veins, the vein of Galen, or those of the tentorium itself. As a result, intracranial, subdural, and even epidural hemorrhage can be seen after an apparently uneventful vaginal delivery (Scheibl, 2012). Bleeding may also be asymptomatic. Conversely, subgaleal hemorrhages associated with forceps of vacuum delivery can be life threatening (Doumouchtsis, 2008; Swanson, 2012). In rare severe head trauma cases, fetal brain tissue can embolize to the heart or lungs (Cox, 2009).

Intracranial Hemorrhage

Most aspects of neonatal intracranial hemorrhage are related to gestational age. Specifically, most hemorrhage in the preterm neonate results from hypoxia and ischemia. However, in term newborns, trauma is the most frequent cause. Some varieties are shown in Table 33-5. *Importantly, in some newborns, a putative cause is not found.* Intracranial hemorrhage is asymptomatic in many cases. The reported incidence varies, but it is highest with operative deliveries—both vaginal and cesarean deliveries. In the study by Moczygemba and colleagues (2010), for more than 8 million singleton deliveries, the overall intracranial hemorrhage rate approximated 0.2 per 1000 births. In another study, Werner and associates (2011) cited a combined incidence in more than 120,000 nulliparous singleton operative deliveries of 0.12 percent, or about 1 in 750 procedures. The rates of intracranial hemorrhage were 1:385 with vacuum delivery; 1:515 with forceps, and 1:1210 with cesarean delivery. In another study, its incidence was nearly 1 percent following vacuum-assisted deliveries (Simonson, 2007).

TABLE 33-5

Major Types of Neonatal Intracranial Hemorrhage

Type	Etiology and Neuropathogenesis	Clinical Outcomes
Subdural	Trauma—tentorial, falx, or venous (sinus) laceration causing hematoma	Uncommon but potentially serious; symptom onset is variable depending on hematoma expansion, but usually <24 hours: irritability, lethargy, and brainstem compression
Primary subarachnoid	Possibly due to trauma or hypoxia—excludes SAH associated with subdural, intraventricular, intracerebral (AVM, aneurysm), or intracerebellar hemorrhage	Common but almost always benign
Intracerebellar	Trauma and perhaps hypoxia—most cases in preterm infants	Uncommon but serious
Intraventricular	Trauma and hypoxia (no discernible cause in 25 percent)—hemorrhage usually from choroid plexus	Uncommon but serious; symptoms as for subdural hemorrhage
Miscellaneous	Trauma with epidural or intracerebral hemorrhage Hemorrhagic infarction—embolism or thrombosis in artery or vein Coagulopathies—thrombocytopenia or inherited factor deficiencies Vascular defect—aneurysm or AVM	Depends on cause

AVM = arteriovenous malformation; SAH = subarachnoid hemorrhage.

Data from Volpe, 1995.

According to the American College of Obstetricians and Gynecologists (2015), the incidence of intracranial hemorrhage from birth trauma has been substantively lowered by elimination of difficult instrumented vaginal deliveries. This was verified in a report of carefully conducted Kielland forceps deliveries (Burke, 2012).

The prognosis after hemorrhage depends on its location and extent (see Table 33-5). For example, subdural and subarachnoid hemorrhage seldom results in neurological abnormalities, whereas large hematomas are serious. Any bleeding into the parenchyma from intraventricular or intracerebellar hemorrhage often causes serious permanent damage or death. Periventricular hemorrhage rarely causes the type of sequelae that are common in those born preterm (Chap. 34, Retinopathy of Prematurity).

Newborns who have traumatic subdural or infratentorial hemorrhage tears will have neurological abnormalities from the time of birth (Volpe, 1995).

Those most severely affected have stupor or coma, nuchal rigidity, and opisthotonos that worsen over minutes to hours. Some newborns who are born depressed appear to improve until about 12 hours of age, when drowsiness, apathy, feeble cry, pallor, failure to nurse, dyspnea, cyanosis, vomiting, and convulsions become evident.

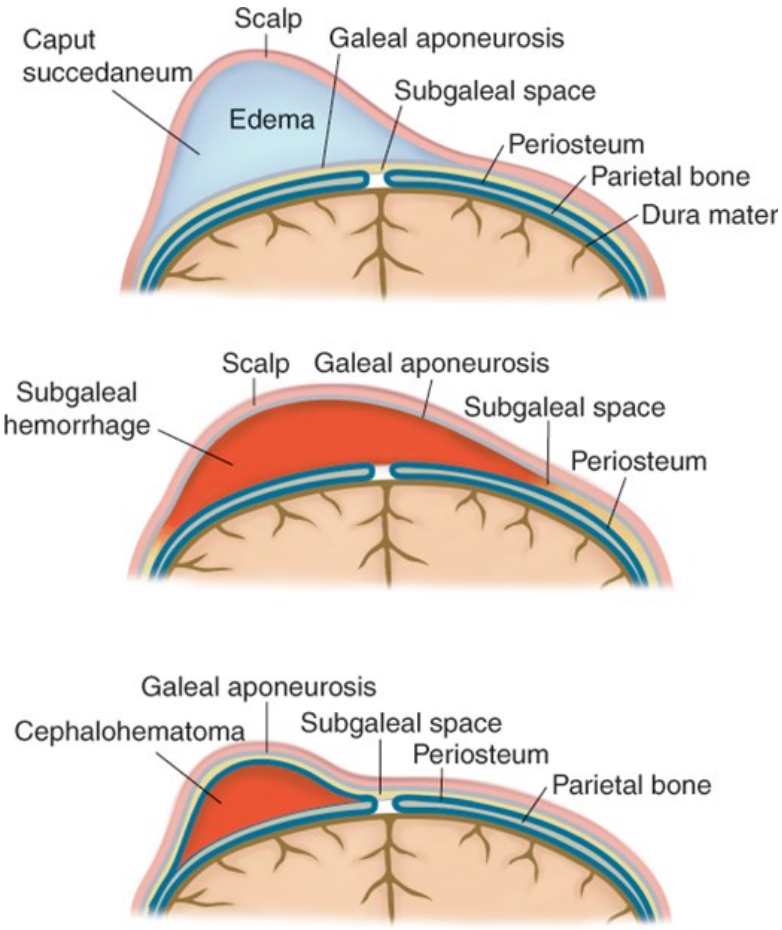
Spontaneous intracranial hemorrhage has also been documented in healthy term neonates (Rutherford, 2012; Shah, 2016). In a prospective MR imaging study, Whitby and coworkers (2004) found that 6 percent of those delivered spontaneously and 28 percent of those delivered by forceps had a subdural hemorrhage. None of these had clinical findings, and hematomas resolved by 4 weeks in all infants.

Extracranial Hematomas

These blood collections accumulate outside the calvarium and are categorized as a *cephalohematoma* or *subgaleal hemorrhage* (Fig. 33-2). From its most superficial surface inward, the scalp is composed of skin, subcutaneous tissue, galea aponeurotica, subgaleal space, and calvarium periosteum. The galea aponeurotica is dense fibrous tissue, whereas the subgaleal space contains loose, fibroareolar tissue. Traversing across the subgaleal space are large, valveless *emissary veins*, which connect the dural sinuses inside the skull with superficial scalp veins. Both the galea aponeurotica and subgaleal space span across the occipital, parietal, and frontal bones. In contrast, periosteum invests each individual skull bone and does not cross suture lines.

FIGURE 33-2

Schematic of extracranial lesions in the neonate that include caput succedaneum, subgaleal hemorrhage, and cephalohematoma.



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

Cephalohematomas are cranial subperiosteal hematomas. These develop from shearing forces during labor and delivery that lacerate the emissary or diploic veins. Fortunately, the densely adhered periosteum impedes rapid enlargement and limits final hematoma size. Hemorrhage can be over one

or both parietal bones, but palpable edges can be appreciated as the blood reaches the limits of the periosteum. These hematomas must be differentiated from *caput succedaneum*, also shown in Figure 33-2. A cephalohematoma may not be apparent until hours after delivery, when bleeding sufficient to raise the periosteum has occurred. After it is identified, it often grows larger and persists for weeks or even months, and bleeding may be sufficient to cause anemia as discussed in Neonatal Abstinence Syndrome. By contrast, with caput succedaneum, swelling of the scalp is from soft-tissue edema that overlies the periosteum. The caput is maximal at birth, rapidly grows smaller, and usually disappears within hours or a few days. Occasionally it becomes infected, and an abscess may form (Kersten, 2008).

Cephalohematomas are common, and in the study from Nova Scotia shown in Table 33-3, these accounted for 80 percent of traumatic injuries with an incidence of 16 per 1000 (Baskett, 2007). They rarely develop in the absence of birth trauma, and an 11-percent incidence was reported in 913 term newborns delivered by vacuum extraction (Simonson, 2007). In the Network study of cesarean delivery outcomes cited above, the incidence of cephalohematoma was 2.4 per 1000 operations (Alexander, 2006). Others have reported lower incidences, although cephalohematoma is more common with vacuum compared with forceps deliveries—0.8 versus 2.7 per 1000 operative deliveries (Werner, 2011).

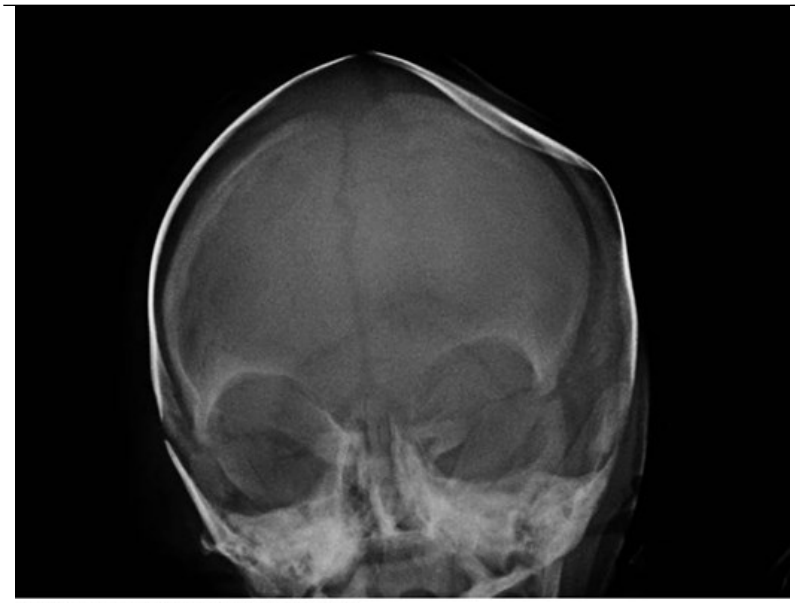
Subgaleal hemorrhage results from laceration of one of the emissary veins, with bleeding between the galea aponeurotica and the skull periosteum (Shah, 2016). Although most common with operative deliveries, cases with spontaneous vaginal delivery have been described (Liu, 2017). Because of its loose areolar tissue and large surface area, significant blood volumes can collect in this potential space and can extend from the neck to the orbits and laterally to the temporal fascia above the ears (Modanlou, 2016). Resulting hypotension can lead to significant morbidity, and cited mortality rates range from 12 to 18 percent (Chang, 2007; Kilani, 2006).

Skull Fractures

These are rare but are especially worrisome because of their association with the serious intracranial hemorrhages. Volpe (1995) considers three types of skull injuries to be fractures—linear and depressed fractures and occipital osteodiastasis. In a French study of nearly 2 million deliveries from 1990 to 2000, the incidence of skull fractures was reported to be 3.7 per 100,000 births, and 75 percent were associated with instrumented vaginal deliveries (Dupuis, 2005). These are occasionally seen with spontaneous or cesarean delivery (Fig. 33-3). These latter fractures are more common when the head is tightly wedged in the pelvis. In such cases, there are at least three possible causes. A fracture may result from skull compression against the sacral promontory, by hand pressure used to lift the head at cesarean delivery, or from transvaginally applied upward hand pressure by an assistant. Fractures are managed with surgical decompression, although spontaneous resolution can follow (Basaldella, 2011).

FIGURE 33-3

Depressed skull fracture evident immediately after cesarean delivery. Labor had progressed, and the head was deep in the pelvis. Dislodgment of the head from the birth canal was performed by an assistant using manual pressure upward through the vagina. (Used with permission from Dr. Kimberly M. Spoonts.)



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

Spinal Cord Injury

Overstretching of the spinal cord and associated hemorrhage and edema are rare. They are usually caused by excessive longitudinal or lateral traction of the spine or by torsion during delivery. In some cases, vertebrae are fractured or dislocated. Menticoglou and associates (1995) described 15 neonates with this type of high cervical spinal cord injury and found that all of the injuries were associated with forceps rotations. Spinal cord injury also can occur during breech delivery. Ross and coworkers (2006) described $C_{5–6}$ vertebral dislocation associated with a Zavanelli maneuver done because of shoulder dystocia (Chap. 27, Shoulder Dystocia Drill).

Peripheral Nerve Injuries

Traumatic injuries to nerves can be serious and distressing, especially if permanent. Injury can involve a single nerve, or it can affect a nerve root, plexus, or trunk (Volpe, 1995).

Brachial Plexopathy

Injuries to the brachial plexus are relatively common. They are identified in 1 to 3 per 1000 term births (Baskett, 2007; Lindqvist, 2012; Wall, 2014). In the study reported by Moczygemba and colleagues (2010), the incidence of brachial nerve injury was 1.5 per 1000 vaginal deliveries and 0.17 per 1000 cesarean deliveries. The incidence among 366,408 neonates born at Parkland Hospital was 3.5 per 1000 births (Wall, 2014). Breech delivery and shoulder dystocia are risks for this trauma. However, severe plexopathy may also occur without risk factors (Torki, 2012).

With plexopathy, the injury damages the nerve roots that supply the brachial plexus—$C_{5–8}$ and T_1. With hemorrhage and edema, axonal function may be temporarily impaired, but the recovery chances are good. However, with avulsion, the prognosis is poor. In 90 percent of cases, damage to the $C_{5–6}$ nerve roots causes *Erb* or *Duchenne paralysis* (Volpe, 1995). Injuries with breech delivery are normally of this type, whereas the more extensive lesions follow difficult cephalic deliveries (Ubachs, 1995). The $C_{5–6}$ roots join to form the upper trunk of the plexus, and injury leads to paralysis of the deltoid, infraspinatus, and flexor muscles of the forearm. The affected arm is held straight and internally rotated, the elbow is extended, and the wrist and fingers flexed. Finger function usually is retained. Because lateral traction on the fetal head is frequently employed to effect delivery of the shoulders in normal vertex presentations, most cases of Erb paralysis follow deliveries that do not appear difficult.

Damage to the C_8-T_1 roots supplying the lower plexus results in *Klumpke paralysis,* in which the hand is flaccid. Total involvement of all brachial plexus nerve roots results in flaccidity of the arm and hand, and with severe damage, there may also be *Horner syndrome*.

Because of its importance, the American College of Obstetricians and Gynecologists (2014a) convened a task force to review extant studies. This Task Force concluded that shoulder dystocia cannot be accurately predicted, but in most cases, axonal death does not occur and the prognosis is good. Lindqvist and associates (2012) reported complete recovery in 86 percent of children with $C_{5–6}$ trauma, which was the most common injury, and in 38 percent of those with $C_{5–7}$ damage. However, those with global $C_{5–8}$–T_1 injuries always had permanent disability. Associated clavicular fracture is somewhat protective (Wall, 2014). Surgical exploration and possible repair may improve function if there is persistent paralysis (Malessy, 2009).

Facial Paralysis

Trauma to the facial nerve commonly occurs as it emerges from the stylomastoid foramen, and this can cause facial paralysis (Fig. 33-4). The incidence, which ranges from 0.2 to 7.5 per 1000 term births, is likely influenced by the vigor with which the diagnosis is sought (Al Tawil, 2010; Moczygemba, 2010). Facial paralysis may be apparent at delivery or may develop shortly after birth. It most frequently is associated with uncomplicated vaginal delivery. However, in one series, a fourth of cases followed cesarean delivery (Alexander, 2006; Al Tawil, 2010). Facial nerve damage is likely more common with low forceps (Levine, 1984). It is possible that damage is caused by pressure exerted by the posterior blade when forceps have been placed obliquely on the fetal head. In these cases, forceps marks indicate the cause of injury. Spontaneous recovery within a few days is the rule, however, permanent paralysis has been described (Al Tawil, 2010).

FIGURE 33-4

Left facial nerve injury. This was almost completely resolved two days after delivery.

Fractures

Most long-bone fractures follow difficult deliveries, however, this is not always the case. At minimum, palpation of the clavicles and long bones is indicated for all newborns after a difficult delivery. Crepitation or unusual irregularity should prompt radiographic examination.

Clavicular fractures are common, unpredictable, and unavoidable complications of normal birth. Their incidence averages 5 to 10 per 1000 live births (Linder, 2012; Moczygemba, 2010). Other than female gender, no specific risk factors—including birthweight and mode of delivery—have been identified. Clavicular fractures protect against brachial plexopathy when there is shoulder dystocia (Wall, 2014).

Humeral fractures are infrequent, and 70 percent follow an uneventful birth (Turpenny, 1993). Others are associated with difficult delivery of the shoulders in cephalic deliveries and of an extended arm in breech deliveries. Radiographically, they are often of the greenstick type, although complete fractures and distal humeral epiphyseal fractures can occur (Tharakan, 2016).

Femoral fractures are rare and usually are associated with vaginal breech delivery. They occasionally follow cesarean delivery, and in one report, they were bilateral (Cebesoy, 2009). Because most breech-presenting fetuses now undergo cesarean delivery, most of these fractures are associated with this mode (Alexander, 2006; Cebesoy, 2009).

Mandibular fractures have been reported, are rare, and have been reviewed by Vasconcelos and coworkers (2009). The rare cases of *cervical vertebral dislocation* in fetuses delivered as breech or after the Zavanelli maneuver were discussed earlier (Ross, 2006). Finally, *rib fractures* are occasionally encountered (Khan, 2016).

Muscle Injuries

Sternocleidomastoid muscle injury in the past was usually seen with vaginal breech delivery. Hematomas of the muscle or the fascial sheath may resolve slowly with cicatricial contraction. With normal neck growth, the less-elastic damaged muscle does not elongate appropriately. As a result, the head is gradually turned toward the side of the injury—*torticollis.*

Soft Tissue Injuries

Conceivably, any fetal organ or part could be injured with either vaginal or cesarean delivery. Some of these include subcapsular hepatic hematomas that presented as inguinal and scrotal hematoma. In such cases, ecchymoses of the inguinal region are termed *Stabler sign,* and those of the scrotum are termed *Bryant sign* (Heyman, 2011; Saroha, 2015). Thymic gland traumatic hemorrhage in those with underlying hyperplasia or cyst has been described before, during, and after delivery (Eifinger, 2007; Saksenberg, 2001). Injuries to the sixth cranial nerve with resultant lateral rectus ocular muscle paralysis have also been reported (Galbraith, 1994).

Congenital Deformity Injuries

Several injuries create morphological defects sustained long before delivery. One is the amnionic band syndrome caused when a free strip of amnion forms a focal ring around an extremity or digit. Eventually, deformation or amputation may result. Occasionally, the amputated part may be found within the uterus. The genesis of such bands is debated and discussed in Chapter 6 (Amniochorion). A similar anomaly is a *limb-reduction defect* associated with chorionic villus sampling performed before 9 weeks' gestation (Chap. 14, Fetal Blood Sampling).

Various congenital postural anomalies form when a normally developed fetal structure becomes deformed by intrauterine mechanical factors. Examples of the latter include chronic oligohydramnios, as well as restricted fetal movement imposed by an abnormally shaped or small uterine cavity or by the presence of additional fetuses. Some mechanical deformations include talipes equinovarus (clubfoot), scoliosis, and hip dislocation (Miller, 1981). Talipes and other positional foot abnormalities are associated with membrane rupture from early amniocentesis between 11 and 13 weeks' gestation (Chap. 14, Chorionic Villus Sampling).

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