CHAPTER 16

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Other Neuromuscular Disorders

Neuromuscular disorders other than cerebral palsy and myelodysplasia are less common; however, patients with these disorders do present in pediatric orthopaedic and neuromuscular clinics. These disorders include the muscular dystrophies and congenital myopathies, spinal muscular atrophy, Friedreich ataxia, hereditary motor sensory neuropathies (HMSN), and poliomyelitis. It is important that an accurate diagnosis be established so that an effective treatment program can be planned and initiated. Delaying the diagnosis of these disorders may lead to inappropriate treatment; furthermore, the mother of an affected child might have further pregnancies and give birth to another child with the genetic disorder (1). Accurate diagnosis requires a careful evaluation of history, physical examination, and appropriate diagnostic studies (2).

HISTORY

The history should include the details of pregnancy, delivery, and growth and development of the child involved. Questions should be asked regarding *in utero* activity, complications of delivery, birth weight, Apgar score, problems during the neonatal period, age at achievement of developmental motor milestones, age at onset of the current symptoms, and information that will clarify whether the condition is static or progressive. Systemic symptoms, such as cardiac disease, cataracts, seizures, or other abnormalities, should also be ascertained.

The family history is important in diagnosis because these disorders, with the exception of poliomyelitis, are genetic in origin. In order to arrive at an accurate diagnosis, family members of the child or adolescent involved may need to be examined for subtle expressions of the same disorder and may also be required to undergo hematologic or other studies.

PHYSICAL EXAMINATION

Most children who present for evaluation of a suspected neuromuscular disorder usually have one or more of the following: a delay in developmental milestones, abnormal gait, foot deformity, or spinal deformity. There is usually a history of progression. Physical examination consists of a thorough musculoskeletal and neurologic evaluation. Observing the child walking and performing simple tasks, such as rising from a sitting position on the floor, can be useful. Observation of the gait may reveal decreased arm swing, circumduction of the legs, scissoring, or short cadence. Standing posture may reveal increased lumbar lordosis or a wide base position for balance. Also, in the standing position, the appearance of the feet should be observed. Pes cavus or cavovarus deformities are common physical findings in many of these disorders. Having the child walk on the heels and toes gives a gross assessment of motor strength, and having the child run may reveal an increase in muscle tone or ataxia. There is an increased incidence of scoliosis in patients with neuromuscular disorders (3, 4).

Inspection of the skin should be performed for evidence of skin rashes or other abnormalities. Typical facies of the patient with spinal muscular atrophy and congenital myotonic dystrophy should become familiar to orthopaedic surgeons. The tongue should be examined to detect evidence of fasciculation suggestive of anterior horn cell diseases. Excessive drooling is common in both cerebral palsy and congenital myotonic dystrophy. In the latter, nasal speech may also be present. A thorough ophthalmologic examination is necessary in order to elicit external ophthalmoplegia or retinitis pigmentosa. In myotonic dystrophy, cataracts may develop during adolescence.

Muscle testing should be carefully performed. Generally, myopathic disorders selectively affect proximal limb muscles before affecting distal muscles. Early in the disease process, the muscles demonstrate proportionally greater weakness than

would be expected from the degree of atrophy. The converse is true in neuropathies.

A careful neurologic evaluation usually completes the musculoskeletal examination. Sensory responses must be checked individually and recorded. Decreased vibratory sensation may be present in HMSNs such as Charcot-Marie-Tooth disease. In spinal muscular atrophy, the deep-tendon reflexes may be absent, but in cerebral palsy, they are increased. A positive Babinski sign confirms upper motor neuron disease. Abnormalities in the Romberg test and rapid alternating movements may indicate cerebellar involvement. Mental function evaluation may be necessary, because organic mental deterioration may be part of some neurologic syndromes. In many cases, the assistance of a pediatric neurologist can be invaluable in performing a careful neurologic and mental evaluation, because minor subtleties may offer clues to diagnosis.

DIAGNOSTIC STUDIES

Appropriate diagnostic studies are imperative for the accurate diagnosis of myopathic and neuropathic disorders (5, 6). These can be divided into hematologic studies, electromyography (EMG) with nerve conduction studies and needle electrode exam, muscle biopsy, and nerve biopsy. Molecular diagnostic studies have become available for many of these disorders, including Duchenne and Becker muscular dystrophies, myotonic dystrophy, the hereditary sensory motor neuropathies, and spinal muscular atrophy.

Hematologic Studies. The measurement of serum creatine phosphokinase (CPK) is the most sensitive test for demonstrating abnormalities of striated muscle function. The level of elevation parallels the rate and amount of muscle necrosis and decreases with time as the muscle is replaced by fat and fibrous tissue. The highest CPK levels are typically seen in the earliest stages of Duchenne or Becker muscular dystrophy, in which increases of 20 to 200 times the normal values may be found (6). The level of elevation of CPK does not correlate with the severity or rate of progression of the disorder. The highest levels are usually found in Duchenne muscular dystrophy. Umbilical cord blood CPK levels should be obtained in all male infants who are suspected of having this disorder (7). Birth trauma may elevate the CPK in umbilical cord blood, but in the healthy child, this elevation disappears promptly, whereas the enzyme level remains elevated in muscular dystrophy. Serum CPK may be mildly or moderately elevated in other dystrophic disorders, such as facioscapulohumeral muscular dystrophy and Emery-Dreifuss muscular dystrophy. It is also mildly elevated in female carriers of Duchenne muscular dystrophy, although they are asymptomatic. In congenital myopathies and peripheral neuropathies, the CPK levels are usually normal or only mildly elevated. In other neuromuscular disorders that do not directly affect striated muscle, the CPK levels are normal. Serum enzymes, such as aldolase and serum glutamic oxaloacetic transaminase (SGOT), are also important in the study of striated muscle function. Aldolase levels correlate well with the CPK levels.

Electromyography. EMG can differentiate between a myopathic and a neuropathic process but is rarely helpful in establishing a definitive diagnosis. Characteristics of neuropathic disorders include the presence of fibrillation potentials, increased insertional activity, and high-amplitude, increased-duration motor unit potentials (6). The fibrillation potential represents denervated individual muscle fibers firing spontaneously.

The EMG in myopathy is characterized by low-voltage, short-duration polyphasic motor unit potentials (6). Myopathies rarely demonstrate EMG changes characteristic of a neuropathy, although in an inflammatory muscle disease with significant muscle breakdown, there may be prominent fibrillations. The use of an experienced electromyographer is imperative in the accurate performance of the test and interpretation of EMG data.

Nerve Conduction Studies. Nerve conduction studies are important in the establishment of the diagnosis of peripheral neuropathy in children. Nerve conduction velocities are normal in children with anterior horn cell diseases, nerve root diseases, and myopathies. The normal value in the child older than 5 years is 45 to 65 m per second. In infants and younger children, the velocity is lower because myelination is incomplete.

Motor conduction velocity may be slowed in HMSN (e.g., Charcot-Marie-Tooth disease) before clinical deficits are present. The nerve conduction studies can help determine whether the neuropathy involves an isolated nerve or is a disseminated process.

Muscle Biopsy. Historically, muscle biopsy has been the most important test in determining the diagnosis of a neuromuscular disorder. More recently, molecular genetic testing has become equally, if not more, important. Muscle biopsy material is usually examined by routine histology, special histochemical stains, and electron microscopy. The criterion for selecting the muscle for biopsy is clinical evidence of muscle weakness. Muscles that are involved but are still functioning are selected in chronic diseases, such as Duchenne muscular dystrophy, because they demonstrate the greatest diagnostic changes. A more severely involved muscle may be chosen in an acute illness because the process has not had sufficient time to progress to extensive destruction. In patients who have proximal lower extremity muscle weakness, biopsy of the vastus lateralis is performed, whereas in those with distal weakness, a biopsy of the gastrocnemius is performed. Biopsy of the deltoid, biceps, or triceps is performed for shoulder girdle or proximal upper extremity weakness.

Muscle biopsies can be performed as an open procedure (8) or by percutaneous needle (9). The biopsies are obtained under general anesthesia, spinal anesthesia, regional nerve block, or a field block surrounding the area of incision. It is important that local anesthetic not be infiltrated into the biopsied muscle, because this may alter the morphology of the muscle. The vastus

lateralis is the most common muscle chosen. A 4-cm incision is made and the underlying fascia is incised longitudinally. The muscle is directly visualized in order to avoid including normal fibrous septae in the specimens. Muscle clamps are used for obtaining three specimens. The clamps are oriented in the direction of the muscle fibers. A 2- to 3-mm piece of muscle is grasped in each end of the clamp. The muscle is cut at the outside edge of each clamp and a cylinder of muscle is excised. The use of a muscle clamp helps keep the muscle at its resting length and minimizes artifact. One specimen is quickly frozen in liquid nitrogen (–160°C) to prevent loss of soluble enzymes. This specimen is used for light microscopy with a variety of special preparations. The other specimens are used for routine histology and electron microscopy. The wound is subsequently closed in layers. Electrocautery may be used during the closure. If it is used before the biopsy, it may inadvertently damage the specimens and alter the morphology.

Nerve Biopsy. Occasionally, biopsy of a peripheral nerve is helpful in demyelinating disorders. Usually, the sural nerve is selected for biopsy because of its distal location and lack of autogenous zone of innervation. The patient notices no sensory change or only a mild sensory diminution after excision of the 3- to 4-cm segment of the nerve. Hurley et al. (8) reported a single incision for combined muscle and sural nerve biopsy. An incision over the posterolateral aspect of the calf allows access to the nerve and either the soleus or the peroneal muscle. This avoids the necessity for making two incisions. This technique was demonstrated to be useful in disorders in which both a muscle and a nerve biopsy may be necessary for arriving at a diagnosis.

Other Studies. Other studies that may be helpful in establishing the diagnosis of a neuromuscular disorder include electrocardiogram (ECG), pulmonary function studies, magnetic resonance imaging (MRI), ophthalmologic evaluation, amniocentesis, and pediatric neurology evaluation.

Duchenne muscular dystrophy, Friedreich ataxia, and myotonic dystrophy demonstrate ECG abnormalities. Duchenne muscular dystrophy is frequently associated with mitral valve prolapse secondary to papillary muscle involvement (10, 11). Arrhythmias under anesthesia have been reported with both Duchenne and Emery-Dreifuss muscular dystrophies (12, 13).

Pulmonary function studies demonstrate involvement of respiratory muscles, but they do not establish the diagnosis. If respiratory muscle involvement is present, the rate of deterioration can be followed up with periodic studies. This is important if surgery is contemplated in children or adolescents with muscular dystrophy, spinal muscular atrophy, or Friedreich ataxia. The forced vital capacity (FVC) is the most important study after arterial blood gas measurements (14).

MRI has been demonstrated to distinguish muscles affected by neuropathic disorders from those affected by myopathic disorders (15). Imaging estimates of the disease severity by degree of muscle involvement correlate well with clinical staging. MRI may also be important in selecting appropriate muscles for biopsy.

Ophthalmologic evaluation may demonstrate subtle or more obvious ocular changes associated with specific disorders.

GENETIC AND MOLECULAR BIOLOGY STUDIES

Genetic research through molecular biologic techniques has tremendously enhanced our understanding of the genetic aspects of many of these disorders (16, 17). The determination of the exact location of chromosomal and gene defects has led to the possibility of genetic engineering being used to correct these disorders. Unfortunately, genetic testing is quite costly, and for many disorders, such testing is not commercially available. Also, a negative test does not necessarily exclude certain disorders. For this reason, the decision to carry out genetic testing should be made only by a neuromuscular specialist or geneticist. In each of the various disorders, the current status of genetic and molecular biology research is discussed in this chapter.

MUSCULAR DYSTROPHIES

The muscular dystrophies are a group of noninflammatory inherited disorders with a progressive degeneration and weakness of skeletal muscle that has no apparent cause in the peripheral or the central nervous system (CNS). These have been categorized according to clinical distribution, severity of muscle weakness, and pattern of genetic inheritance (Table 16-1). An accurate diagnosis is important, both for prognosis and management of the individual patient and for identification of genetic factors that may be crucial in planning for subsequent children by the family involved.

SEX-LINKED MUSCULAR DYSTROPHIES

Duchenne Muscular Dystrophy. Duchenne muscular dystrophy is the most common form of muscular dystrophy (18).

TABLE 16-1 Classification of Muscular Dystrophies

Sex-linked muscular dystrophy
Duchenne
Becker
Emery-Dreifuss
Autosomal recessive muscular dystrophy
Limb-girdle
Infantile facioscapulohumeral
Autosomal dominant muscular dystrophy
Facioscapulohumeral
Distal
Ocular
Oculopharyngeal

Transmission is by an X-linked recessive trait. A single gene defect is found in the short arm of the X chromosome. The disease is characterized by its occurrence exclusively in the male sex, except for rare cases associated with Turner syndrome. In this rare event, the XO karyotype who carries the defective gene may demonstrate the phenotype found in male patients with the disorder (6). This disorder is associated with a high mutation rate, and a positive family history is present in approximately 65% of the cases. Duchenne muscular dystrophy occurs in approximately 1 in 3500 live male births, with about one-third of the children involved having acquired the disease because of a new mutation.

Becker muscular dystrophy is a similar, but less common and less severe form of muscular dystrophy. It occurs in approximately 1 in 30,000 live male births, becomes apparent later in childhood, and has a more protracted and variable course than Duchenne muscular dystrophy. This disorder is discussed later but is mentioned here because of the similar inheritance pattern and molecular biology abnormality.

Clinical Features. Duchenne muscular dystrophy is generally clinically evident when the child is at an age of between 3 and 6 years. Earlier onset may also occur. The family may have observed that the child's ability to achieve independent ambulation was delayed or that he has become a toe walker. Children at the age of 3 years or older may demonstrate frequent episodes of tripping and falling, in addition to difficulty in activities requiring reciprocal motion, such as running or climbing stairs. Inability to hop and jump normally is commonly present.

In Duchenne muscular dystrophy, there is progressive weakness in the proximal muscle groups that descend symmetrically in both lower extremities, particularly the gluteus maximus, gluteus medius, quadriceps, and tibialis anterior muscles. The abdominal muscles are involved. Involvement of the shoulder girdle muscles (i.e., trapezius, deltoid, and pectoralis major muscles) and lower facial muscles occurs later. Pseudohypertrophy of the calf muscles caused by the accumulation of fat is common but not invariably present. Most patients have cardiac involvement, most commonly a sinus tachycardia and right ventricular hypertrophy. Life-threatening dysrhythmia or heart failure ultimately develops in approximately 10% of patients. Many also have a static encephalopathy, with mild or moderate mental retardation (19). Death from pulmonary failure and occasionally from cardiac failure occurs during the second or third decades of life.

During gait the child's cadence is slow, and he or she develops compensatory changes in gait and stance as weakness progresses. Sutherland et al. (20, 21) documented disease progression by measuring the gait variables of cadence, swing phase, ankle dorsiflexion, and anterior pelvic tilt. The hip extensors, primarily the gluteus maximus, are the first muscle group to be involved. Initially, the patient compensates by carrying the head and shoulders behind the pelvis, maintaining the weight line posterior to the hip joint and center of gravity (Fig. 16-1). This produces an anterior pelvic tilt and increases

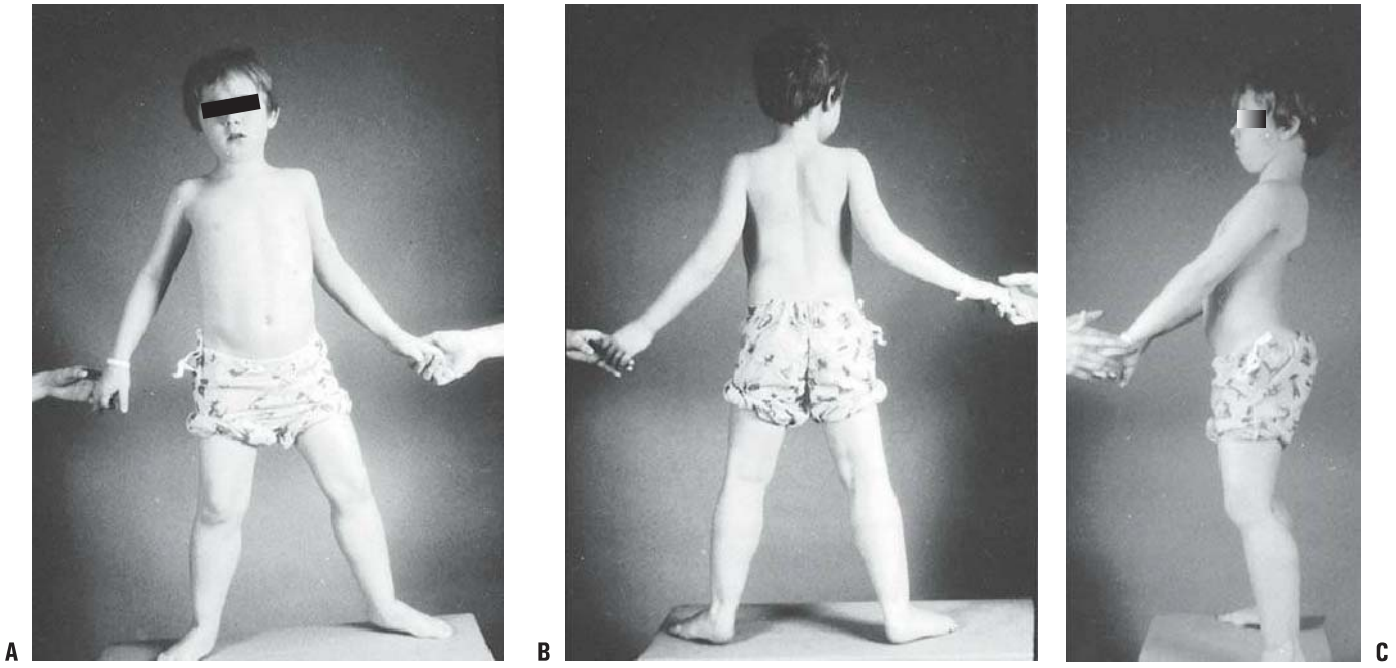


FIGURE 16-1. **A:** A 7-year-old boy with Duchenne muscular dystrophy demonstrates precarious stance due to mild hip abduction contractures. Observe the pseudohypertrophy of the calves. **B:** Posterior view demonstrates mild ankle equinus in addition to the calf pseudohypertrophy. **C:** Side view shows an anterior tilt to the pelvis and increased lumbar lordosis, and the head and the shoulders are aligned posterior to the pelvis. This characteristic posture maintains the weight line posterior to the pelvis and center of gravity, compensates for the muscle weakness, and helps maintain balance.

lumbar lordosis. Cadence and swing-phase ankle dorsiflexion decrease, and the patient develops a waddling, wide-based gait with shoulder sway to compensate for gluteus medius weakness. Muscle weakness requires that the force line remains behind the hip joint and in front of the knee joint throughout single limb support (20–22), and hip abductors and quadriceps muscles force the patient to circumduct during the swing phase of gait while at the same time shifting the weight directly over the hip joint. The generalized pelvic weakness requires considerable forward motion to be generated by the spine for the patient to advance. Ankle plantar flexion becomes fixed, and the stance phase is reduced to the forefoot, resulting in even more difficulty with balance and cadence. Foot inversion develops as peroneal strength diminishes. The tibialis posterior muscle, which is one of the last muscles to be involved, is responsible for the inversion or varus deformity of the foot.

Weakness in the shoulder girdle, which occurs 3 to 5 years later, precludes the use of crutches to aid in ambulation. It also makes it difficult to lift the patient from under the arms. This tendency for the child to slip a truncal grasp has been termed *Meyeron sign*. As the weakness in the upper extremities increases, the child becomes unable to move his or her arms. Although the hands retain strength longer than the arms, use of the hands is limited because of weakness of the arms.

Clinical diagnosis of Duchenne muscular dystrophy is established by physical examination, including gait and specific muscle weakness, and by the absence of sensory deficits. The upper extremity and knee deep-tendon reflexes are lost early in the disease, whereas the ankle reflexes remain positive until the terminal phase. A valuable clinical sign is the *Gower sign*. The patient is placed prone or in the sitting position on the floor and asked to rise. This is usually difficult, and the patient may require the use of a chair for assistance. The patient is then asked to use his or her hands to grasp the lower legs and force the knees into extension. The patient then walks his or her hands up the lower extremities to compensate for the weakness in the quadriceps and gluteus maximus. This sign may also be found in congenital myopathies and spinal muscular atrophy. The contracture of the iliotibial band can be measured by the *Ober test*. To perform this test, the child is placed on his or her side with both hips flexed. The superior leg is then abducted and extended and allowed to fall into adduction. The degree of abduction contracture can be measured by the number of degrees the leg lacks in coming to the neutral position. Tendo-Achilles contractures also occur. Contracture of the tendo-Achilles and the iliotibial band are the most consistent deformities noted during the physical examination.

Duchenne muscular dystrophy progresses slowly but continuously. A rapid deterioration may be noted after immobilization in bed, even for short periods after respiratory infections or, perhaps, extremity fractures. Every effort should be made to maintain a daily ambulatory program. In the absence of treatment, children are usually unable to ambulate effectively by the age of 10 years (5, 23–25). The chief cause is loss of strength in the hip extensors and ankle dorsiflexors (26). These two factors can be used as a guide to predict when ambulation will cease. With loss of standing ability, the child becomes wheelchair dependent. This results in a loss of the accentuated lumbar lordosis that protected the child from kyphoscoliosis (27). As a consequence, most patients subsequently develop a progressive spinal deformity.

Myocardial deterioration is also a constant finding. ECG changes are present in more than 90% of children with Duchenne muscular dystrophy. The average intelligence quotient of these patients has been shown to be approximately 80 (19).

Hematologic Studies. The serum CPK is markedly elevated in the early stages of Duchenne muscular dystrophy. This may be 200 to 300 times the normal value, but decreases as the disease progresses and muscle mass is reduced. CPK levels are also elevated in female carriers of the disease (two to three times the normal value for women and girls), although not to the same extent as in affected boys. There is an 80% consistency in the results when the CPK test is repeated at three consecutive monthly intervals (28). Aldolase and SGOT levels may also be elevated, but the elevations are not unique to striated muscle disease.

Electromyography. Although EMG will support the diagnosis of a myopathy, if the clinical findings and CPK are both suggestive of a muscular dystrophy, this test is typically not necessary. EMG shows characteristic myopathic changes with reduced amplitude, short duration, and polyphasic motor action potentials (6).

Muscle Biopsy. The muscle biopsy specimen reveals degeneration with subsequent loss of fiber, variation in fiber size, proliferation of connective tissue and, subsequently, of adipose tissue as well (6). Increased cellularity is present, with occasional internal migration of the sarcolemmal nuclei. Histochemical testing reveals loss of clear-cut subdivisions of fiber types, especially with adenosine triphosphatase reaction, and a tendency toward type I fiber predominance. In the past, this was the diagnostic procedure of choice. However, the standard today is to first obtain blood samples for DNA polymerase chain reaction (PCR) testing for dystrophinopathies. If this is positive, there is no need for a muscle biopsy. If PCR testing is negative, then muscle biopsy is indicated for arriving at a definitive diagnosis.

Genetic and Molecular Biology Studies. A single gene defect in the short arm of the X chromosome has been identified as being responsible for both Duchenne and Becker muscular dystrophies (16, 17, 29, 30). The status of genetic and molecular biology in Duchenne muscular dystrophy has been summarized by Shapiro and Specht (6). The gene is located at the Xp21.2 region and spans 2 million base pairs (31, 32). It includes 65 exons (i.e., coding regions) and encodes the 400-kDa protein dystrophin. The large size of the gene correlates with the high rate of spontaneous mutation. Dystrophin is a component of cell membrane cytoskeleton and represents 0.01% of skeletal muscle protein. Its distribution within

skeletal, smooth, and cardiac muscle and within the brain correlates well with the clinical features in Duchenne and Becker muscular dystrophies. A structural role for the dystrophin protein is suggested by studies that demonstrate concentration of the protein in a lattice organization in the cytoplasmic membrane of skeletal muscle fibers (33, 34). Demonstrable mutations, deletions, or duplications of dystrophin are found in 70% to 80% of the affected male patients (31, 32, 35, 36). The reading frame hypothesis distinguishes the mutations that correlate with the more severe Duchenne muscular dystrophy from those that correlate with the less severe Becker muscular dystrophy. Mutations that disrupt the translational reading frame or the promoter (i.e., the specific DNA sequence that signals where RNA synthesis should begin) result in a presumably unstable protein, and this correlates with Duchenne muscular dystrophy. In contrast, mutations that do not disrupt the translational reading frame or the promoter have a lower molecular weight and semifunctional dystrophin. This correlates with the less severe Becker muscular dystrophy (31, 37).

Dystrophin testing (by dystrophin immunoblotting), DNA mutation analysis (by PCR or DNA Southern blot analysis), or both, provide methods of differentiating between Duchenne and Becker muscular dystrophies on the one hand, and other initially similar disorders [such as dermatomyositis, limb-girdle muscular dystrophy (LGMD), Emery-Dreifuss muscular dystrophy, and congenital muscular dystrophy] on the other (36, 38, 39). In the latter disorders, the dystrophin is normal. In patients with Duchenne muscular dystrophy, there is a complete absence of dystrophin, whereas in Becker muscular dystrophy, dystrophin is present, but is altered in size, decreased in amount, or both. Nicholson et al. (40) reported a positive relation between the amount of dystrophin and the age at loss of independent ambulation in 30 patients with Duchenne muscular dystrophy and in 6 patients with Becker muscular dystrophy. The researchers found that even low concentrations of dystrophin in Duchenne muscular dystrophy may have functional significance and may explain the variability of age at which ambulation ceases. The presence of partially functional dystrophin protein is sufficient to minimize the phenotypic expression, leading to the milder disorder of Becker muscular dystrophy (31, 35, 38). The same tests can be used to improve detection of female carriers (36, 39). On the basis of smaller-than-normal dystrophin protein, two atypical forms of Becker muscular dystrophy have been recognized. These are myalgia without weakness in male patients (similar to metabolic myopathy), and cardiomyopathy with little or no weakness in male patients (41).

Research studies are investigating the possibility of dystrophin replacement in diseased muscles. This involves the implantation of myoblasts, or muscle precursor cells, into the muscles of patients with Duchenne muscular dystrophy (42). This has been successful in producing dystrophin in the murine mdx model of Duchenne muscular dystrophy (43). Unfortunately, the results in human male patients have been disappointing (44–48). Perhaps the most promising evolving treatment for Duchenne's is the genetic technique of "exon skipping" or splice modulation, where there is modulation of dystrophin premessenger RNA splicing, enabling functional dystrophin protein to be produced (49).

Medication Treatments. A number of medications have been tried to improve strength and function and prolong time to disability in Duchenne dystrophy. Steroids, such as prednisone and deflazacort, have been shown to preserve or improve strength, prolong ambulation, and slow the progression of scoliosis (50–59). Thus, this has become a mainstay of therapy in many neuromuscular clinics. Unfortunately, the side effects—weight gain, osteoporosis with vertebral fractures, and myopathy—limit their usefulness (37, 52–54, 56, 60). Alternate day therapy, or pulse therapy with steroid treatment on the first 10 days of each month, may limit the side effects, slow deterioration of muscle function and not impact on patient quality of life (61, 62). Although prednisone and deflazacort appear to be equally efficacious, deflazacort appears to cause fewer side effects, especially related to weight gain (63). Creatinine supplementation has been evaluated and demonstrated an increase in handgrip strength and fat-free mass, but no improvement in functional tasks or activities of daily living (64). It did demonstrate a significant improvement in resistance to fatigue (65). Perhaps more promising is treatment with extended release albuterol, which has demonstrated increase in lean body mass, decrease in fat mass, and improved functional measures in short-term treatment of dystrophinopathy patients (66, 67). Azathioprine has also been evaluated in Duchenne muscular dystrophy but has not shown beneficial effects (68). Aminoglycoside therapy with intravenous gentamicin administration has been studied in two trials (69, 70). A decrease in serum CPK levels was demonstrated, but there was no effect on muscle strength.

Gene therapy for muscular dystrophies has proven difficult, primarily because of the size of the viral vectors and also because of the complications of immune reactions that may occur. Therefore, gene therapy is still very much in the early investigational stages. This treatment has been reviewed in detail by Chamberlain (71). Dystrophin delivery to muscle has been attempted with four primary vectors: adenovirus, retroviruses, adeno-associated viruses, and plasmids. Complications of this technology included triggering of a cellular immune response, poor integration of the vector into the host gene, and lack of a sustained response, to name only a few (72). Stem cell therapy may be a promising intervention for the dystrophinopathies. In the mdx mouse, bone marrow transplantation and injection of normal muscle-derived stem cells led to partial restoration of dystrophin expression (73).

Treatment. Orthopaedic problems in children with Duchenne muscular dystrophy include decreasing ambulatory ability, soft-tissue contractures, and spinal deformity (5, 6, 18, 74). The goals of treatment should be to improve or maintain the functional capacity of the affected child or adolescent.

The treatment modalities in Duchenne muscular dystrophy include medical therapy, physical therapy, functional

testing, use of orthoses, fracture management, surgery, use of wheelchair, cardiopulmonary management, and genetic and psychological counseling.

Medical Therapy. Recently, the use of steroids has shown promise in preserving strength, prolonging ambulation, and slowing the progression of scoliosis. However, this therapy is not in wide use because of the attendant complications as described in the earlier text.

Physical Therapy. Physical therapy is directed toward prolongation of functional muscle strength, prevention or correction of contractures by passive stretching, gait training with orthoses and transfer techniques, ongoing assessment of muscle strength and functional capacity, and inputs regarding wheelchair and equipment measurements.

After the diagnosis of Duchenne muscular dystrophy has been established and before muscle strength has deteriorated, a program of maximum-resistance exercises should be commenced, to be performed several times a day. This may help preserve strength and delay the onset of soft-tissue contractures. Physical therapy is more effective in preventing or delaying contractures than in correcting them. Contractures develop in the ambulatory patient because the progression of muscle weakness results in the development of adaptive posturing to maintain lower extremity joint stability. A home exercise program can be effective in minimizing hip and ankle soft-tissue contractures. Exercises should be performed twice a day on a firm surface, and should include stretching of the tensor fascia lata, hamstrings, knee flexors, and ankle plantar flexors. Occasionally, serial casting may be useful in correcting existing deformities before physical therapy. Knee-flexion contractures of <30 degrees may benefit from serial or wedge casting. This enhances the use of knee–ankle–foot orthoses (KAFOs). Unless orthoses are used after casting and in conjunction with physical therapy, these contractures rapidly recur.

Functional Testing. Functional testing predominantly involves periodic muscle testing. Muscle strength is tested by measurement of the active range of motion of a joint against gravity. This type of testing allows assessment of the rate of deterioration as well as the functional capacity of the individual.

Orthoses. Lightweight molded plastic ankle–foot orthoses (AFOs) or KAFOs are used in independently ambulatory patients when gait becomes precarious, when early soft-tissue contractures of the knees and ankle are developing, and after surgical correction of these deformities (75–78). AFOs can also be helpful in improving tendo-Achilles contractures, especially when worn both during the day and at night (79). KAFOs are usually supplemented with a walker because of the excessive weight on the orthoses and the risk of falling. Important prescription components include partial ischial weight-bearing support, posterior thigh cuff, and a spring-loaded, drop-lock knee joint with an ankle joint set at a right angle. Ambulation may be extended for up to 3 years by the combined use of surgery and orthoses. The maintenance of a straight lower extremity also enables the nonwalking patient to stand with support, and thereby assists in transfers.

Spinal orthoses are usually of no value in progressive spinal deformities, but wheelchair-bound patients, especially those with severe cardiopulmonary compromise and severe scoliosis, may benefit from the use of a custom wheelchair, a thoracic suspension orthosis, or a custom-made thoracic–lumbar spinal orthosis (TLSO). A mobile arm-support orthosis attached to the wheelchair may help the patient in performing personal hygiene tasks and self-feeding (80).

Fracture Management. Fractures of the lower extremities occur frequently in children with Duchenne muscular dystrophy. This is due to decreased bone mineral density from disuse osteoporosis, steroid induced osteoporosis, or both (81–84). Fractures can result in a permanent loss of function (81, 83, 84). This occurs predominantly after ambulation has ceased and the child is wheelchair bound. These fractures are best treated by closed reduction and cast immobilization. Occasionally, open reduction and internal fixation may be needed. In children who are still ambulatory, it is important that they be placed on a program of early mobilization to allow weight bearing. This may require the use of an electrically powered circle bed. Once early healing is present, the child can be returned to the KAFO to decrease weight and enhance mobility.

Surgery. Contractures of the lower extremities and progressive weakness impair ambulation. Surgery is indicated when independent ambulation becomes precarious and when contractures are painful or interfere with essential daily activities. The major contractures that are amenable to surgical intervention include equinus and equinovarus contractures of the ankle and foot, knee-flexion contractures, and hip-flexion and abduction contractures. In thin individuals, these contractures may be released by percutaneous techniques (74, 85). For ambulatory patients, orthotic measurements should be obtained before surgery. This allows the orthoses to be applied shortly after surgery to assist in rapid restoration of ambulation. Correction of contractures and the use of orthoses can prolong effective ambulation and assisted standing ability by a period of 1 to 3 years (5, 18, 22, 75–78, 85–90). Hsu and Furumasu (22) reported a mean prolongation of walking of 3.3 years in 24 patients with Duchenne muscular dystrophy ranging in age from 8 to 12 years at the time of surgery. It is usually not possible to restore functional ambulation once the patient has been unable to walk for more than 3 to 6 months (75). Each patient must be individually assessed to determine the functional needs and the best procedures. Common contraindications for correction of lower extremity contractures include obesity, rapidly progressive muscle weakness, or poor motivation (those who prefer to use a wheelchair rather than attempt ambulation) (6).

Foot and Ankle. Equinus contractures occur first, followed by equinovarus contractures. This is because of a combination of tendo-Achilles contracture and muscle imbalance induced by the stronger tibialis posterior muscle. This latter muscle retains

good function despite the progression of muscle weakness in other areas. These equinovarus deformities can be managed by a combination of tendo-Achilles lengthening by means of percutaneous open tenotomy (18, 74, 77, 78, 86, 87) with or without resection, or by Vulpius (5) or open Z-lengthening (89), and tibialis posterior lengthening, tenotomy, or transfer through the interosseous membrane to the dorsum of the foot (5, 6, 18, 25, 74, 76–78, 86, 87, 91–93). Scher and Mubarak have also recommended toe flexor tenotomies (94). Tibialis posterior transfer prevents recurrence of equinovarus deformities and maintains active dorsiflexion of the foot. Some orthopaedists, however, have questioned the necessity of a transfer, because it is a more extensive procedure. They prefer tenotomy, recession, or lengthening (74, 76, 86). Postoperative gait analysis has shown that the transferred tibialis posterior muscle is electrically silent (95). Greene (91) has reported that tibialis posterior myotendinous junction recession in six patients (12 ft) resulted in an increased recurrence rate when compared with transfer in nine patients (18 ft), making the former a less desirable procedure. Percutaneous tendo-Achilles lengthening under local anesthesia is usually reserved for nonambulatory patients, who typically have an equinus deformity and cannot wear shoes. The nonambulatory patient with a moderately severe equinovarus deformity may require open tenotomies of the tendo-Achilles, the tibialis posterior, and long toe flexors. Severe equinovarus contractures have been managed effectively by talectomy. Leitch et al. (96) recently studied 88 Duchenne muscular dystrophy patients and found no difference in the long-term results of those treated surgically and those who did not.

Knee. Knee-flexion contractures coexist with hip-flexion contractures and develop rapidly when the patient is wheelchair bound. These contractures limit proper positioning in bed and may lead to the development of hamstring spasm, causing considerable discomfort when the patient attempts to transfer. A Yount procedure (97) (release of the distal aspect of the tensor fascia lata and iliotibial band) is the most common procedure used in correcting knee-flexion contractures (18, 74, 76–78). Hamstring tenotomies, recession or Vulpius-type lengthening, and formal Z-lengthening may also be necessary. These procedures enhance quadriceps power and function and also relieve symptoms. Postoperatively, KAFOs are necessary in order to prevent recurrence.

Hip. Hip-flexion and -abduction contractures increase lumbar lordosis and interfere with the ability to stand and to lie comfortably supine. Patients with hip-flexion contractures may experience low back pain. Correction of flexion contractures involves release of the tight anterior muscles, including the sartorius, rectus femoris, and tensor fascia femoris (6, 18, 74). Abduction contractures are improved by release of the tensor fasciae lata proximally with use of the Ober procedure (98), modified Soutter release, the Yount procedure distally (97), or by complete resection of the entire iliotibial band.

Chan et al. (99) studied 54 patients with Duchenne muscular dystrophy and found that 15 had unilateral subluxation, 1 had bilateral subluxation, and 3 had a unilateral dislocation. They recommended serial pelvic radiographs in patients with this disorder. They also felt that any pelvic obliquity should be corrected at the time of spinal stabilization.

Upper Extremity. Upper extremity contractures are common in adolescents with Duchenne muscular dystrophy, but usually do not require treatment. These contractures include shoulder adduction, elbow flexion, forearm pronation, wrist flexion, metacarpophalangeal and proximal interphalangeal joint flexion, and others. These usually do not preclude the use of wheelchairs. Muscle weakness is the most devastating aspect of upper extremity involvement. Wagner et al. (100) demonstrated wrist ulnar deviation and flexion contractures in addition to contractures of the extrinsic and intrinsic muscles of the fingers in adolescents with Duchenne muscular dystrophy. These contractures produce boutonniere and swan neck deformities and hyperextension of the distal interphalangeal joints. The treatment of upper extremity contractures involves physical therapy with daily passive range-of-motion exercises. When passive wrist dorsiflexion is limited to neutral, a nighttime extension orthosis may be helpful. Surgery is rarely indicated for these contractures.

Spinal Deformity. Approximately 95% of patients with Duchenne muscular dystrophy develop progressive scoliosis (27, 101–108). This typically begins to occur when ambulation ceases, and it is rapidly progressive. Approximately 25% of older ambulating patients, however, have mild scoliosis (23, 109). Prolongation of ambulation by appropriate soft-tissue releases of the lower extremity contractures, thereby maintaining accentuated lumbar lordosis, can delay the onset of scoliosis (88). The curves are usually thoracolumbar, associated with kyphosis, and lead to pelvic obliquity. Scoliosis cannot be controlled by orthoses or wheelchair seating systems (102, 110–114). Although orthotic management may slow curve progression, it does not slow the systemic manifestations of Duchenne muscular dystrophy (e.g., decreasing pulmonary function and cardiomyopathy). These may complicate spinal surgery at a later time. As the scoliosis progresses, it can result in a loss of sitting balance, produce abnormal pressure, and occasionally cause the patient to become bedridden. Heller et al. (114) reported improved sitting support with an orthosis in 28 patients who either refused surgery or were considered to be inoperable.

Surgical correction of scoliosis both improves sitting balance and minimizes pelvic obliquity (102, 109, 113–116). It is usually recommended that a posterior spinal fusion be performed once the curve is >20 degrees (102, 109, 112–114, 117–119). Fusion extends from the upper thoracic spine (T2 or T4) to L5 or the pelvis. It is important to center the patient's head over the pelvis in both the coronal and sagittal planes. This usually allows complete or almost complete correction of the deformity, maintains sitting balance, improves head control, and allows more independent hand function. Although autogenous bone grafting is used in most patients, there appears to be no difference in fusion rates when allograft

bone is used (120–123). Segmental spinal instrumentation techniques using Luque rod instrumentation are most commonly used (18, 74, 102, 109, 112, 116, 120, 121, 124–129) (Fig. 16-2). Other modern segmental instrumentation systems, can also be used (120, 121, 125, 130). The use of pedicle screws and iliac bolts can improve results (131, 132) (see Fig. 16-2). All of these techniques allow sufficient fixation so that postoperative immobilization is not necessary (Fig. 16-2). Fixation to the pelvis is achieved using the Galveston or other techniques (117, 120, 124–133).

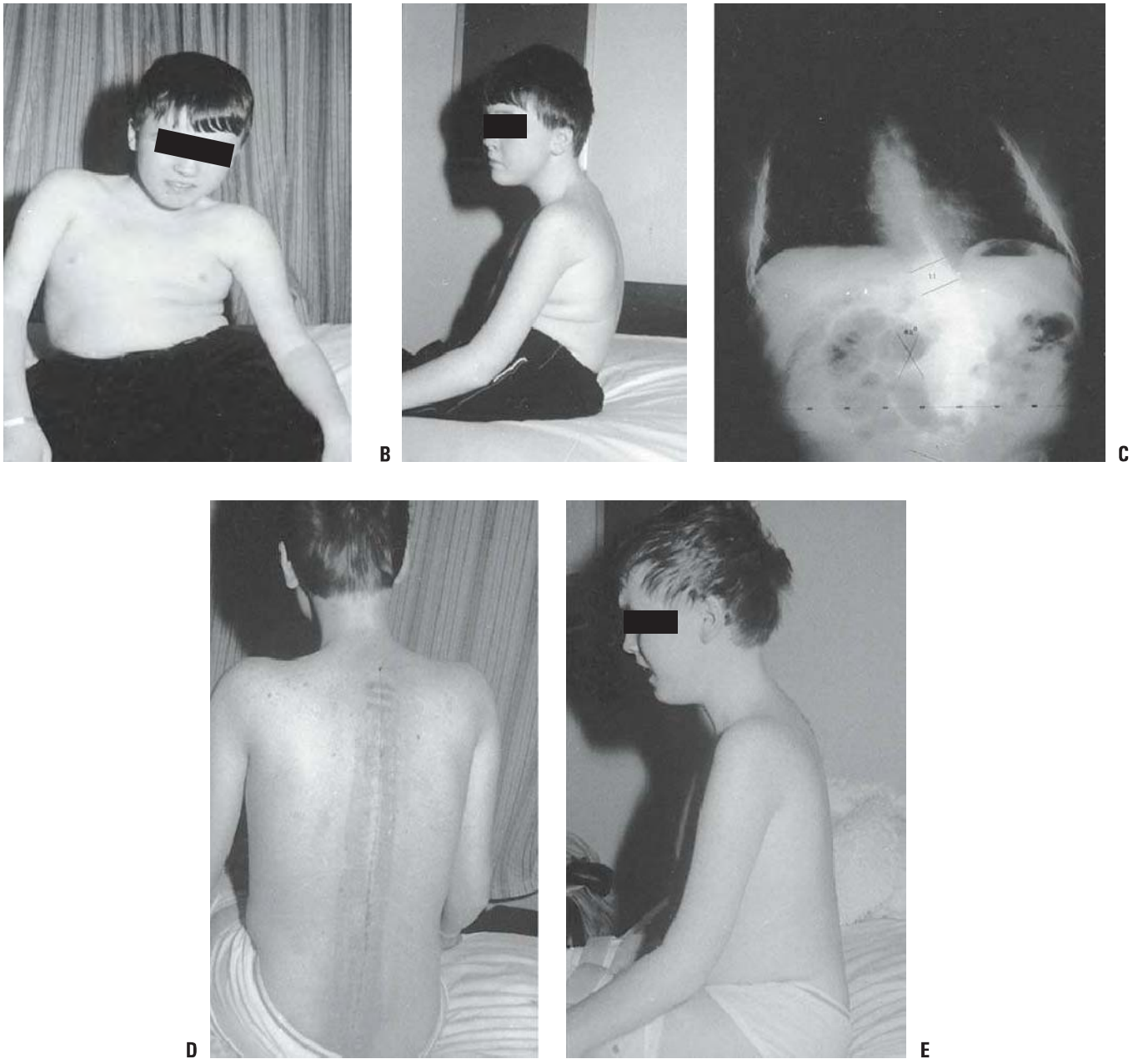
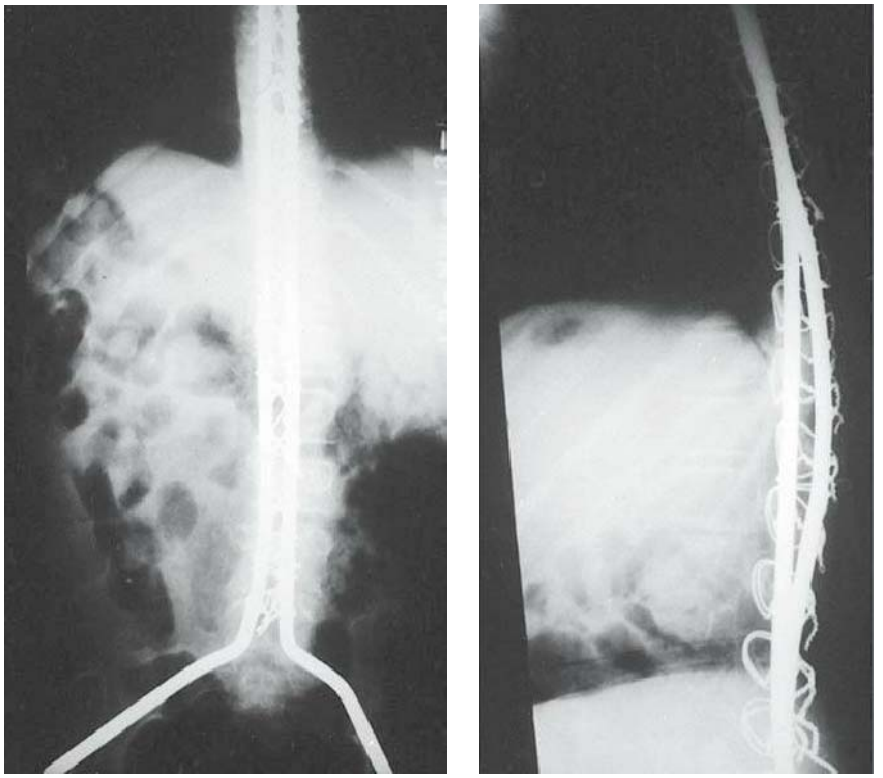


FIGURE 16-2. **A:** An 11-year-old boy with Duchenne muscular dystrophy with a rapidly progressive right thoracolumbar scoliosis and decreasing sitting balance. He uses his hands to maintain sitting balance. **B:** Side view shows an associated mild kyphotic deformity. **C:** Preoperative sitting posteroanterior radiograph demonstrates a long, sweeping, 48-degree thoracolumbar curve between T11 and L5. Six months earlier, no clinical or radiographic deformity was evident. **D:** Postoperatively, an immediate improvement in spinal alignment and sitting balance is noted. **E:** Side view demonstrates correction of the associated kyphosis. **F:** Postoperative sitting radiograph after posterior spinal fusion and Luque rod instrumentation from T4 to the sacrum. The Galveston technique, with insertion of the Luque rod into the wing of the ilium, was used for pelvic fixation. Almost complete correction of his spinal deformity was achieved. **G:** Postoperative lateral radiograph shows improved sagittal alignment.

FIGURE 16-2. *(continued)*



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These techniques are thought to maintain better correction of pelvic obliquity. Some authors believe that fusion to L5 is sufficient, and that there will be no spinopelvic deformity throughout the remainder of the patient's life (122, 134–136). However, a postoperative spinopelvic deformity can occur and progress, and most authors recommend fusion to the pelvis (127, 129, 137). Mubarak et al. (133) recommend fusion to L5 if the curve is >20 degrees, the FVC is >40%, and the patient is using a wheelchair full time, except for occasional standing. If the patient's curve is >40 degrees or if there is pelvic obliquity >10 degrees, then fusion to the sacropelvis is recommended. In severe deformities, vertebral osteotomies may be beneficial to improve postoperative correction (138).

Careful preoperative evaluation, including pulmonary function studies and cardiology consultation, is mandatory because of the associated pulmonary and cardiac abnormalities and the risk of malignant hyperthermia (2, 3, 139–144). Children with Duchenne muscular dystrophy have a decreased FVC, commencing at approximately the age of 10 years, because of weakness of the intercostal muscles and associated contractures. There is a linear decrease over time (14, 103, 106, 119, 139). Kurz et al. (14) observed a 4% decrease in FVC for each year of age or each 10 degrees of scoliosis. It stabilizes at approximately 25% of normal until death. The presence of severe scoliosis may increase the rate of decline in the FVC. Jenkins et al. (137) reported that when the FVC is 30% or less, there is an increased risk of postoperative complication such as pneumonia and respiratory failure. Smith et al. (105) found that most patients with curves of more than 35 degrees had FVC <40% of predicted normal values. They therefore recommend that spinal arthrodesis be considered for all patients with Duchenne muscular dystrophy when they can no longer walk. Nevertheless, successful surgery can be performed in many patients with FVC as low as 20% of predicted normal valves (121). Marsh et al. (139) recently reported similar results in 17 patients with FVC >30% and 13 patients with FVC <30%. They concluded that spinal fusion could be offered to patients in the presence of a low FVC.

It is debatable whether spinal stabilization increases longevity, although it definitely increases the quality of the remaining life (102, 120, 140). In a study of 55 patients with Duchenne muscular dystrophy, of whom 32 underwent spinal fusion and 23 did not, Galasko et al. (102) found that FVC remained stable in the operated group for 36 months postoperatively and then fell slightly. In the nonoperated group, it progressively declined. The survival data showed that a significantly higher mortality rate was seen in the nonoperated group. This study indicated that spinal stabilization can increase survival for several years if it is done early, before significant progression has occurred. Velasco et al. (141) in 2007 showed that posterior spinal fusion in 56 Duchenne muscular dystrophy patients was associated with a significant decrease in the rate of respiratory decline compared with preoperative rates. Other studies, however, have shown that posterior spinal fusion has no effect on the steady decline in pulmonary function when compared with unoperated patients (118, 121, 145–147). In addition to correction and stabilization of the spine, patients experience improved quality of life, as measured by ability to function, self-image, and cosmesis (118, 124, 125, 148). Parents also reported improvement in their ability to provide care to their child.

Complications are common during and following surgery (103, 112–114, 118, 125, 134). These include excessive intraoperative blood loss, neurologic injury, cardiopulmonary compromise, postoperative infection, poor wound healing, curve progression, hardware problems, and late pseudarthrosis. Intraoperative blood loss can be minimized by early surgery and the use of hypotensive anesthesia (121). The increased intraoperative blood loss in patients with Duchenne muscular dystrophy appears to result from inadequate vasoconstriction caused by the lack of dystrophin in the smooth muscle (149). Malignant hyperthermia has been thought to be a potential complication. A recent systematic analysis by Gurnaney et al. (150) on patients with Duchenne muscular dystrophy, Becker muscular dystrophy, and other types of muscular dystrophy did not find an increased risk for malignant hyperthermia compared to the general population. Succinylcholine administration was associated with life-threatening hyperkalemia and should be avoided in those patients; tranexamic acid and epsilon aminocaproic acid (amicar) can be beneficial in decreasing intraoperative and perioperative blood loss (151, 152).

The role of intraoperative spinal cord monitoring in children with Duchenne muscular dystrophy is controversial. Noordeen et al. (149) reported that a 50% decrease in amplitude was suggestive of neurologic impairment.

Wheelchair. A wheelchair is necessary for patients who are no longer capable of independent ambulation. This is typically a motorized wheelchair that allows the patient to be independent of parents or aides, especially while attending school. The wheelchair may be fitted with a balanced mobile arm orthosis for the purpose of facilitating personal hygiene and self-feeding (80).

Cardiopulmonary Management. Respiratory failure in Duchenne muscular dystrophy is a constant threat and is the most common cause of death early in the third decade of life. Kurz et al. (14) found that the vital capacity peaks at the age when standing ceases, then declines rapidly thereafter. The development of scoliosis compounds the problems and leads to further diminution of the vital capacity (146). The complication rate in spinal surgery increases when the FVC is <30% of the normal value. Programs of vigorous respiratory therapy and the use of home negative-pressure and positive-pressure ventilators may allow patients with Duchenne muscular dystrophy to survive into the third and fourth decades of life (153–156).

Cardiac failure may occur in the second decade of life. After initially responding to digitalis and diuretics, the involved cardiac muscle becomes flabby, and the patient goes into congestive heart failure. Myocardial infarction has been reported in boys as young as 10 years. There is no correlation between the severity of pulmonary dysfunction and cardiac function, or between age and cardiac function (157). The cardiomyopathy of Duchenne muscular dystrophy exists clinically as a separate entity.

Genetic and Psychological Counseling. Proper diagnosis and early genetic counseling may help prevent the birth of additional male infants with Duchenne muscular dystrophy. It must be remembered that approximately 20% of families have already conceived and delivered a second affected male infant before the diagnosis is made in the first (78, 158). Genetic counseling with parents and family groups is important in the management of psychological problems arising when the genetic nature of the diagnosis becomes known.

Becker Muscular Dystrophy. Becker muscular dystrophy is similar to Duchenne muscular dystrophy in clinical appearance and distribution of weakness, but it is less severe (159, 160). Onset is generally after the age of 7 years and the rate of progression is slower. The patients usually remain ambulatory until adolescence or the early adult years. The Gower maneuver may occur as the weakness progresses (Fig. 16-3). Pseudohypertrophy of the calf is common, and eventually equinus and cavus foot deformities develop (Fig. 16-4). Cardiac involvement is frequent. There may be a family history of atypical muscular dystrophy. Pulmonary problems are less severe and the patient's life expectancy is greater.

Treatment. The treatment of the musculoskeletal deformities associated with Becker muscular dystrophy is essentially the same as in Duchenne muscular dystrophy. Steroid therapy (prednisone) has recently been shown to decrease serum creatine kinase levels and improve strength (161). Ankle and forefoot equinus occur commonly. Shapiro and Specht (6) have reported good outcome with the Vulpius tendo-Achilles lengthening in patients with equinus contractures. A tibialis posterior tendon transfer is performed if necessary. Forefoot equinus may require a plantar release and possibly a midfoot dorsal-wedge osteotomy for correction. The use of orthotics is also beneficial because the rate of progression is slower and the remaining muscle strength greater than in Duchenne muscular dystrophy. The incidence of scoliosis is high, especially in those adolescents who have ceased walking. These patients require careful evaluation and periodic spinal radiographs. Posterior spinal fusion and segmental instrumentation, usually Luque, are useful for patients in whom there is progression (162).

Emery-Dreifuss Muscular Dystrophy. Emery-Dreifuss muscular dystrophy is an uncommon sex-linked recessive disorder characterized by early contractures and cardiomyopathy (12). The typical phenotype is seen only in the male sex, although milder or partial phenotypes have been reported in female carriers (163–166). Affected boys show mild muscle weakness in the first 10 years of life and a tendency for toe walking. The Gower maneuver may be present in young children. The distinctive clinical criteria occur in late childhood or early adolescence. These include tendo-Achilles contractures, elbow-flexion contractures, neck-extension contracture, tightness of the lumbar paravertebral muscles, and cardiac abnormalities involving brachycardia and first-degree, and eventually complete, heart block (165, 167). The muscle weakness is slowly progressive, but there may be some stabilization in adulthood.

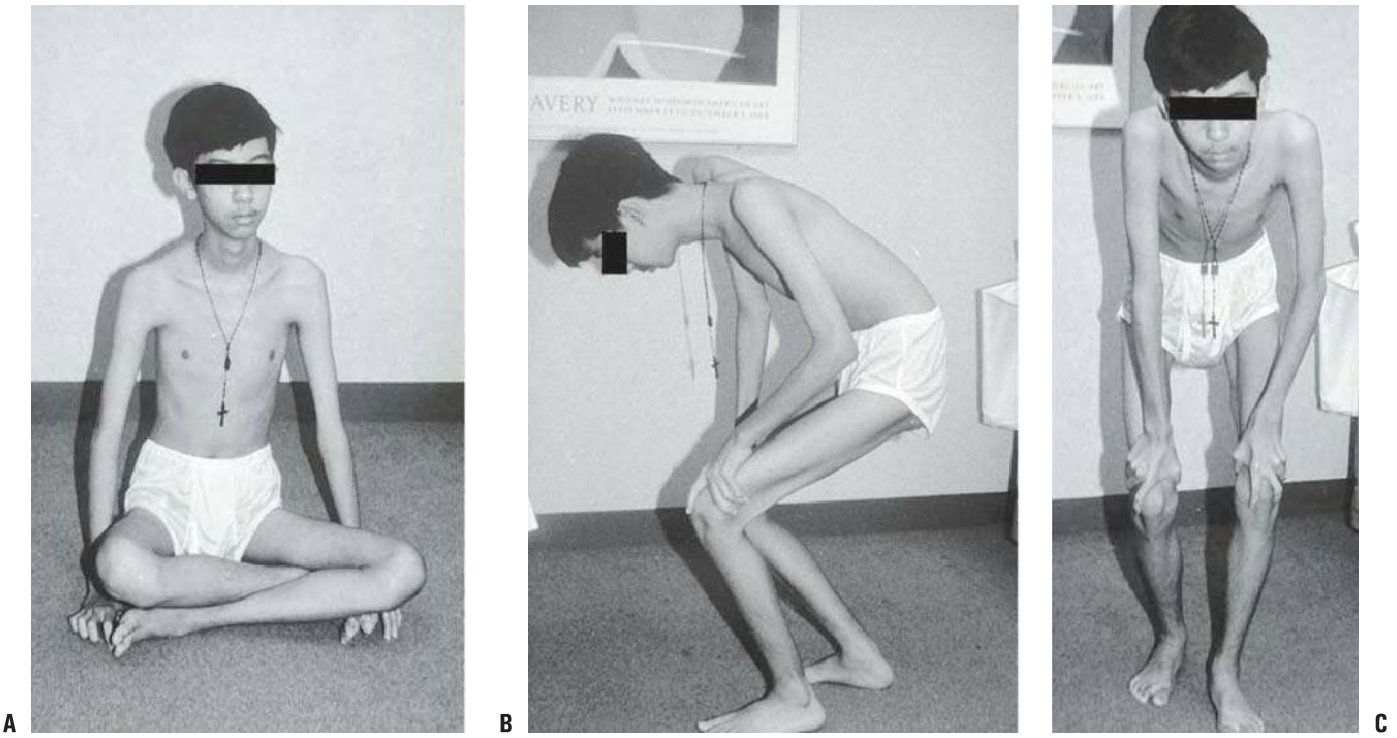

FIGURE 16-3. **A:** A 13-year-old boy with suspected Becker muscular dystrophy uses the Gower maneuver to stand from a sitting position. **B:** Manually assisted knee extension is necessary to achieve upright stance. **C:** Front view.

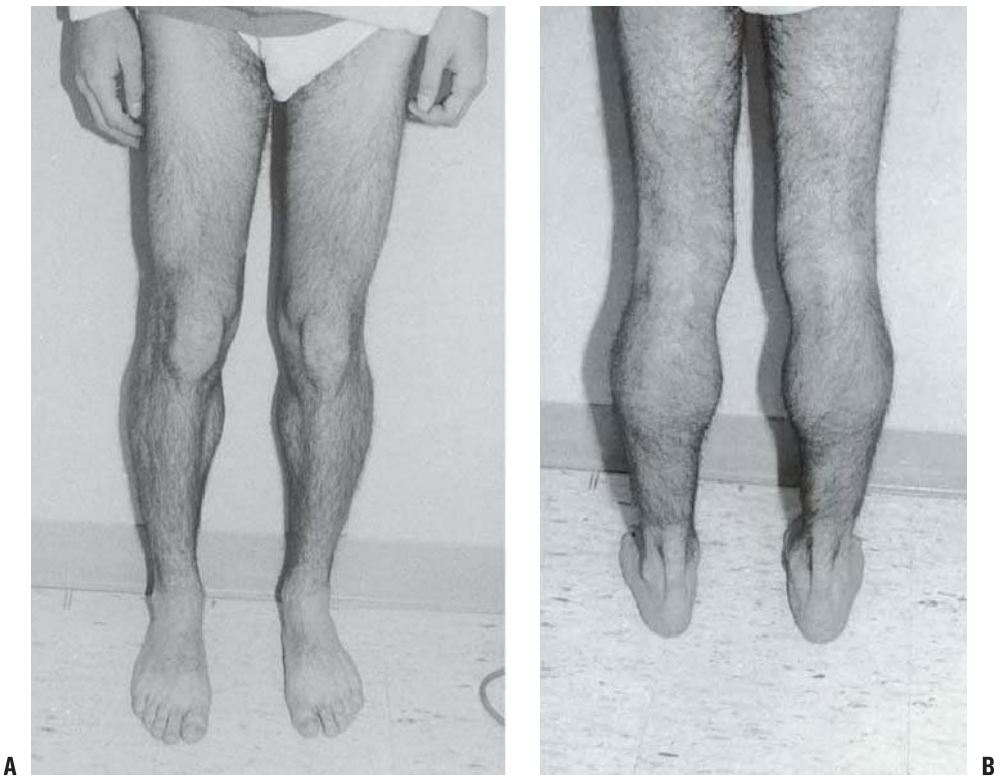

FIGURE 16-4. **A:** Pseudohypertrophy of the calves in an 18-year-old man with Becker muscular dystrophy. He is a brace-free ambulator. **B:** Posterior view.

Most patients are able to ambulate into the fifth and sixth decades of life. Obesity and untreated equinus contractures can lead to the loss of ambulatory ability at an earlier age (6).

The CPK level in patients with Emery-Dreifuss muscular dystrophy is only mildly or moderately elevated. EMG and muscle biopsy reveal myopathy. The diagnosis of this form of muscular dystrophy should be considered in patients with a myopathic phenotype, after Duchenne and Becker muscular dystrophies have been ruled out (usually by testing for dystrophin) (6). The condition should also be distinguished from scapuloperoneal muscular dystrophy and the rigid spine syndrome (167).

Genetic and Molecular Biology Studies. The gene locus for the most common variant of Emery-Dreifuss muscular dystrophy, the X-linked recessive form, has been localized, in linkage studies, to the long arm of the X chromosome at Xq28 (168–170). Rarely, an autosomal dominant form and, even less frequently, an autosomal recessive form may be seen. The autosomal dominant and autosomal recessive forms have an identified gene mutation on the lamin A/C gene on chromosome 1q21 (170). The specific type of gene testing depends on the family history and sex of the affected individual.

Treatment. The treatment for Emery-Dreifuss muscular dystrophy is similar to what is used in other forms of muscular dystrophy. The goals are to prevent or correct deformities and maximize function. Treatment modalities include physical therapy, correction of soft-tissue contractures, spinal stabilization, and cardiologic intervention.

Physical Therapy. This can be useful in the management of neck-extension contractures, elbow-flexion contractures, and tightness of the lumbar paravertebral muscles. Decreased neck flexion, which is characteristic of this disorder, can begin as early as the first decade of life, but is usually not present until the second decade. This is due to contracture of the extensor muscles and the ligamentum nuchae. According to Shapiro and Specht (6), this contracture does not progress past neutral. Lateral bending and rotation of the neck also become limited as the extensor contractures progress. Physical therapy can be helpful in maintaining limited flexion of the neck.

Soft-tissue Contractures. Tendo-Achilles lengthening and posterior ankle capsulotomy, combined with anterior transfer of the tibialis posterior tendon, can be helpful in providing long-term stabilization of the foot and ankle (6, 165). Elbow-flexion contractures usually do not require treatment. These contractures can be as severe as 90 degrees, although most do not exceed 35 degrees (6). Full flexion from this position and normal forearm pronation and supination are preserved. Physical therapy may be helpful in slowing the progress of the elbow-flexion contractures. Surgery has not been shown to be beneficial.

Spinal Stabilization. Scoliosis is common in this form of muscular dystrophy, but it shows a lower incidence of progression. This has been attributed to contractures at the lumbar and ultimately the thoracic paravertebral muscles, which seem to prevent progression (6, 165). Patients with scoliosis need to be followed closely, but most do not require treatment. Curves that progress beyond 40 degrees may require surgical stabilization.

Cardiologic Intervention. Severe brachycardia caused by complete heart block has been a major cause of sudden death in these patients. Most of them do not have cardiac symptoms preceding death. Merlini et al. (166) reported that 30 out of 73 patients with Emery-Dreifuss muscular dystrophy died suddenly, of whom only four were symptomatic. It is recommended that a cardiac pacemaker be inserted shortly after confirmation of the diagnosis (166, 171).

AUTOSOMAL RECESSIVE MUSCULAR DYSTROPHIES

Limb-Girdle Muscular Dystrophy. LGMD is common and may be more benign than the other forms of muscular dystrophy. It is a rather heterogeneous group of disorders with various classifications proposed for it over the years. The age at onset and rate of progression of muscle weakness are variable. It usually begins in the second or third decade of life. It is transmitted as an autosomal recessive trait, but an autosomal dominant pattern of inheritance has been reported in some families (172–174).

The symptoms of LGMD are similar to facioscapulohumeral muscular dystrophy, except that the facial muscles are not involved. The initial muscle weakness involves either the pelvic or shoulder girdle. The rate of progression is usually slow, with soft-tissue contractures and disability developing 20 years or more after the onset of the disease. The patients remain ambulatory for many years.

The distribution of weakness is similar to that seen in Duchenne and Becker muscular dystrophies. The iliopsoas, gluteus maximus, and quadriceps muscles are involved early in the disease process. Usually, shoulder girdle involvement occurs at about the same time. The serratus anterior, trapezius, rhomboid, latissimus dorsi, and sternal portions of pectoralis major muscles are affected most often. The disease later spreads to involve other muscles, such as the biceps brachia and the clavicular portion of the pectoralis major. Deltoid involvement may occur, but usually only later in the course of the disease. In patients with severe involvement, weakness may involve the distal muscles of the limbs, such as the wrist and finger flexors and extensors.

Two forms of LGMD are the more common pelvic-girdle type and a scapulohumeral form. The latter is rare, with symptoms involving primarily the shoulder girdle. Involvement of the pelvic girdle may not occur for many years. In the pelvic-girdle type, there is weakness of the hip extensors and abductors, resulting in accentuated lumbar lordosis, gait abnormalities, and hip instability.

The CPK level is moderately elevated in patients with LGMD. The clinical characteristics are indistinguishable

from those of sporadic Becker muscular dystrophy, carriers of Duchenne or Becker muscular dystrophies, and those of childhood acid-maltase deficiency (6). Therefore, a dystrophin assay is essential in establishing the diagnosis (172).

Treatment for LGMD is similar to that for Duchenne and Becker muscular dystrophies. Significant scoliosis rarely occurs because of the late onset of the disease process. When present, it usually is mild and does not require treatment (173). Patients usually succumb to the disease process before the age of 40 years.

Genetic and Molecular Biology Studies. Presently, a multitude of gene loci have been identified for this heterogeneous group of muscular dystrophies. The European Neuromuscular Center workshop on LGMD adopted a nomenclature to help categorize this complex and heterogeneous group of disorders. Presently, five autosomal dominant and nine autosomal recessive conditions have been identified that fit into this clinical grouping (173, 174).

Infantile Facioscapulohumeral Muscular Dystrophy. Infantile facioscapulohumeral muscular dystrophy (IFSH MD) is being identified more frequently. It is a severe variant of the more common later-onset facioscapulohumeral muscular dystrophy (175–177). A Mobius type of facial weakness may also be present and progress asymptomatically at a relatively slow pace (178). Although many of these infants represent sporadic cases, genetic diagnosis is positive for many of them and is identical to that seen in adults (179). Facial diplegia is noted in infancy, followed by sensorineural hearing loss in childhood (mean age 5 years). Ambulation begins at a normal age, but because of progressive muscle weakness, most patients become wheelchair bound during the second decade of life. Weakness causes the child to walk with the hands and forearms folded across the upper buttocks to provide support for the weak gluteus maximus muscles (6, 175, 177). This marked lumbar lordosis is progressive and is almost pathognomonic for IFSH MD (Fig. 16-5). After the patient becomes wheelchair dependent, the lordosis leads to fixed hip flexion contractures. Equinus or equinovarus deformities and scoliosis occur less frequently.

Treatment. The treatment of patients with IFSH MD (177) is individualized because most patients do not have significant orthopaedic deformities. These patients usually have severely compromised pulmonary functions and succumb in early adolescence. Shapiro et al. outlined the possible treatment modalities for children with IFSH MD. Flexible equinus and equinovarus deformities respond well to AFOs. Occasionally, a Vulpius-type tendo-Achilles lengthening may be necessary. Hip-flexion contractures usually do not require treatment in ambulatory patients, because treatment may decrease function. Spinal orthoses control the lordosis but do not provide correction because the spine remains flexible early in the course of the disorder. Because an orthosis interferes with ambulation, it is usually not employed. When wheelchair use is full time, a modified wheelchair with an orthosis may be useful, or perhaps a posterior spinal fusion and segmental instrumentation, depending on the severity of the deformity. Scapulothoracic stabilization is not indicated because the severity of dysfunction is so great that minimal or no improvement in shoulder function can be achieved.

FIGURE 16-5. Marked lumbar lordosis in a 15-year-old girl with infantile facioscapulohumeral muscular dystrophy. She is still ambulatory but having increasing back pain.

AUTOSOMAL DOMINANT MUSCULAR DYSTROPHIES

Facioscapulohumeral Muscular Dystrophy. Facioscapulohumeral muscular dystrophy is an autosomal dominant disorder having variable expression (180). The disease is characterized by muscular weakness in the face, shoulder girdle, and upper arm. It is caused by a gene defect, *FRG1*, on chromosome 4q35 (181). There is selective sparing of the deltoid, the distal part of the pectoralis major muscle, and the erector spinae muscles (182). This results in decreased scapulothoracic motion, with scapular winging and a marked decrease in shoulder flexion and abduction. Glenohumeral motion is usually preserved. The onset may occur at any age but is most common in late childhood or early adulthood. The disease occurs in both genders but is more common in women. Abortive (minimally affected) cases are common. Progression is insidious and periods of apparent arrest may occur. Cardiac and CNS involvement are absent. Life expectancy is relatively good.

Initially, the face and shoulder girdle muscles are involved, but they may be affected only mildly for many years. Facial signs, which may be present in infancy, include lack of mobility, incomplete eye closure, pouting lips with a transverse smile, and absence of eye and forehead wrinkles. It tends to produce a "pop-eye" appearance. The shoulder girdle weakness leads to scapular winging. The weight of the upper extremities, together with the weakness of the trapezius, permits the clavicles to assume a more horizontal position. It also leads to a forward-sloping appearance of the shoulders. As the disease progresses, pelvic girdle and tibialis anterior muscle involvement may also occur. Scoliosis is rare because of the late onset of the disease process.

The CPK levels in patients with facioscapulohumeral muscular dystrophy are usually normal. The diagnosis is made by physical examination and DNA confirmation. Presently, genetic testing is more than 95% sensitive and highly specific for FSHD (183).

Treatment. The winging of the scapula, with weakness of shoulder flexion and abduction, is the major orthopaedic problem in facioscapulohumeral muscular dystrophy. The deltoid, supraspinatus, and intraspinatus muscles are usually normal, however, or minimally involved. Posterior scapulocostal fusion or stabilization (scapulopexy) by a variety of techniques can be helpful in restoring mechanical advantage to the deltoid and rotator cuff muscles (184–191). This can result in increased active abduction and forward flexion of the shoulder, and improved function as well as cosmesis. Jakab and Gledhill (186) reported the results of a simplified technique for scapulocostal fusion. The technique involves wiring of the medial border of the scapula to ribs three through seven. Internal fixation is achieved with 16-gauge wire. The wires ensure firm fixation and eliminate the need for postoperative immobilization and subsequent rehabilitation. The child uses a sling for 3 to 4 days postoperatively, and then begins a physical therapy program. Jakab and Gledhill (186) found that shoulder flexion increased 28 degrees (range 20 to 40 degrees) and abduction 27 degrees (range 20 to 35 degrees) at a mean follow-up of 2.9 years. This allowed all patients to raise their arms above their heads, conferring a greater mechanical advantage. A similar technique and results were reported in 9 patients (18 shoulders) by Giannini et al. in 2006 (191). The beneficial effects do not seem to deteriorate with time (184–186, 190, 191).

Distal Muscular Dystrophy. This is a rare form of muscular dystrophy. It is also known as *Gower and M. Yoshi muscular dystrophy*. It typically begins in young adults. It is transmitted as an autosomal dominant trait. The initial involvement is in the intrinsic muscles of the hand. The disease process spreads proximally. In the lower extremities, the calves and tibialis anterior are involved first. The absence of sensory abnormalities, especially vibratory, differentiates this from Charcot-Marie-Tooth disease.

Ocular Muscular Dystrophy. Ocular muscular dystrophy, also known as *progressive external ophthalmoplegia*, is another rare form of muscular dystrophy. It typically begins in the adolescent years. The extraocular muscles are affected, resulting in diplopia and ptosis. This is followed by limitation of ocular movement (192). The upper facial muscles are often affected. The disease is slowly progressive and may involve the proximal upper extremities. The pelvis may be involved late in the disease process. Most patients with this disorder have an identifiable mitochondrial myopathy (193).

Oculopharyngeal Muscular Dystrophy. This form of muscular dystrophy is inherited in an autosomal dominant pattern with complete penetrance, and begins in the third decade of life. It is particularly common in French Canadians (194, 195).

Pharyngeal muscle involvement results in dysarthria, and in dysphasia, which leads to repetitive regurgitation and weight loss. This condition necessitates cricopharyngeal myotomy, a procedure that does not alter pharyngeal function (196). Ptosis develops in middle life.

MYOTONIA

Myotonia is a group of disorders characterized by the inability of skeletal muscle to relax after a strong contraction from either voluntary movement or mechanical stimulation. This is best demonstrated by the slowness with which a clenched fist relaxes in such patients. The most common myotonias include myotonic dystrophy, congenital myotonic dystrophy, and myotonia congenita. These are all rare disorders that are transmitted by autosomal dominant inheritance (6, 17).

Myotonic Dystrophy. Myotonic dystrophy is a systemic disorder characterized by myotonia, progressive muscle weakness, gonadal atrophy, cataracts, frontal baldness, heart disease, and dementia (197, 198). The genetic defect is located on chromosome 19q (199, 200). The distal musculature is affected first, and the myotonia begins to disappear as muscle weakness progresses. The onset occurs usually in late adolescence or early adulthood. In women, the diagnosis is frequently made only after they have given birth to a child who is more severely involved. The disease spreads slowly proximally and involves the quadriceps, hamstrings, and eventually the hip extensors. The lower extremities are more involved than the upper extremities. The most common presenting symptoms are weakness of the hands and difficulty in walking. Patients may be unable to relax their fingers after shaking hands and may need to palmar flex the hand to open the fingers. Muscles of the face, mandible, eyes, neck, and distal limbs may also be affected. The levels of serum enzymes are normal. Muscle biopsies show type I atrophy of the muscle fibers and the presence of some internal nuclei. These are nonspecific findings. The "dive-bomber" pattern on EMG is diagnostic (6). DNA testing that demonstrates a cytosine–thymine–guanine expansion affecting a protein kinase is confirmatory (199).

Examination reveals an expressionless face, ptosis, and a fish mouth that is difficult to close. There is marked wasting of the temporal, masseter, and sternocleidomastoid muscles. Deep-tendon reflexes are diminished or lost. Slit-lamp examination of the eyes reveals that most patients have lenticular opacities, cataracts, and retinopathy. Cardiac involvement is also common and includes mitral valve prolapse and arrhythmias (200, 201). Organic brain deterioration may also occur. Frontal baldness in men and glaucoma in both sexes occur in midadult life. The course of the disease is one of steady deterioration. Most patients lose the ability to ambulate within 15 to 20 years of onset of symptoms (201). There are no characteristic orthopaedic deformities, although a slight tendency toward increased hindfoot varus has been observed (6). Lifespan is shortened, and death is usually caused by pneumonia or cardiac failure.

Treatment of myotonic dystrophy is primarily orthotic because the onset is usually after skeletal maturity. An AFO may be helpful in patients with a drop foot caused by weakness of the tibialis anterior and peroneal muscles.

Congenital Myotonic Dystrophy. This is a relatively common muscle disorder of variable expression that occurs most frequently in children whose mothers have either a forme fruste or mild clinical involvement (200–204). Although it has autosomal dominant transmission, it is predominantly transmitted from mother to child (202). This is an exception in autosomal dominant disorders and indicates additional maternal factors. Approximately 40% of patients have severe involvement or die in infancy, whereas 60% will be affected later (204). The child may have an expressionless, long, narrow face; hypotonia; delayed developmental milestones; facial diplegia; difficulty in feeding because of pharyngolaryngeal palsy; respiratory failure; and mild mental retardation. The ability to swallow improves with growth, but the hypotonia persists. Examination shows diffuse weakness and absent deep-tendon reflexes. The appearance is similar to spinal muscular atrophy. Ambulation is usually delayed. If the mother is the carrier, the child may have other organic disorders later in life. Cataracts usually occur after the age of 14 years.

The defective gene has been localized to chromosome 19, and a test for prenatal diagnosis is available (198, 205). As in the adult form, there appears to be an expansion of a highly repeated sequence of three nucleotides: cytosine, thymine, and guanine. The trinucleotide repeat is at the 3' end of a protein kinase gene on chromosome 19, which lengthens as it passes from one generation to another. The length of the sequence correlates with the severity of the disorder. DNA testing is readily available for this disorder and is the diagnostic test of choice.

Orthopaedic problems in congenital myotonic dystrophy include congenital hip dislocation and talipes equinovarus (i.e., clubfeet). There is a tendency to develop soft-tissue contractures of other major joints of the lower extremities. Clubfeet may behave like those in arthrogryposis multiplex congenita (206). Serial casting may be tried, but most require surgery, such as an extensive, complete release. If this fails, a talectomy or Verebelyi-Ogston procedure may be useful (207). Scoliosis is also common and may require orthotic or surgical intervention (162). Spine surgery is fraught with a high incidence of complications, such as cardiac arrhythmias and postoperative infection (208). Nevertheless, because life expectancy is at least up to the early adult years, aggressive orthopaedic management improves the quality of life.

Myotonia Congenita. Myotonia congenita is usually present at birth, but does not become clinically apparent until after the age of 10 years. In some cases, it may present as low back pain or impaired athletic ability (209–211). The severity of the myotonia varies considerably. The distribution is widespread, although it is more marked in the lower extremities than in the upper extremities (212). Myotonia is most evident during the initial movement. Repetitive movement decreases the myotonia and facilitates subsequent movements. The stiffness usually disappears within 3 to 4 minutes, and normal activities, including running, are possible. Some patients appear herculean (massively muscled) because of generalized muscle hypertrophy, particularly in the buttocks, thighs, and calves. Children with myotonia congenita have no associated weakness and no other endocrine or systemic abnormalities. The disease is compatible with a normal lifespan. A patient's disability is not great when the limits of the disease have been accepted. Procainamide and diphenylhydantoin (Dilantin) have been used with some success to decrease the myotonia, but they should be used only in severe cases (213). There are no characteristic orthopaedic deformities (6). The disorder, a chloride channelopathy, is caused by various mutations in the skeletal muscle voltage-gated chloride channel gene *ClCN1* (214, 215). To date, four mutations of the *ClCN1* gene on chromosome 7q35 have been identified with myotonia congenita (216).

CONGENITAL MYOPATHIES AND CONGENITAL MUSCULAR DYSTROPHY

Congenital myopathies and congenital muscular dystrophy cause the baby at birth or in early infancy to be "floppy" or hypotonic. When these conditions occur in an older child, they can present as muscle weakness. These disorders are not well understood clinically or at the molecular level. The diagnostic categorization is not uniform or predictive. They are defined histologically from muscle biopsies (6, 217, 218). When the biopsy findings are abnormal but not dystrophic, the patient is diagnosed as having a nonspecific myopathy (6). When considerable fibrosis is present along with necrotic fibers, congenital muscular dystrophy may be diagnosed.

CONGENITAL MYOPATHIES

The congenital myopathies include central core disease, nemaline myopathy (rod-body myopathy), myotubular myopathy (centronuclear), congenital fiber-type disproportion, and

metabolic myopathies. Differentiation between these types can be accomplished through histochemical analysis and electron microscopy of muscle biopsy specimens (6, 217–219).

Central Core Disease. Central core disease is a nonprogressive autosomal dominant congenital myopathy that frequently presents as hypotonia in infants and as delayed motor developmental milestones in young children (217, 218, 220, 221). Independent ambulation may not be achieved until the age of 4 years. The distribution of muscle involvement is similar to that found in Duchenne muscular dystrophy, with the trunk and lower extremities showing more involvement than the upper extremities, and the proximal muscles more than the distal muscle groups. The pelvic girdle shows more involvement than the shoulder. Use of the Gower maneuver is common. No deterioration in strength occurs with time; sensation is normal; and the deep-tendon reflexes are either decreased or absent. Muscle wasting is a common finding, but progression of muscle weakness is rare. Muscle biopsies show mostly type I fibers, containing central circular or oval regions that are devoid of oxidative enzymes, adenosine triphosphate activity, and mitochondria. Serum CPK and nerve conduction studies are normal, whereas EMGs show myopathic abnormalities. Scoliosis, soft-tissue contractures, neuromuscular hip subluxation and dislocation, talipes equinovarus, pes planus, and hypermobility of joints (especially the patella) are the most common musculoskeletal problems, and they may require treatment (220–223). Scoliotic deformities have patterns similar to those of idiopathic scoliosis, progress rapidly, and tend to be rigid (222). Posterior spinal fusion and segmental instrumentation yield satisfactory results. Soft-tissue contractures around the hip and knee may need to be released. Clubfeet require extensive soft-tissue releases in order to achieve correction. Congenital dislocation of the hip can be treated by open or closed reduction techniques, but the recurrence rate is high and may require osseous procedures such as pelvic or proximal femoral osteotomies (223). Central core disease is one of the disorders in which patients are susceptible to malignant hyperthermia. This association with malignant hyperthermia has led researchers to link both disorders with the long arm of chromosome 19 as the probable site of mutation (224, 225).

Nemaline Myopathy. Nemaline, or rod-body, myopathy is a variable congenital myopathy that usually begins in infancy or early childhood, with hypotonia affecting all skeletal muscles (6, 217, 218, 226, 227). There is no involvement of cardiac muscle. Elongated facies, with a high-arched palette and a nasal, high-pitched voice, are frequently noted. Skeletal changes may resemble those seen in arachnodactyly. Martinez and Lake (226), in a review of the literature relating to 99 patients, recognized these distinct forms: neonatal (severe), congenital (moderate), and adult onset. The neonatal form is characterized by severe hypotonia, with 90% mortality in the first 3 years of life because of respiratory insufficiency. The mean survival after birth was 16 months. The moderate congenital form, which is the most common and prototypic, is diagnosed during or after the neonatal period and is characterized by mild or moderate hypotonia, weakness, and delayed developmental milestones. Most patients begin to walk at the age of 2 to 4 years, and the weakness is usually nonprogressive or only slowly progressive. The mortality rate is approximately 5% in the congenital form. Death is usually caused by severe involvement of the pharyngeal and respiratory muscles (228–230). The adult-onset form is characterized by proximal weakness that occasionally progresses acutely. There is no correlation between the number of rods and the phenotype in nemaline myopathy (227). The inheritance pattern in this disorder is variable, with autosomal recessive, autosomal dominant, and sporadic cases identified. However, all mutations identified to date follow an autosomal recessive inheritance pattern (231).

Soft-tissue contractures are uncommon in nemaline myopathy. The major musculoskeletal problems are scoliosis and lumbar lordosis. Posterior spinal fusion and segmental instrumentation may be indicated in progressive scoliotic deformities (6). Lower extremity orthoses can be helpful in providing stability to the joints and in aiding ambulation. Because of their diminished pulmonary function and the heightened risk for malignant hyperthermia, patients undergoing surgery require careful monitoring during the administration of anesthesia (232).

Centronuclear Myopathy. Centronuclear (i.e., myotubular) myopathy is a disorder of considerable variability (217, 218, 233). Muscle biopsies demonstrate persistent myotubes that would be normal in fetal life. There are X-linked recessive, autosomal recessive, and autosomal dominant forms (234, 235). The defect in the X-linked recessive form is at the locus Xq28. The defective gene has been identified and named as *MTM1* (236). Mutation detection analysis is now available, and sensitivity of testing is up to 72% (236). These children have varying degrees of weakness, generally noted in infancy. Patients with X-linked recessive forms are usually severely involved and die in infancy. The infant with the autosomal recessive form of the disease is hypotonic at birth, but the hypotonia is not progressive and may improve with time. Most of these children are able to walk. They may have a myopathic facies, high-arched palate, and proximal muscle weakness. There is an increased incidence of cavovarus foot deformities, scoliosis, lumbar lordosis, and scapular winging. By late adolescence or early adult life, some patients lose their ability to ambulate.

Congenital Fiber-type Disproportion. Congenital fiber-type disproportion is characterized by generalized hypotonia at or shortly after birth. The histologic findings (from muscle biopsies) that may suggest this diagnosis include a predominance of type I fibers of reduced size and relatively large type II fibers. It is recognized as a nonspecific pathologic change that occurs in many patients and has a myopathic, neuropathic, or CNS origin (237). The degree of weakness is variable, and sequential examinations determine

the prognosis. Most patients become ambulatory. The most serious problem is the vulnerability to life-threatening respiratory infections during the first years of life. Proximal muscle weakness is frequently associated with acetabular dysplasia (237). To prevent postural contractures from developing, an appropriate lower extremity splint should be used until the patient achieves ambulation. Severe, rigid scoliosis can occur. Orthoses are usually ineffective, and early spinal arthrodesis may be necessary (6).

Metabolic Myopathies. These myopathies represent a broad spectrum of metabolic abnormalities that are generally clinically evident in the first two decades of life (238). These include disorders of glycolysis, lipid metabolism, mitochondrial dysfunction, and purine nucleotide cycle defects. Myopathies caused by metabolic errors in the first step of glycolysis, for example, myophosphorylase and phosphofructokinase deficiencies, are clinically associated with cramping, weakness, and exercise intolerance with anaerobic activity (i.e., short-duration but vigorous activity). The other glycolytic disorders, such as acid maltase or debrancher enzyme deficiencies, are associated with progressive muscle weakness and wasting (239). Carnitine palmityl transferase deficiency, which is a disorder of lipid metabolism, presents with muscle cramping, weakness, and myoglobinuria following prolonged exercise. Myopathies caused by deficiencies in mitochondrial enzymes are less well defined and may be associated with severe benign exercise intolerance and progressive myopathic syndromes (239–241).

CONGENITAL MUSCULAR DYSTROPHY

Congenital muscular dystrophy is a rare disorder in which babies are "floppy," with generalized muscle weakness and with the involvement of respiratory and facial muscles (242, 243). It is a muscle disorder in which the muscle biopsy demonstrates dystrophic features characterized by considerable perimysial and endomysial fibrosis. It is different from Duchenne muscular dystrophy and Becker muscular dystrophy because it affects children of both sexes, is not associated with massively elevated levels of CPK, does not involve abnormalities of the dystrophin gene or protein, and is associated with a more variable prognosis (6). There are several forms of congenital muscular dystrophy. In one, the infant is weak at birth. Many have severe stiffness of joints, whereas others do not. A few infants have rapid progression and do not survive after the first year of life. Most, however, stabilize and survive into adulthood (243). Another type is seen in Japanese infants and has been termed *Fukuyama congenital muscular dystrophy*. It is characterized by a marked developmental defect in the CNS (244, 245). There is progressive muscle degeneration and mental retardation. Severe joint contractures develop, and many children with this condition die in the first decade of life. Three disorders are associated with congenital muscular dystrophy and CNS malformations: Fukuyama congenital muscular dystrophy, Walker-Warburg syndrome, and muscle–eye–brain disease. Merosin-deficient congenital muscular dystrophy is associated with changes in the white matter of the brain as seen on MRI and has been linked to chromosome 6q2 (246, 247).

Common orthopaedic problems include congenital hip dislocation and subluxation, tendo-Achilles contractures, and talipes equinovarus (Fig. 16-6). Because most patients survive, aggressive orthopaedic management is warranted. This may include physical therapy, orthoses, soft-tissue releases, and perhaps osteotomy (6, 248). Early physical therapy may be helpful in preventing soft-tissue contractures. Soft-tissue releases in the treatment of congenital dislocation of the hip are characterized by a high incidence of recurrent dislocation (Fig. 16-7) (248). Progressive scoliosis may be initially treated by an orthosis, although most patients require surgical stabilization similar to the procedure used in other forms of muscular dystrophy (127).

SPINAL MUSCULAR ATROPHY

Spinal muscular atrophy is a group of disorders characterized by degeneration of the anterior horn cells of the spinal cord, and occasionally the neurons of the lower bulbar motor nuclei, resulting in muscle weakness and atrophy (249–253). They are autosomal recessive disorders that occur in approximately 1 in 6000 to 10,000 individuals. The prevalence of carriers is estimated at 1 in 40 to 1 in 50 (254). The loss of anterior horn cells is considered to be an acute event without progression. The neurologic deterioration may stabilize and remain unchanged for long periods (255, 256). The progression of muscle weakness is a reflection of normal growth that exceeds muscle reserve. Respiratory function is compromised, and atelectasis and pneumonia are the usual causes of death.

Clinical Classification. The clinical features of spinal muscular atrophy vary widely and are based on the age at onset and the functional capacity of the child at the time of diagnosis. This has led to the disorder being classified into three types. These include Type I (severe), or acute Werdnig-Hoffman disease; Type II (intermediate), or chronic Werdnig-Hoffman disease; and Type III (mild), or Kugelberg-Welander disease (257). All three fall within the spectrum of the same disorder, but each has its specific diagnostic criteria and prognosis. There is a considerable overlap between these three disorders, however, and most authors consider them to be a single disorder, namely, spinal muscular atrophy (258). Generally, the earlier the onset, the worse the prognosis.

Type I, Acute Werdnig-Hoffman Disease. The Type I spinal muscular atrophy is characterized by clinical onset between birth and 6 months. These children typically have severe involvement with marked weakness and hypotonia. They usually die from respiratory failure between the ages of 1 and 24 months. Because of their young age and severe involvement, orthopaedic intervention is not indicated in

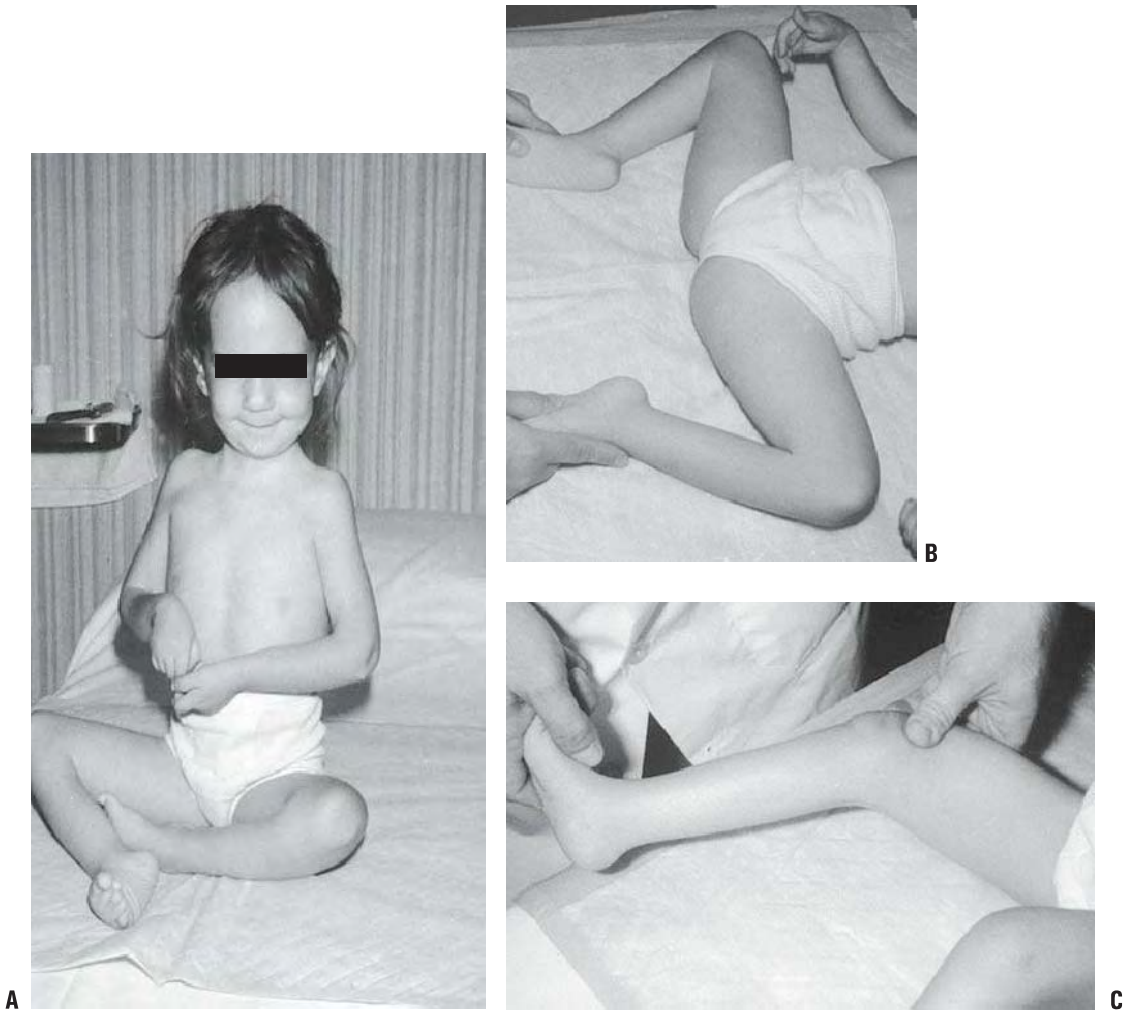

FIGURE 16-6. **A:** Clinical photograph of a 3-year-old girl with congenital muscular dystrophy. Observe the position of the upper and lower extremities. **B:** The hips are flexed, abducted, and externally rotated. **C:** Moderate knee-flexion contractures are present.

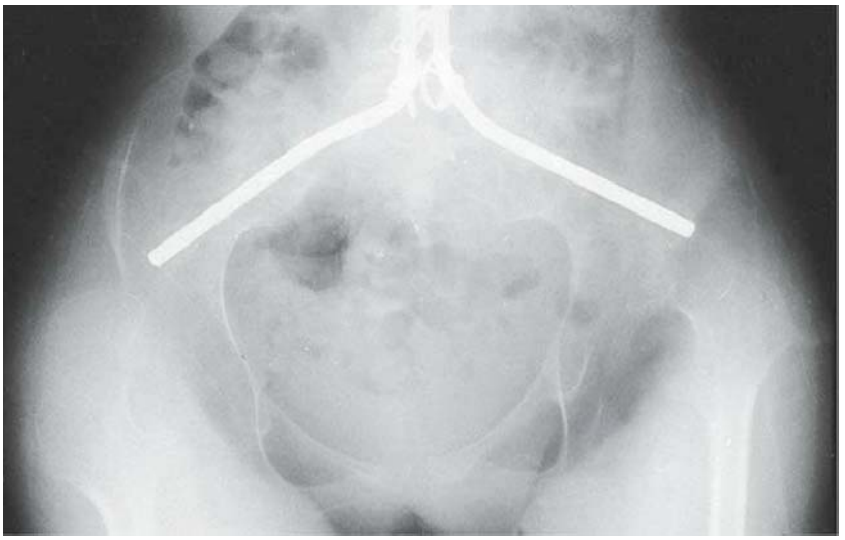

FIGURE 16-7. Pelvic radiograph of an 11-year-old girl with congenital muscular dystrophy, 3 years after posterior spinal fusion and Luque rod instrumentation, including the Galveston technique. She is wheelchair dependent and has developed bilateral asymptomatic hip dislocations despite extensive soft-tissue releases in early childhood.

these children. Pathologic fractures may occur because of *in utero* osteoporosis secondary to decreased movement at birth, thereby suggesting the presence of osteogenesis imperfecta (259). These fractures heal rapidly with immobilization.

Type II, Chronic Werdnig-Hoffman Disease. The clinical onset of Type II spinal muscular atrophy occurs at between the ages of 6 and 24 months. These children show less severe involvement than those with Type I spinal muscular atrophy but are never able to walk. They may, however, live into the fourth and fifth decades of life.

Type III, Kugelberg-Welander Disease. The clinical onset of Type III spinal muscular atrophy occurs after the age of 2 years and usually before the age of 10 years. Walking is usually possible until late childhood or early adolescence. These patients are usually not able to run. Their motor capacity decreases with time, and they have difficulty rising from the floor because of weakness of the pelvic-girdle muscles; this is known as the *Gower sign*. There is atrophy of the lower limbs, with pseudohypertrophy of the calves. Cranial nerve muscles are usually not affected. These patients have normal intelligence and may function effectively in society. Both the quality and quantity of life may be extended in Type II and Type III spinal muscular atrophy by the use of nighttime or full-time assisted ventilation (260).

Functional Classification. Evans et al. (261) developed a four-group functional classification that may be useful prognostically:

Group I. Children never sit independently, have poor head control, and develop early progressive scoliosis.

Group II. Children have head control and the ability to sit if placed in a sitting position but are unable to stand or walk, even with orthotics.

Group III. Children have the ability to pull to stand and to walk with external support, such as orthoses.

Group IV. Children have the ability to walk and run independently.

Other studies have supported the use of this classification (251, 257).

Genetic and Molecular Biology Studies. Linkage studies have established that the genetic homogeneity for the three types of spinal muscular atrophy occur at the same locus on chromosome 5q (16, 17, 249, 262). Two genes have been found to be associated with disease, the survival motor neuron (*SMN*) gene and the neuronal apoptosis inhibitory protein (*NAIP*) gene (250, 263, 264). The presence of large-scale deletions involving both genes corresponds to a more severe phenotype. Prenatal diagnosis is available with the use of PCR amplification assays. No specific gene therapy is available.

Clinical Features. The clinical features of spinal muscular atrophy vary according to the clinical classification. The clinical characteristics common to all groups are relatively symmetric limb and trunk weakness, and muscle atrophy that affects the lower extremities more than the upper extremities and the proximal muscles more than the distal muscles. Hypotonia and areflexia are present. Sensation and intelligence are normal. In infants, gross fasciculations of the tongue and fine tremors of the fingers are commonly present (256, 265). The only muscles not involved are the diaphragm, sternothyroid, sternohyoid, and the involuntary muscles of the intestine, bladder, heart, and sphincters (249, 257).

Diagnostic Studies. The studies used in the initial diagnosis of spinal muscular atrophy include laboratory studies, EMG, nerve conduction studies, DNA testing, and muscle biopsies. Hematologic studies in spinal muscular atrophy are not particularly useful (253). The CPK and aldolase levels are normal to only slightly elevated. In patients with spinal muscular atrophy, electrophysiologic studies such as EMG show typical neuropathic changes such as increased amplitude and duration of response (253). Denervational changes, manifest as prominent fibrillation potentials, are a hallmark of this disorder. Nerve conduction velocities are typically normal, although the compound muscle action potential amplitude is typically markedly diminished (266). Muscle biopsies are usually diagnostic, demonstrating muscle fiber degeneration and atrophy of fiber groups (253). However, with the recent advent of genetic testing for this disorder, muscle biopsy is usually not necessary. DNA testing is highly sensitive for this disorder and is readily available. DNA PCR for spinal muscular atrophy is now the diagnostic procedure of choice.

Radiographic Evaluation. There are no specific radiographic characteristics that are useful in making the diagnosis of spinal muscular atrophy. The most common radiographic abnormalities are nonspecific and include hip subluxation or dislocation and progressive spinal deformity (253). Spinal radiographs, posteroanterior and lateral, should be obtained in the sitting position to avoid the compensations seen in the standing and supine positions.

Treatment. The major orthopaedic abnormalities associated with spinal muscular atrophy include the presence of soft-tissue contractures of the lower extremities, hip subluxation and dislocation, and spinal deformity (252, 253).

Lower Extremity Soft-Tissue Contractures. Soft-tissue contractures of the lower extremities are the result of progressive muscle degeneration and replacement with fibrous tissue. Ambulation may be promoted and soft-tissue contractures delayed by the use of orthoses such as KAFOs (267). Contractures tend to occur most frequently after the child becomes wheelchair bound. The prolonged sitting posture enhances hip- and knee-flexion contractures. Contractures of the soft tissues of the hip may also result in abnormal growth

of the proximal femur, predisposing the patient to coxa valga and progressive hip subluxation. Soft-tissue contractures without an associated osseous deformity usually do not require treatment. Even when they are released, the sitting posture of the child promotes their recurrence.

Hip Subluxation and Dislocation. Progressive hip subluxation leading to dislocation occurs predominantly in spinal muscular atrophy Types II and III (268, 269). It is important that hip dislocation be prevented in order to provide comfort and sitting balance and to maintain pelvic alignment. A comfortable sitting posture is important if the adolescent or young adult is to function in society. Periodic anteroposterior radiographs of the pelvis, beginning in mid- to late childhood, are important in order to ensure early recognition of coxa valga and subluxation. Once diagnosed, it is usually progressive because of the continued muscle weakness and soft-tissue contractures. Procedures that have been used with some success include soft-tissue releases such as adductor tenotomy, iliopsoas recession, and medial hamstring lengthening. This restores some balance to the proximal musculature. A varus derotation osteotomy is frequently indicated if the hip is severely subluxated (253). If the hip is dislocated, an open reduction with capsulorrhaphy and pelvic osteotomy of the Chiari type may be of benefit to the patient. The usual pelvic rotation osteotomies (e.g., Salter, Sutherland, Steel) sacrifice posterior coverage to gain lateral (superior) and anterior coverage. In the child who will be predominantly in a sitting position, this lack of posterior coverage may predispose the patient to a posterior subluxation and pain. Therefore, the pelvic osteotomy method chosen must allow improved posterior coverage. This is usually accomplished with the Chiari osteotomy or perhaps a shelf procedure. Even after satisfactory alignment of the hip, resubluxation and dislocation can occur because of the progressive degeneration of the proximal muscles (270). These children require annual clinical and radiographic evaluation to assess the hips postoperatively. Thompson and Larsen (269) reported four cases of recurrent hip dislocation after corrective surgery. Two patients had second operations followed by recurrent dislocation. Therefore, these orthopaedists question the advisability of treatment of hip dislocations in patients with spinal muscular atrophy. Sporer and Smith (268) recently documented that patients with a hip dislocation had minimal pain or problems with sitting, and no difficulty with perineal care. They suggested observation rather than surgery for hip dislocation. Similar recommendations were recently made by Zenios et al. (271). Thus, treatment of hip subluxation and dislocation in spinal muscular atrophy is controversial. Each patient must be evaluated individually. The presence of pain, rather than the radiographic appearance of the hips, should be the main indication for treatment.

Spinal Deformity. Most children with this condition who survive into adolescence develop a progressive spinal deformity. This occurs in 100% of the children and adolescents with Type II disease, and most of those with Type III, especially when they lose their ability to walk (261, 272–276). As in other neuromuscular disorders, the progression of the curve has an adverse effect on pulmonary function (274).

The deformity typically begins in the first decade of life because of severe truncal weakness. Once the deformity begins, it is steadily progressive and can reach a high magnitude of severity unless appropriately managed. The thoracolumbar paralytic C-shaped and single thoracic patterns, usually curved to the right, are most common. Approximately 30% of the children also have an associated kyphosis, which is also progressive (273, 276). In Type II spinal muscular atrophy, the mean expected increase in scoliosis is 8.3 degrees per year, whereas in Type III it is 2.9 degrees per year.

Orthotic Management. Bracing is ineffective in preventing or halting the progression of scoliosis or kyphosis in children with spinal muscular atrophy (252, 261, 272, 276–280). However, it can be effective in improving sitting balance and slowing the rate of progression in young ambulatory children (280). This has the advantage of allowing them to reach an older, more suitable age for undergoing surgical intervention. Orthotic treatment may help maintain overall posture, aid sitting posture, and slow the curve progression in younger nonambulatory children with deformities between 20 and 40 degrees. The TLSO is the most common orthosis used in children with spinal muscular atrophy. This orthosis must be carefully molded in order to distribute the forces over a large surface area. This is necessary for preventing skin irritation and breakdown, which is a major problem for children with neuromuscular diseases. Furumasu et al. (281) found that orthoses had the effect of decreasing the ability to function because of decreased spinal flexibility. It is also important to ensure that the TLSO does not further compromise the child's limited pulmonary functions. Occasionally, wheelchair modifications can also be effective in controlling truncal alignment and improving sitting posture (253). This may also be helpful in slowing the rate of curve progression. Unfortunately, almost all children with spinal muscular atrophy eventually require surgery for spinal deformity.

Surgery. The criteria for surgical spinal stabilization in spinal muscular atrophy include curve magnitude >40 degrees, satisfactory flexibility on supine lateral bending as seen on radiographs, and an FVC >40% of normal (251). When these criteria are met, a posterior spinal fusion with segmental spinal instrumentation techniques such as Luque rod instrumentation and sublaminar wires is used (Fig. 16-8) (116, 177, 123, 125, 126, 252, 272–275, 277–279, 281, 282). Other segmental spinal instrumentation systems can also be utilized. However, these do not usually distribute the forces of instrumentation throughout the spine as efficiently as the Luque rods with sublaminar wiring do. The spine is usually osteopenic, and there is a risk of bone failure unless the forces produced by instrumentation are minimized by extensive distribution. Fixation to the pelvis using the Galveston technique (130) or other techniques (133, 282) is common. In most children who are nonambulatory and have pelvic obliquity, fusion to the pelvis provides

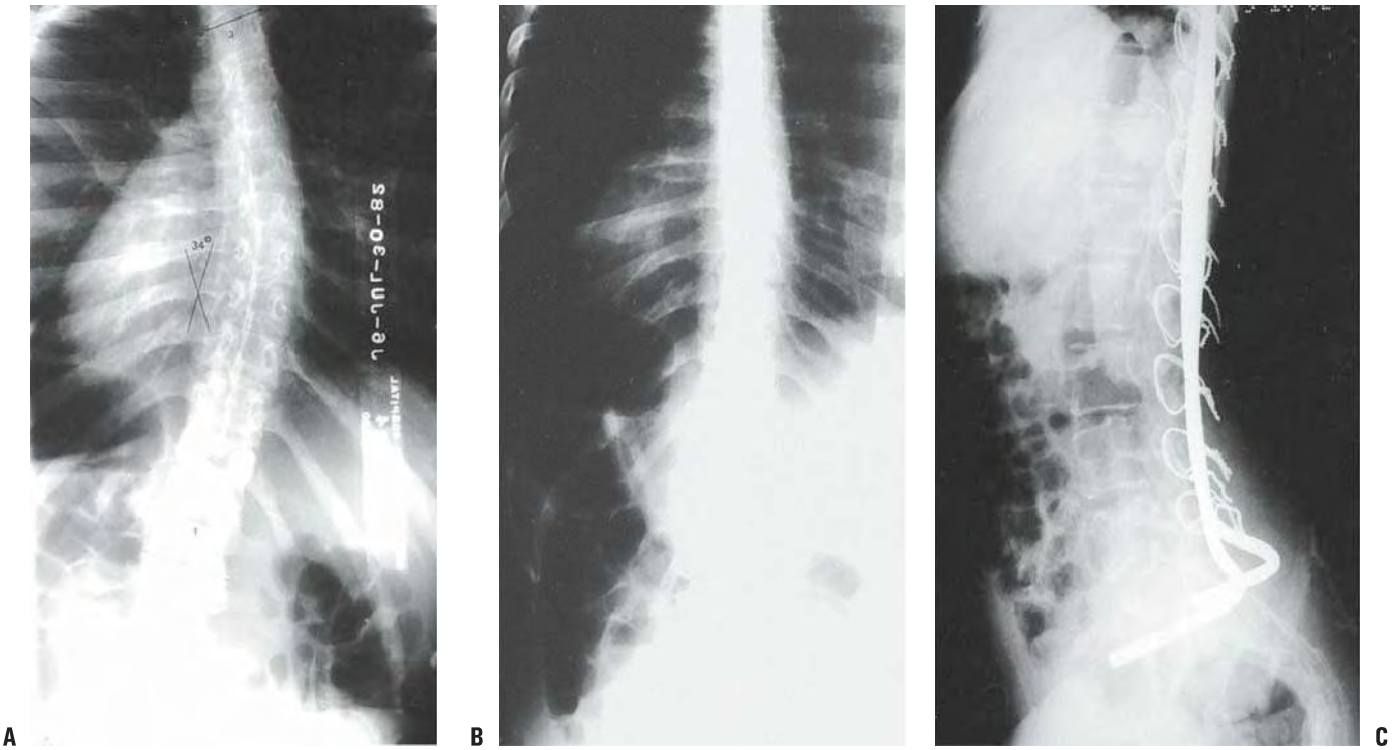

FIGURE 16-8. **A:** Sitting posteroanterior spinal radiograph of an 18-year-old woman with spinal muscular atrophy. A slowly progressive scoliosis has affected her wheelchair sitting balance. **B:** Postoperative radiograph after posterior spinal fusion and Luque rod instrumentation using the Galveston technique provided almost complete correction of the spinal deformity. Thirteen years postoperatively she functions independently despite the subsequent need for a tracheostomy and ventilator support. **C:** Lateral view demonstrates preservation of lumbar lordosis, which is important for proper sitting balance. **D:** Anteroposterior view of the pelvis shows proper positioning of the Luque rods in the ilium. They should penetrate as far into the ilium as possible for maximum strength.

improved spinopelvic stability and alignment. Anterior spinal fusion and instrumentation are rarely indicated in view of the compromised pulmonary status of these children, which could predispose them to pulmonary complications postoperatively (279). Anterior fusions alone are too short to adequately stabilize the entire spine. When the procedure is performed, it is combined with a simultaneous or staged posterior spinal fusion, usually with Luque rod instrumentation (116). Whatever posterior instrumentation system is used, it is important to ensure that no postoperative immobilization is necessary; this enhances sitting balance and pulmonary status and makes transfers easier.

Patients experience a decrease in function after spine fusion (272, 281). Although spinal alignment and sitting balance are improved, the loss of spinal mobility decreases the function of the upper extremities and activities of daily living such as performing transfers and maintaining personal hygiene. Askin et al. (283) recommended early surgery to preserve function. They found as well that the patient's functional ability may not improve following surgery, but the cosmetic results are gratifying, and the caregivers also find it easier to carry out their tasks. Bridwell et al. (123) reported improved function, self-image, cosmesis, and caregiver ability in 21 patients with spinal muscular atrophy followed for a mean of 7.8 years postoperatively (range 2 to 12.6 years). Growing rods or rods that can be elongated periodically may be helpful in young children with spinal muscular atrophy who have severe deformities (284). This allows definitive surgery to be delayed until an older age. Pelvic fixation can be used as a distal foundation (285).

Operative complications are similar to those in other neuromuscular disorders. These include excessive blood loss, pulmonary complications, neurologic injury, wound infection, loss of fixation (caused by osteopenia), pseudarthrosis, and even death (115, 272, 276, 277, 279, 282). The use of segmental spinal instrumentation techniques and aggressive preoperative and postoperative respiratory therapy may lead to fewer complications. Hypotensive anesthesia and intraoperative spinal cord monitoring may be helpful in decreasing intraoperative blood loss and neurologic injury. Noordeen et al. (149) reported that a 50% decrease in amplitude of motor action potential may be indicative of an impending neurologic injury.

FRIEDREICH ATAXIA

Spinocerebellar degenerative diseases are a group of relatively uncommon disorders that are hereditary and progressive. Friedreich ataxia is the most common form and has orthopaedic implications because it is associated with a high incidence of scoliosis. In whites, this disorder accounts for up to half of all cases of hereditary ataxia (286). Friedreich ataxia is characterized by slow, progressive spinocerebellar degeneration. It occurs in approximately 1 in 50,000 live births. It is autosomal recessive and occurs most commonly in North America in people of French–Canadian heritage. Both sexes are affected equally.

Clinical Features. Friedreich ataxia is characterized by a clinical triad consisting of (i) ataxia (which is usually the presenting symptom); (ii) areflexia of the knees and ankles; and (iii) a positive plantar response, or the Babinski sign (253, 286). Geoffroy et al. (287) established strict criteria for the clinical diagnosis of typical Friedreich ataxia. This has been modified by Harding (288, 289). The primary symptoms and signs that occur in all affected patients include onset before the age of 25 years; progressive ataxia of limbs and gait; absent knee and ankle deep-tendon reflexes; positive plantar response; decreased nerve conduction velocities in the upper extremities, with small or absent sensory action potentials; and dysarthria. The secondary symptoms and signs that are present in more than 90% of the cases include scoliosis, pyramidal weakness in the lower extremities, absent reflexes in the upper extremities, loss of position and vibratory sense in the lower extremities, and an abnormal ECG. Supplementary symptoms and signs are present in fewer than 50% of the cases. These include optic atrophy, nystagmus, distal weakness and wasting, partial deafness, pes cavus, and diabetes mellitus.

The mean age at onset is between 7 and 15 years, although the range is wide, from the age of 4 years to as late as 25 years (253, 286–290). Most of the patients lose their ability to walk and are wheelchair bound by the second or third decade of life. Labelle et al. (291) demonstrated that the muscle weakness is always symmetric, initially proximal rather than distal, more severe in the lower extremities, and rapidly progressive when the patients become nonambulatory. The first muscle to be involved is the hip extensor (gluteus maximus). They also demonstrated that muscle weakness is not the primary cause of loss of ambulatory function. Ataxia and other factors also play a role. Death usually occurs in the fourth or fifth decade because of progressive hypertrophic cardiomyopathy, pneumonia, or aspiration (286, 288).

Nerve conduction studies show decreased or absent sensory action potentials in the digital and sural nerves. Conduction velocity in the motor and sensory fibers of the median and tibial nerves is moderately slowed. An EMG shows a loss of motor units and an increase in polyphasic potentials. The ECG in adults typically shows a progressive hypertrophic cardiomyopathy. Hematologic tests such as CPK are normal, but there is increased incidence of clinical and chemical diabetes mellitus.

Genetic and Molecular Biology Studies. Chamberlain et al. (292) have demonstrated that individuals with Friedreich ataxia have a defect on chromosome 9q13. Additional studies have identified two loci on chromosome 9 (*D9S5* and *D9S15*) that are linked to Friedreich ataxia (293). It is now known that this condition is caused by a trinucleotide repeat of GAA, which causes loss of expression of the frataxin protein. There is an inverse relation between the number of trinucleotide repeats and the age at onset of the disease (294). Various medications such as physostigmine, tryptophan, buspirone, and amantadine have been tried for symptomatic treatment, with generally disappointing results (295–300). DNA testing is available and is the diagnostic test of choice.

Treatment. The major orthopaedic problems in Friedreich ataxia are pes cavovarus, spinal deformity, and painful muscle spasms (253, 286).

Pes Cavovarus. Pes cavovarus is common in patients with Friedreich ataxia. It is slowly progressive and tends to become rigid. When combined with ataxia, it can result in decreased ability to stand and walk. Orthotic management is usually ineffective in preventing the deformity, but an AFO can be used after surgery to stabilize the foot and ankle and to prevent recurrent deformity. Surgical procedures can be used in ambulatory patients to improve balance and walking ability. Procedures that have been shown to be effective include tendo-Achilles lengthening and tibialis posterior tenotomy, lengthening, or anterior transfer to the dorsum of the foot (253, 286). The tibialis anterior muscle may also be involved and may require tenotomy, lengthening, or centralization to the dorsum of the foot to prevent recurrence. In fixed, rigid deformities, a triple arthrodesis may be necessary for achieving a plantigrade foot.

Spinal Deformity. Scoliosis occurs in almost all patients with Friedreich ataxia (286, 288, 301–304). The age at onset is variable and usually begins while the patient is still ambulatory. The incidence of curve progression has been shown to correlate

to the age at clinical onset of the disease process. Labelle et al. (303) demonstrated that when the disease onset is before the age of 10 years and scoliosis occurs before the age of 15 years, most scoliotic curves progress to >60 degrees and require surgical intervention. When the disease onset is after the age of 10 years and the scoliosis occurs after the age of 15 years, the curve progression is not as severe; most do not reach 40 degrees by skeletal maturity, and do not progress thereafter. There was found to be no correlation between curve progression, degree of muscle weakness, level of ambulatory function, and duration of the disease process. The patterns of scoliosis in patients with Friedreich ataxia are similar to those in adolescent idiopathic scoliosis rather than to those in neuromuscular scoliosis. The pathogenesis of scoliosis in Friedreich ataxia appears to be not muscle weakness but ataxia that causes a disturbance of equilibrium and postural reflexes. Double major (i.e., thoracic and lumbar) and single thoracic or thoracolumbar curves are the most common curve patterns (301–304). Only a few patients have lumbar or long C-shaped thoracolumbar curves. About two-thirds of these patients develop an associated kyphosis >40 degrees (303). The treatment of scoliosis in Friedreich ataxia can be by either orthotic or surgical methods.

Orthoses. A TLSO may be tried in ambulatory patients having 25- to 40-degree curves. It is usually not well tolerated, but it may slow the rate of progression although it rarely stabilizes the curve (263, 276, 304). In ambulatory patients, an orthosis may interfere with walking because it prevents the compensatory truncal movement that is necessary for balance and movement.

Surgery. In progressive curves >60 degrees, especially in older adolescents confined to wheelchairs, a single-stage posterior spinal fusion stabilizes the curve and yields moderate correction. Curves between 40 and 60 degrees can be either observed or treated surgically, depending on the patient's age at clinical onset, the age when scoliosis was first recognized, and evidence of curve progression. Posterior segmental spinal instrumentation using Harrington rods and sublaminar wires or Luque rod instrumentation has been demonstrated to be effective in achieving correction and a solid arthrodesis (115, 301–303). Other segmental spinal instrumentation systems will also be effective (304). Fusions are typically from the upper thoracic (T2 or T3) to lower lumbar regions. Fusion to the sacrum is usually unnecessary, except in C-shaped thoracolumbar curves with associated pelvic obliquity (302). Autogenous bone supplemented with banked bone, when necessary, usually produces a solid fusion. Anterior surgery, with or without instrumentation, usually followed by a posterior spinal fusion and instrumentation, is limited to rigid curves that are >60 degrees and associated with poor sitting balance. Intraoperative spinal cord monitoring using somatosensory evoked potentials are usually ineffective (304). Surgery is performed only after a thorough cardiopulmonary evaluation and under careful intraoperative and postoperative monitoring. Postoperative immobilization should be avoided. Vertebral osteopenia and spinal stenosis are not problems in Friedreich ataxia.

Painful Muscle Spasms. Painful muscle spasms occur in some patients with Friedreich ataxia (253). They usually begin in the late adolescent or early adult years and worsen with time. The spasms are characterized by a sudden onset and short duration. The hip adductors and the knee extensors are commonly involved. Initial treatment is usually massage, warming, and perhaps muscle relaxants, such as diazepam and Baclofen. In adults, if the adductor or quadriceps spasms are interfering with perineal care or sitting balance, the patient may benefit from tenotomies. However, this is rarely necessary.

HEREDITARY MOTOR SENSORY NEUROPATHIES

HMSNs are a large group of variously inherited neuropathic disorders (253, 286, 305). Charcot-Marie-Tooth disease is the prototype, but there are other disorders with similar but different manifestations.

Classification. The classification system for HMSN is presented in Table 16-2 HMSN Types I, II, and III are encountered predominantly in pediatric orthopaedic and neuromuscular clinics, whereas HMSN Types IV, V, VI, and VII tend to be late-onset and occur in adults (253).

HMSN Type I is an autosomal dominant disorder, and includes disorders referred to as peroneal atrophy, Charcot-Marie-Tooth disease (hypertrophic form), or Roussy-Levy syndrome. It is a demyelinating disorder that is characterized by peroneal muscle weakness, absent deep-tendon reflexes, and slow nerve conduction velocities. HMSN Type II is the neuronal form of Charcot-Marie-Tooth disease with progressive axon loss. It is characterized by persistently normal reflexes, sensory and motor nerve conduction times that are only mildly abnormal, decreased compound motor action potentials, and variable inheritance patterns (253). These two types are clinically

TABLE 16-2 Classification of Hereditary Motor Sensory Neuropathies

Type	Name(s)	Inheritance
I	Peroneal atrophy, Charcot-Marie-Tooth syndrome (hypertrophic form), or Roussy-Levy syndrome (areflexic dystaxia)	Autosomal dominant
II	Charcot-Marie-Tooth syndrome (neuronal form)	Variable
III	Dejerine-Sottas disease	Autosomal recessive
IV	Refsum disease	
V	Neuropathy with spastic paraplegia	
VI	Optic atrophy with peroneal muscle atrophy	
VII	Retinitis pigmentosa with distal muscle weakness and atrophy	

similar, although HMSN Type II often causes less severe weakness and has a later onset than HMSN Type I. HMSN Type III is the autosomal recessive disorder, Dejerine-Sottas disease. This disorder begins in infancy and is characterized by more severe alterations in nerve conduction and by sensory disturbances that are more extensive than in HMSN Types I and II. The HMSN Types I and III are caused by demyelinization of peripheral nerves, whereas Type II is caused by axon loss. These are characterized by muscle weakness in the feet and hands, absent deep-tendon reflexes, and diminution of distal sensory capabilities, particularly light touch position and vibratory sensation (253).

The four additional types are of late onset, and are rarely seen by pediatric orthopaedists or in pediatric neuromuscular clinics: HMSN Type IV, Refsum disease, is characterized by excessive phytanic acid; HMSN Type V is an inherited spastic paraplegia, with distal weakness in the limbs presenting in the second decade of life, and characterized by an awkward gait and equinus foot deformities; HMSN Type VI is characterized by optic atrophy in association with peroneal muscle atrophy; and HMSN Type VII is associated with retinitis pigmentosa, distal weakness in the limbs, and muscle atrophy.

Diagnostic Studies. Diagnosis of HMSN is made by physical examination, in combination with EMG, nerve conduction studies, and genetic testing. The EMG findings in HMSN show typical neuropathic changes, with increased amplitude and duration of response. Nerve conduction studies in patients with the demyelinating HMSN Types I and III show marked slowing of the rate of impulse conduction in the muscles involved. A biopsy specimen of a muscle such as the gastrocnemius demonstrates typical neuropathic findings, including atrophy of the fiber group, with all of the fibers in an abnormal group having uniformly small diameter. A biopsy specimen of a peripheral nerve, usually the sural nerve, shows typical demyelinization, confirming the diagnosis of peripheral neuropathy.

Genetic and Molecular Biology Studies. Many individuals with HMSN Type I have a DNA duplication of a portion of the short arm of chromosome 17 in the region of p11.2 to p12 (17, 306–308). Additional studies have shown a human peripheral myelin protein-22 gene to be contained within the duplication (309–311). It is thought that the abnormality in the peripheral myelin protein-22 gene, which encodes the myelin protein, has a causative role in Charcot-Marie-Tooth disease. Either a point mutation in peripheral myelin protein-22 or duplication of the region that contains the peripheral myelin protein-22 gene can result in the disorder (312).

HMSN Type II is heterogeneous in its inheritance mode, occurring either as an autosomal dominant or as an autosomal recessive trait (313). Chromosome linkage has been identified at 1p35–36 (314), at 8p21 involving the neurofilament-light gene (315), and on 7q11-q21 (316). HMSN Type III, previously referred to as Dejerine-Sottas disease, also shows genetic heterogeneity, with multiple loci identified to date. Inheritance typically follows an autosomal recessive pattern.

Confirmatory diagnosis can be made by DNA testing.

Treatment. Children with HMSN typically present with gait disturbance or foot deformities. The severity of involvement is variable. In severe involvement, there may be proximal muscle weakness. The major orthopaedic problems include pes cavovarus, hip dysplasia, spinal deformity, and hand and upper extremity dysfunction.

Historically, the mainstay in the treatment of the HMSNs has been the orthopaedic approach. Recently, however, there have been promising results with the use of progesterone receptor antagonists. In transgenic rat studies, administration of selective progesterone receptor antagonists led to decreased overexpression of PMP22 and improved CMT phenotype (317). Presently, human studies are underway and appear promising (318).

Pes Cavovarus. The pathogenesis of cavovarus deformities in children with HMSN and other neuromuscular disorders is becoming better understood (319–325). The components of the pes cavovarus deformity include claw toes; plantar-flexed first metatarsal with adduction and inversion of the remaining metatarsals; midfoot malposition of the navicular, cuboid, and cuneiforms, leading to a high arch (cavus); and hindfoot varus malposition between the talus and calcaneus (Fig. 16-9). Initially, HMSNs affect the more distal muscles. The mildest cases show involvement of the toes and forefoot, whereas the midfoot and hindfoot are progressively affected with progression of the disease process. In a computed tomography study of 26 patients with HMSN I, II, or III, Price et al. (326) found that the interossei and lumbrical muscles of the feet demonstrated earlier and more severe involvement than the extrinsic muscles. These intrinsic muscles have the most distal innervation. Even with minimal weakness, the invertor muscles, such as the tibialis anterior and tibialis posterior muscles, are stronger than the evertors, such as the peroneus longus; this relation favors the development of adduction and varus deformities.

Pes cavovarus deformities are progressive, but the rate is variable, even among patients belonging to the same family. Initially, the deformity is flexible but later becomes rigid. Shapiro and Specht (253) identify the plantar-flexed first metatarsal as the key finding. As the first metatarsal becomes increasingly plantar flexed, increasing hindfoot varus and supination and cavus of the forefoot and midfoot follow. The block test is useful for determining the mobility of the remainder of the foot in children with a rigid plantar-flexed first metatarsal (322).

The goals in the treatment of foot deformities in children with HMSN include maintenance of a straight, plantigrade, and relatively flexible foot during growth (324, 325, 327). This maximizes function and minimizes the development of osseous deformities that may require more extensive surgery (such as a triple arthrodesis) in adolescence and early adult years.

The treatment options for the management of foot deformities include plantar release, plantar–medial release,

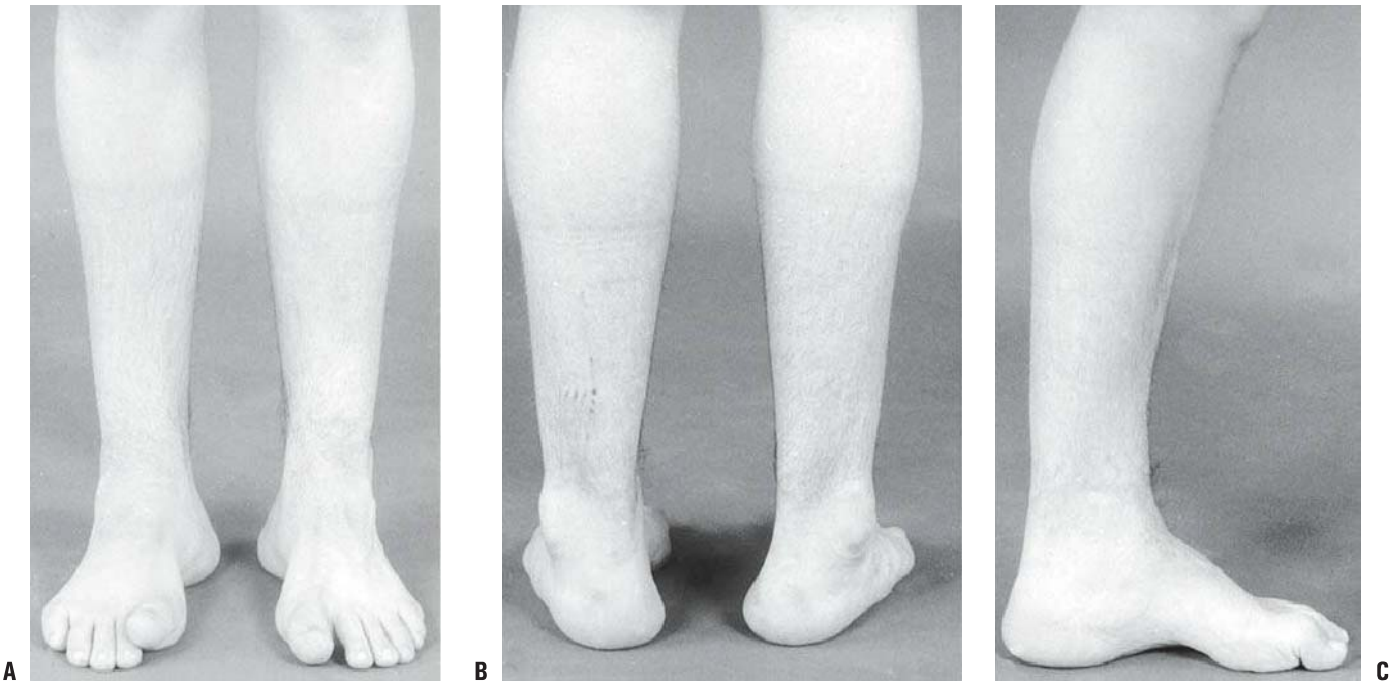

FIGURE 16-9. **A:** Front view of the lower legs and feet of a 16-year-old boy with hereditary motor sensory neuropathy Type I (i.e., Charcot-Marie-Tooth disease). His calves are thin, and he has mildly symptomatic cavus feet. Clawing of the toes is minimal. **B:** Posterior view demonstrates moderate heel varus. **C:** The cavus foot deformity is most apparent when viewed from the medial side. A mild flexion deformity of the great toe interphalangeal joint is present.

tendon transfers, calcaneal osteotomy, midtarsal osteotomy, triple arthrodesis, and correction of toe deformities (321, 322, 324, 325).

Plantar Release. In children younger than 10 years with a mild cavovarus deformity, a plantar release may be helpful in correcting the plantar-flexed first metatarsal and providing correction of the associated flexible deformities of the hindfoot and midfoot (328). In the radical plantar release described by Paulos et al. (322), selective Z-lengthening of the long toe flexor tendons and the tibialis posterior tendon are performed if there is a "bowstring" effect after plantar release.

Plantar–Medial Release. In a child younger than 10 years, if the hindfoot deformity is rigid and leading to fixed varus deformity, the plantar release may be combined with a medial release (322). The medial structures to be released include the ligamentous and capsular structures between the talus and calcaneus (except the posterior talocalcaneal ligament), and the capsule of the talonavicular joints. The navicular is then reduced onto the head of the talus and secured with a smooth Steinmann pin. The posterior ankle and subtalar joint ligaments and the tendo-Achilles are not disturbed because they are necessary for counterresistance during postoperative serial casting. Once the incision has healed, a series of corrective weight-bearing casts are applied. Excellent correction of the entire foot has been reported after this technique.

Tendon Transfers. In children and adolescents with flexible cavovarus deformities in which active inversion is associated with relative weakness of the evertor muscles, a transfer of the tibialis anterior tendon to the dorsum of the midtarsal region in line with the third metatarsal may be helpful (329). The transfer is designed to balance strength, but the foot must be aligned initially by a plantar release and perhaps the plantar–medial release.

Other tendinous procedures that may be used depend on the individual needs of the patient. These may include tendo-Achilles lengthening, anterior transfer at the tibialis posterior tendon, long toe extensors to the metatarsals or midfoot, and flexor-to-extensor tendon transfers for claw toes (322, 329). Tendo-Achilles lengthening is rarely necessary, as the equinus is due to the plantar-flexed first metatarsal and forefoot. The hindfoot is typically in a calcaneus position.

Calcaneal Osteotomy. In children who are younger than 10 years and who have mild but fixed deformity, a calcaneal osteotomy may be helpful in correcting the varus deformity of the hindfoot (253). This osteotomy does not interfere with growth because it is not made through a cartilaginous growth area. To allow lateral translation, the osteotomy is cut slightly obliquely, passing from a superior position on the lateral surface to a more inferior position on the medial surface. It is possible to translate the distal fragment by as much as one-third of its transverse diameter, thereby allowing conversion of weight bearing from varus to mild valgus. In patients who are older than 10 years or who are more severely affected, a lateral closing-wedge calcaneal osteotomy, with lateral translation of the distal and posterior fragments, is performed (Fig. 16-10) (253). In both procedures, the osteotomy is stabilized with staples or Steinmann pins.

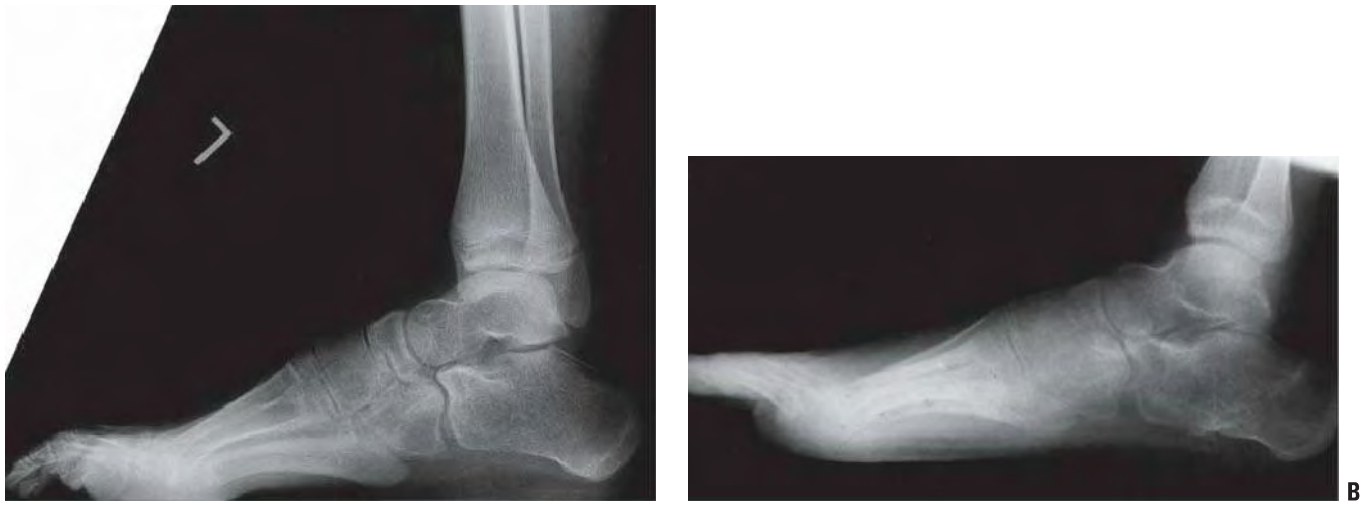

FIGURE 16-10. **A:** Moderate cavovarus deformity of the left foot in a 14-year-old boy with Charcot-Marie-Tooth disease. His condition was managed with a closing-wedge valgus osteotomy at the calcaneus, an opening-wedge, plantar-based osteotomy of the medial cuneiform, and soft-tissue balancing. **B:** Postoperatively, the cavovarus deformity has been improved. He is a brace-free ambulator because of restoration of muscle balance.

Metatarsal Osteotomy. The metatarsal osteotomy provides correction by removal of a dorsal and slightly laterally based wedge, with the proximal osteotomy cut through the acicular and cuboids, and the distal cut through the cuboids and three cuneiforms. Moderate deformities can be corrected satisfactorily with this procedure, especially if it is augmented with a plantar release, calcaneal osteotomy, and perhaps an anterior transfer of the tibialis anterior tendon. Equinus deformities of the midfoot and varus deformities of the forefoot can be corrected with appropriate wedge resections. Growth retardation and limitation of mobility are minimal when compared with the situation after a triple arthrodesis. Recently, the use of the Ilizarov external fixator and a V-osteotomy has been shown to be effective in achieving a painless plantigrade foot (330). This approach can obviate the need for a triple arthrodesis in selected patients. Recently, Ward et al. (331) reported very long-term results of 25 patients (41 ft) treated with a base at the first metatarsal osteotomy, transfer of the extensor hallucis longus to the metatarsal neck, a plantar release, transfer of the peroneus longus to the peroneus brevis, and, in a few selected cases, centralization of the tibialis anterior tendon. At a mean follow-up of 26.1 years, the feet were functioning well. They had a slight increase in hindfoot varus and low evidence of ankle degenerative osteoarthritis.

Triple Arthrodesis. In adolescents who have reached skeletal maturity and who have a severe deformity, walk with difficulty, and cannot run, a triple arthrodesis may be performed. Every attempt should be made to avoid this procedure because of the associated complications of undercorrection, overcorrection, pseudoarthrosis of the talonavicular joint, and degenerative changes in the ankle and midfoot joints (332–335).

Wetmore and Drennan (334) reported unsatisfactory results in 23 of 30 ft (16 patients) at a mean follow-up at 21 years. The progressive muscle imbalance resulted in recurrent pes cavovarus deformities. There was also an increased incidence of degenerative osteoarthritis of the ankle as a consequence of the deformity and the loss of subtalar joint motion. These surgeons were of the opinion that triple arthrodesis should be limited to patients with severe, rigid deformities. Saltzman et al. (336) reported similar results in 67 ft in 57 patients, including 6 ft in patients with Charcot-Marie-Tooth disease, at 25 and 44 years of mean follow-up. However, 95% of the patients were satisfied with the clinical results.

The Ryerson triple arthrodesis is preferred because the surfaces of the talocalcaneal, talonavicular, and calcaneal cuboids joints are removed, along with appropriate-sized wedges to correct the various components of the hindfoot and midfoot deformities (Fig. 16-11). In patients who have marked equinus of the midfoot and forefoot in relation to a relatively well-positioned hindfoot, the Lambrinudi triple arthrodesis may be performed (337). Once an arthrodesis has been performed to straighten the foot, tendon transfers to balance muscle power are of great importance.

Toe deformities in adolescent patients or in those who have undergone a triple arthrodesis may be corrected by proximal and distal interphalangeal fusion or flexor-to-extensor tendon transfer. The great toe may require an interphalangeal joint fusion and transfer of the extensor hallucis longus from the proximal phalanx to the neck of the first metatarsal (Jones procedure). The latter then serves as a foot dorsiflexor.

Hip Dysplasia. Hip dysplasia in HMSN occurs in approximately 6% to 8% of the children who are affected (338, 339). Occasionally, hips may be dislocatable at birth, although the neuropathy does not become apparent for several years. It is more likely to occur in HMSN Type I than in HMSN Type II

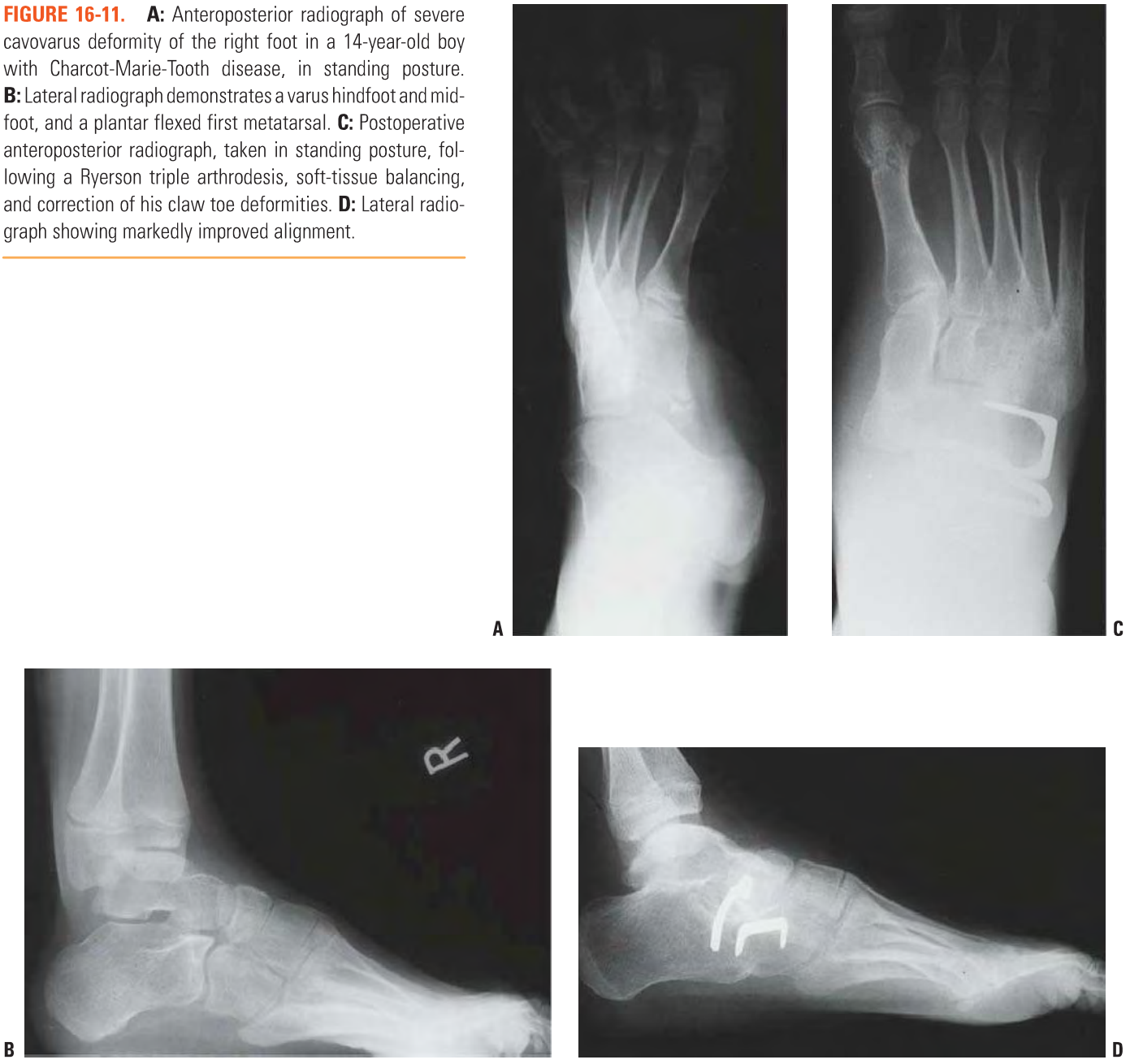

FIGURE 16-11. **A:** Anteroposterior radiograph of severe cavovarus deformity of the right foot in a 14-year-old boy with Charcot-Marie-Tooth disease, in standing posture. **B:** Lateral radiograph demonstrates a varus hindfoot and midfoot, and a plantar flexed first metatarsal. **C:** Postoperative anteroposterior radiograph, taken in standing posture, following a Ryerson triple arthrodesis, soft-tissue balancing, and correction of his claw toe deformities. **D:** Lateral radiograph showing markedly improved alignment.

because of the more severe neurologic involvement in the former. Walker et al. (339) proposed that the slight muscle weakness about the hip in growing children with HMSN may be sufficient to distort growth and development, leading to dysplasia. Usually, hip dysplasia is diagnosed between the ages of 5 and 15 years following mild discomfort (338–341). However, dysplasia may be present in asymptomatic patients (Fig. 16-12). Annual anteroposterior radiographs of the pelvis have been recommended to allow early diagnosis and treatment. Typical radiographic findings include acetabular dysplasia, coxa valga, and subluxation. The treatment of HMSN hip dysplasia includes soft-tissue releases to correct contractures and restore muscle balance, and pelvic or proximal femoral varus derotation osteotomies, or both, to stabilize and adequately realign the hip (338, 340–343). The type of pelvic osteotomy is determined by the patient's age and the severity of the dysplasia. Rotational osteotomies (Salter, Steel) are useful in many children with mild dysplasia, whereas periacetabular osteotomies are useful in adolescents and young adults (342), and the Chiari osteotomy (343) is used when there is severe dysplasia.

Spinal Deformity. Scoliosis occurs in approximately 15% of children with HMSN (344, 345). These children are usually ambulatory, with age of onset of spinal deformity of approximately 12 years. A study by Walker et al. (346) found a 37% incidence of scoliosis or kyphoscoliosis in children with HMSN. A more recent large study by Karol and Elerson (345)

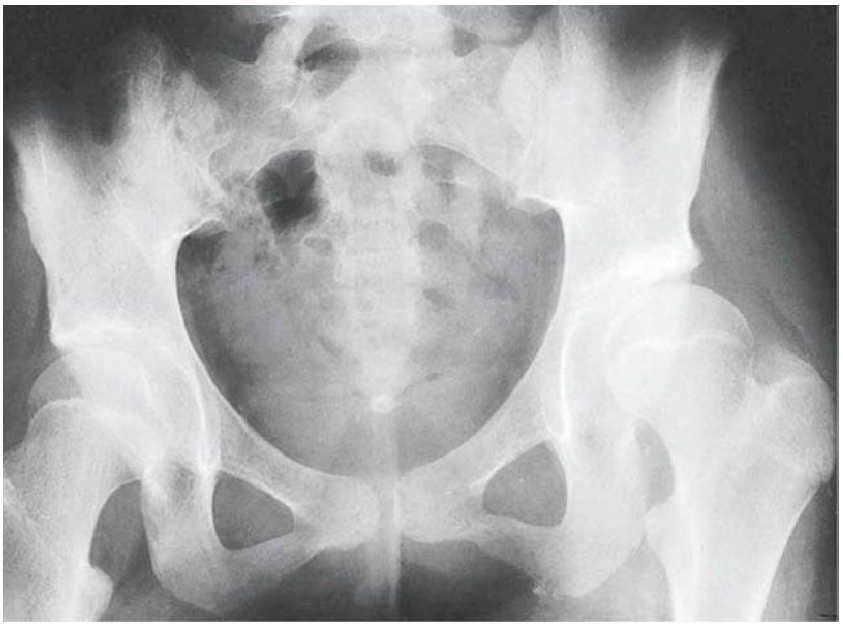

FIGURE 16-12. Anteroposterior pelvic radiograph of a 15-year-old girl with Charcot-Marie-Tooth disease. Asymptomatic acetabular dysplasia of the left hip is visible. The medial joint is slightly widened. The Shenton line is disrupted, and the center-edge angle is 16 degrees. This condition was first observed 6 years earlier and did not progress.

demonstrated a 15% incidence. The incidence increases to 50% in those who were skeletally mature. Spinal deformity is more common in girls and in HMSN Type I. Curve progression requiring orthoses or surgery is common. The curve patterns and management are similar to those in idiopathic adolescent scoliosis, except for an increased incidence of left-sided thoracic curves and associated kyphosis (345). As a consequence, orthotic management can be effective in arresting progression of the deformity. If progression reaches 45 to 50 degrees, a posterior spinal fusion and segmental spinal instrumentation similar to idiopathic scoliosis can effectively stabilize and partially correct the deformity (344, 345). Intraoperative spinal cord monitoring with somatosensory cortical-evoked potentials may show no signal transmission (345, 347). This is because of the demyelinization of the peripheral nerves and perhaps the degeneration of the dorsal root ganglion and dorsal column of the spinal cord. A wake-up test may need to be performed.

Hand and Upper Extremity Dysfunction. The upper extremities are involved in about two-thirds of individuals with HMSN (348, 349). The involvement tends to be milder, however, and does not appear until a later age. Intrinsic muscle weakness with decreased stability is a relatively common finding. In a study of 68 patients with Charcot-Marie-Tooth disease, the mean age at onset of symptoms in the hands and upper extremities was 19 years. Intrinsic muscle function was initially impaired, and patients became aware of motor weakness and a lack of dexterity. Sensory changes such as numbness are usually present concomitantly. Physical and occupational therapy may be helpful. In some patients, operative intervention, such as transfer of the flexor digitorum sublimis to restore opposition, nerve compression releases, soft-tissue contracture releases, and joint arthrodeses, may be effective in improving function. Preoperative EMG has been shown to aid in selecting optimal forearm muscles for tendon transfers to the hand (350).

POLIOMYELITIS

Acute poliomyelitis results from an acute viral infection, with localization in the anterior horn cells of the spinal cord and certain brain stem motor nuclei. It is caused by one of three poliomyelitis viruses known as *Brunhilde* (Type 1), *Lansing* (Type 2), and *Leon* (Type 3). Humans are the natural host for poliomyelitis virus, transmitting the disease by the oropharyngeal route. The poliomyelitis viruses have varying virulence. Most poliomyelitis virus infections have an abortive course, with only mild gastrointestinal symptoms. Fewer than 1% of infections develop into the paralytic form of the disease. The development of prophylactic vaccines has greatly reduced the incidence of polio, although the disease remains a major health problem in developing countries. Fewer than 10 cases occur in the United States annually, and these most commonly result from administering the active oral polio vaccine (351, 352).

Pathology. The poliomyelitis virus invades the body through the oropharyngeal route and multiplies in the gastrointestinal tract lymph nodes before spreading to the CNS by the hematogenous route. The incubation period ranges from 6 to 20 days. Motor neurons in the anterior horn cells of the spinal cord and brain stem are acutely attacked. In the spinal cord, the lumbar and cervical regions are particularly involved. The medulla, cerebellum, and midbrain may also be involved. Except for the motor areas, the white matter of the spinal cord and the cerebral cortex are uninvolved.

Damage to the anterior horn cells may be caused directly by viral multiplication and toxic by-products of the virus, or indirectly from ischemia, edema, and hemorrhage in the glial

tissues surrounding the anterior horn cells. In addition to acute inflammatory cellular reaction, edema with perivascular mononuclear cuffing occurs.

The inflammatory response gradually subsides, and the necrotic ganglion cells are surrounded and partially dissolved by macrophages and neutrophils. After 4 months, the spinal cord is left with residual areas of gliosis and lymphocytic cell collections occupying the area of the destroyed motor cells. Evidence of continuous disease activity has been found in spinal cord segments examined two decades after the onset of the disease. Histopathologic sections demonstrate a loss or atrophy of motor neurons, severe reaction gliosis, and mild-to-moderate perivascular interparenchymal inflammation, with sparing of corticospinal tracts. The skeletal muscle demonstrates gross atrophy and histologic tests show that this lost muscle has been replaced with fat and connective tissue. The percentage of motor units destroyed in an individual muscle varies markedly, and the resultant clinical weakness is proportionate to the number of lost motor units. Sharrard (353) reported that clinically detectable weakness is present only when more than 60% of the motor nerve cells supplying the muscle have been destroyed. The muscles involved may range from those of just one extremity to those of all four extremities, the trunk, and the bulbar musculature.

Muscles innervated by the cervical and lumbar segments are the ones most frequently involved. However, involvement occurs twice as frequently in the lower extremity as in the upper extremity muscles. Sharrard (354) combined clinical and histologic studies that demonstrated that muscles with short motor nerve cell columns are often severely paralyzed, whereas those with long motor cell columns are more frequently left paretic or weak. The quadriceps, tibialis anterior, medial hamstrings, and hip flexors are the lumbar innervated muscles most frequently involved. The deltoid, triceps, and pectoralis major are most frequently affected in the upper extremities. The sacral nerve roots are usually spared, resulting in the characteristic preservation of the intrinsic muscles of the foot (355).

Recovery of muscle function depends on return to function of the anterior horn cells that have been damaged but not destroyed. Clinical recovery begins during the first month after the acute illness and is nearly complete by the 6th month, although there is limited potential for additional recovery through the 2nd year. Sharrard (353) has stated that the mean final grade of a muscle is two grades above its assessment at 1 month and one grade above it at 6 months.

Disease Stages. Management of poliomyelitis varies according to the stage of the disease process. The stages are designated as acute, convalescent, or chronic. Because the acute and convalescent stages are rarely encountered in this country, orthopaedic management is usually confined to the chronic stage. Every year, most pediatric orthopaedic programs see several children with poliomyelitis in the chronic stage. These children have usually been adopted from nonindustrialized nations or from parents who have immigrated from such countries.

Acute Stage. Acute poliomyelitis may cause symptoms ranging from mild malaise to generalized encephalomyelitis with widespread paralysis. Diagnosis is based on clinical findings, because there are no diagnostic laboratory tests. This phase generally lasts 7 to 10 days. The return to normal temperature for 48 hours and the absence of progressive muscle involvement indicates the end of the acute phase. This phase is usually managed by pediatricians because there may be medical problems, especially respiratory, that may be life threatening.

The orthopedist should be familiar with the clinical signs of acute poliomyelitis. Meningismus is reflected in the characteristic flexor posturing of the upper and lower extremities. The muscles involved are tender, even to gentle palpation. Clinical examination can be difficult because of pain during the acute stage.

Orthopaedic treatment during this phase emphasizes prevention of deformity and ensuring comfort. This approach consists of physical therapy with gentle, passive range-of-motion exercises and splinting. Muscle spasms, which can lead to shortening and contractures, may respond to the application of warm, moist heat. This can relieve muscle sensitivity and discomfort. Sharrard (353) emphasized that rapid loss of elasticity, coupled with shortening of tendons, fascia, and ligaments, leads to contractures.

Convalescent Stage. The convalescent phase of poliomyelitis begins 2 days after the temperature returns to normal and progression of the paralytic disease ceases. The phase continues for 2 years, during which spontaneous improvement of muscle power occurs. The assessment of the rate of recovery in poliomyelitis is made by serial examination of the muscle strength. Muscle assessment should be performed once every month for 6 months and then at 3-month intervals during the remainder of the convalescent stage.

Any muscle that demonstrates <30% of normal strength at 3 months after the acute phase should be considered to be permanently paralyzed. Muscles showing evidence of more than 80% return of strength require no specific therapy. Muscles that fall between these two parameters retain the potential for useful function, and therapy should be directed toward recreating hypertrophy of the remaining muscle fibers.

The treatment goals during this phase include efforts to prevent contractures and deformity, restoration and maintenance of normal range of motion of the joints, and help for individual muscles to achieve maximum possible recovery. Physical therapy and orthotics are the main treatment modalities. Physical therapy is directed toward having individual muscles assume maximum capability within their pattern of normal motor activity and not permitting adaptive or substitute patterns of associated muscles to persist. Hydrotherapy can also be helpful in achieving these goals. Orthoses, both ambulatory and nighttime, are necessary for supporting the extremity during this phase.

Chronic Stage. The chronic stage of poliomyelitis begins after 2 years, and it is during this stage that the orthopedist

assumes responsibility for the long-term management resulting from muscle imbalance (356).

The management goal during the chronic stage is to achieve maximal functional capacity. This is accomplished by restoring muscle balance, preventing or correcting soft-tissue contractures, correcting osseous deformities, and directing allied personnel, such as physical therapists, occupational therapists, and orthotists. Using this approach, Arora and Tandon (357) have shown that ambulation can be restored in patients who could only crawl earlier (328). Therefore, each patient requires a careful evaluation to determine what procedures may be effective in restoring ambulation, if possible, and maximizing function.

Treatment

Soft-Tissue Contractures. Flaccid paralysis, muscle imbalance, and growth all contribute to soft-tissue contractures and fixed deformities in poliomyelitis. Contractures result from the increased mechanical advantage of the stronger muscles that continue the attenuation of their weaker antagonists. The greater the disparity in muscle balance, the sooner a contracture may develop.

Instability of a joint does not result in a fixed deformity, except in cases where it is allowed to persist over a period of years in a growing child. Static instability can be controlled readily and indefinitely by orthoses. Dynamic instability of a joint readily produces a fixed deformity, and orthotic control is difficult. Deformities are initially confined to soft tissues, but later, bone growth and joint alignment may also be affected.

The age at onset of poliomyelitis is significant. The osseous growth potential of young children makes them more vulnerable to secondary osseous deformities. The worst deformities occur in young children and those with severe muscle imbalance. Release of soft-tissue contractures and appropriate tendon transfers performed in a young child are crucial for preventing structural changes.

Tendon Transfers. Achievement of muscle balance in patients with dynamic instability effectively halts progression of paralytic deformity. Tendon transfers are performed when dynamic muscle imbalance is sufficient to produce deformity, and when orthotic protection is required. Transfers should be delayed until the paralyzed muscle has been given adequate postural treatment to ensure that it has regained maximum strength and that the proposed tendon transfer is really required. The objectives of tendon transfer are to provide active motor power to replace function of a paralyzed muscle or muscles, to eliminate the deformity caused by a muscle when its antagonist is paralyzed, and to produce stability through better muscle balance.

The muscle to be transferred should be rated good or fair before transfer, and must have adequate strength to actively perform the desired function. On an average, one grade of motor power is lost after muscle transfer. The length and range of motion of the transferred muscle and that of the muscle being replaced must be similar. Loss of original function resulting from tendon transfers must be balanced against potential gains. Free passive range of motion is essential in the absence of deformity at the joint to be moved by the tendon transfer. A transfer as an adjunct to bony stabilization cannot be expected to overcome a fixed deformity. The smooth gliding channel for the tendon transfer is essential. A traumatic handling of the muscle tissue can prevent injury to its neurovascular supply and prevent adhesions. The tendon should be rooted in a straight line between its origin and new insertion. Attachment of the tendon transfer should be under sufficient tension to correspond to normal physiologic conditions and should allow the transferred muscle to achieve a maximum range of contraction.

Osteotomies. Osseous deformities may produce deformities in the joints, and thereby impair the alignment of the extremities, mostly the lower extremities, and limit their ability to function. Osteotomies can be helpful in restoring alignment and improving function. Because of possible recurrence during subsequent growth, these procedures are usually postponed, if possible, until late childhood or early adolescence.

Arthrodeses. Arthrodeses are usually performed for salvage, except in the foot where a subtalar, triple, or pantalar arthrodesis may be useful in stabilization and realignment.

Treatment Guidelines. The basic treatment guidelines for chronic or postpoliomyelitis in children have been outlined by Watts (358). These guidelines include restoring ambulation, correcting the factors that cause deformities with growth, correcting factors that reduce dependency on orthoses, correcting upper extremity problems, and treating spinal deformities. Understandably, these guidelines allow the child or adolescent to achieve the maximum possible functional level. The specific methods of achieving each guideline are multiple, sometimes complex, and based on careful evaluation of the patient. Because children with previous poliomyelitis are infrequently encountered, specific details on the various procedures are not presented. Such information can be obtained from the references in the various sections.

The orthopedist must establish a comprehensive plan for each child on the basis of a thorough musculoskeletal examination—in particular, range of motion of the joints, existing deformities, and manual testing of the individual muscles of the extremities and trunk. The latter should be individually recorded on a worksheet that can be available for future reference. It is important to remember that a muscle normally loses one grade of power when transferred. To be functionally useful, a muscle grade of at least 4 is necessary, although a grade 3 muscle, when transferred, may be an effective tenodesis in preventing deformity by balancing an opposing muscle.

Upper Extremity. In polio, involvement of the upper extremities tends to be less severe than that of the lower extremities. A stable upper extremity, especially the shoulder, is necessary for supporting body weight when using a walker or crutches. It is also necessary for transfers or for shifting the

trunk if the patient is wheelchair bound. A functional elbow, wrist, and hand are necessary for optimum independent functioning.

Shoulder. Shoulder stability is essential for all upper extremity activities. Satisfactory levels of functioning of the hand, forearm, and elbow are a prerequisite for any reconstructive surgery on the shoulder. The major problems affecting the shoulder are paralysis of the deltoid, pectoralis major, subscapularis, supraspinatus, and infraspinatus muscles. Rarely are all these muscles involved because they are innervated at different levels. Tendon transfers can occasionally be effective in restoring shoulder stability. When there is extensive weakness, shoulder arthrodesis may be helpful. Arthrodesis may also be indicated where there is a painful subluxation or dislocation. A strong trapezius serratus anterior muscle is necessary for allowing improved functioning after fusion. El-Gammal et al. (359) recently demonstrated that, after a shoulder fusion and a free-functioning gracilis muscle transplantation, there was improvement in upper extremity function in children and adolescents with a flail shoulder and elbow caused by poliomyelitis. The muscle was reinnervated by the spinal accessory or phrenic nerve. All transplanted muscles gained at least grade 3 power. The best results occurred with the reinnervation by the spinal accessory nerve.

Elbow. The major problem affecting the elbow is loss of flexion. When the biceps and brachialis are paralyzed, a tendon transfer may be helpful in restoring useful elbow flexion. Possible procedures include a Steindler flexorplasty, which transfers the origin of the wrist flexors to the anterior aspect of the distal humerus (360). The best functional results occur in patients whose elbow flexors are only partially paralyzed and whose fingers and wrist flexors are normal. Transfer of the sternal head of the pectoralis major may also be considered. Other possible procedures include transfer of the sternocleidomastoid and latissimus dorsi, and anterior transfer of the triceps brachii. Paralysis of the triceps brachii muscle may occur in poliomyelitis, but it seldom interferes with elbow function because gravity passively extends the elbow. The triceps brachii muscles need to function, however, for activities in which the body weight is shifted to the hands (such as in transferring from bed to wheelchair) or in crutch walking.

Forearm. Fixed deformities of the forearm seldom create major functional disabilities in children and adolescents with poliomyelitis. Pronation contractures are the most common disability. Functioning can be improved with release of the pronator teres and transfer of the flexor carpi ulnaris muscle.

Hand. Tendon transfers and fusions for improving the functioning of the hand can be considered in selected cases. The number of possible transfers is large, and each patient requires a careful evaluation in order to ensure maximum functional improvement. Carpal tunnel syndrome has also been reported as one of the long-term sequelae of poliomyelitis and is associated with prolonged use of crutches or a cane (361).

Lower Extremity. Lower extremity problems are most common in poliomyelitis. They can have a significant impact on functional ability, especially ambulation.

Lower Extremity Length Discrepancy. This is a common problem when there is asymmetrical neurologic involvement. If the discrepancy is >2 cm, it can produce a great many disturbances. An appropriately timed contralateral epiphyseodesis is the usual procedure of choice. Greater discrepancy may be treated orthotically. Lengthening is rarely considered as an option. However, D'Souze and Shah (362) recently demonstrated that circumferential periosteal sleeve resection of the distal femur and/or distal tibia can produce a transient growth stimulation that can be helpful in mild discrepancies, usually 2 to 3 cm.

Hip. Hip problems in poliomyelitis include muscle paralysis, soft-tissue contractures, internal or medial femoral torsion, coxa valga, and hip subluxation and dislocation. Periodic anteroposterior radiographs of the pelvis are necessary for assessing growth and the relation between the femoral head and the acetabulum. Functioning can be improved and subluxation–dislocation prevented, with appropriate soft-tissue releases, tendon transfers, proximal femoral varus derotation osteotomy, and pelvic osteotomy (Fig. 16-13) (363). It is important that the procedures be coordinated in order to provide as balanced a musculature as possible so that hip stability can be maintained. Lau et al. (363) reported good or satisfactory results in 70% of patients with paralytic hip instability caused by poliomyelitis. The key parameters for successful management are muscle balance, the femoral neck shaft and anteversion angles, and the acetabular geometry.

Knee. Flexion contractures, extension contractures, genu valgum, and external rotation of the tibia are the common knee deformities in poliomyelitis that can produce an adverse effect on functional ambulation. Hamstring release, distal femoral extension osteotomy, proximal femoral extension osteotomy, and rotational tibial osteotomies are common procedures (364–368). One of the most common soft-tissue procedures is that described by Yount (97), in which the distal iliotibial band, including the intermuscular septum, is released. This may be combined with an Ober (98) release proximally if hip-flexion contractures are also present. Shahcheraghi et al. (369) recently reported that anterior hamstring tendon transfer significantly improved active knee extension and function in patients with paralysis of the quadriceps femoris muscle following poliomyelitis.

Foot and Ankle. Deformities of the foot (usually cavus and cavovarus) and ankle are among the most common in adolescents with poliomyelitis (324, 370). Drennan (370) has discussed possible procedures for correcting the deformities and improving muscle balance. This is achieved by a combination of procedures: correction of soft-tissue contractures, tendon transfers, and bone-stabilizing procedures such as calcaneal osteotomy, subtalar arthrodesis, triple arthrodesis, and pantalar arthrodesis (371–377). Recently, the use of the Ilizarov external

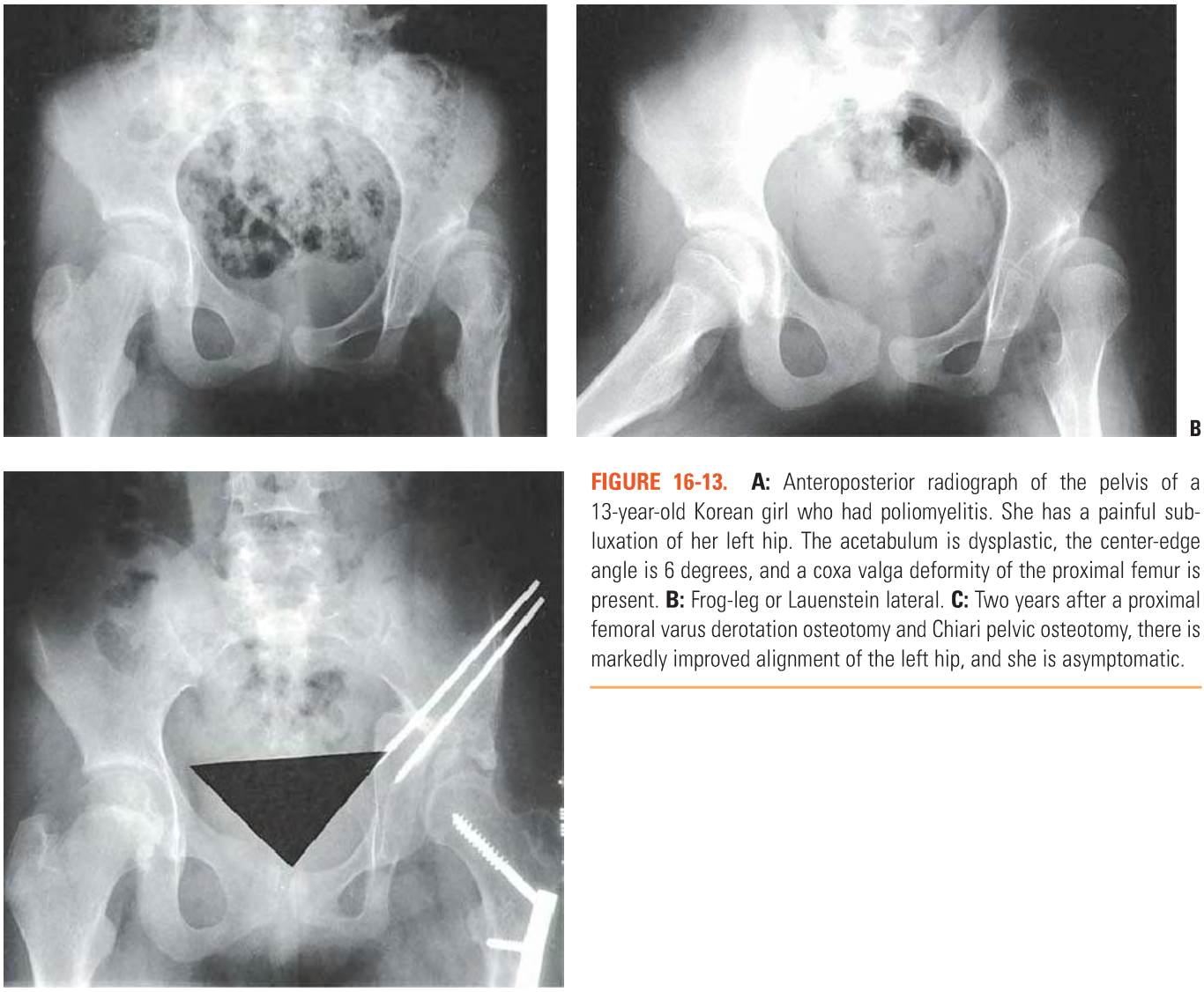

FIGURE 16-13. **A:** Anteroposterior radiograph of the pelvis of a 13-year-old Korean girl who had poliomyelitis. She has a painful subluxation of her left hip. The acetabulum is dysplastic, the center-edge angle is 6 degrees, and a coxa valga deformity of the proximal femur is present. **B:** Frog-leg or Lauenstein lateral. **C:** Two years after a proximal femoral varus derotation osteotomy and Chiari pelvic osteotomy, there is markedly improved alignment of the left hip, and she is asymptomatic.

fixator has been shown to be helpful in correction of complex foot deformities following poliomyelitis (378). A careful evaluation of the patient is required for determining the appropriate procedures. Arthrodeses produce good long-term results with a low incidence of ankle degenerative arthritis, because patients with poliomyelitis place lower functional demands and stresses on the ankle (371, 374, 375).

Spine. Scoliosis occurs in about one-third of patients with poliomyelitis. The type and severity of the curvature depends on the extent of paralysis and residual muscle power of the trunk muscles and pelvic obliquity. The most common curve patterns are the double major thoracic and lumbar curves, followed by the long paralytic C-shaped thoracolumbar curve (379). Pelvic obliquity occurs in approximately 50% of the patients with spinal deformity. Because of severe rotation, kyphosis in the lumbar spine and lordosis in the thoracic spine are also common.

The goals of treatment are to obtain a balanced, vertical torso over a level pelvis. This permits stable sitting and leaves the hands free for activities. It also helps prevent decubiti and paralytic hip dislocation. In young children with curves of between 20 and 40 degrees, orthotic management with a TLSO can be tried. It rarely provides complete stability, but can be effective in slowing the rate of progression and allowing the child to reach a more suitable age for surgery. In severe cases in young children, segmental spinal instrumentation without fusion may be considered. Eberle (380), however, reported failure of segmental spinal instrumentation in 15 of 16 children with poliomyelitis between the ages of 5 and 12 years. Therefore, children who undergo instrumentation without fusion should be treated with TLSO and subsequently undergo a fusion procedure as soon as possible in order to prevent late complications. For adolescents with a supple spine and a curve of <60 degrees, a posterior spinal fusion with segmental instrumentation, usually Luque rod instrumentation, provides stability and a low pseudoarthrosis rate (116, 379). Other segmental spinal instrumentation systems are also effective. In severe curves of 60 to 100 degrees, a combined anterior and posterior spinal fusion is usually necessary (381). Anterior

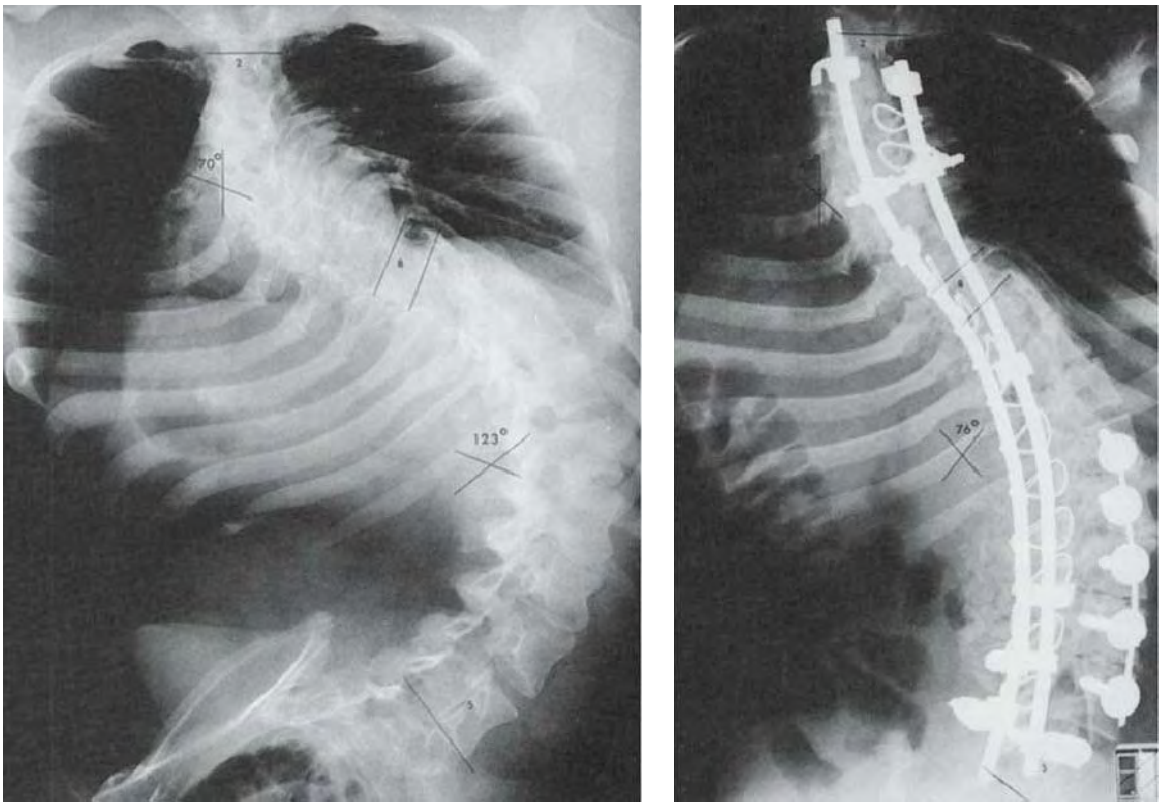

FIGURE 16-14. **A:** Anteroposterior spinal radiograph, taken in the seated position, of a 17-year-old girl from the Middle East who has a severe paralytic scoliosis. There is a 123-degree left thoracolumbar scoliosis and a 70-degree right thoracic scoliosis. She contracted poliomyelitis at the age of 2 years, which left her with flail lower extremities and essentially normal upper extremities. She is wheelchair dependent and has pain from rib-pelvis impingement. **B:** Postoperative radiograph after staged anterior spinal fusion and Zielke instrumentation and posterior spinal fusion using Isola instrumentation from T3 to the sacrum. Pain relief was complete and sitting balance improved. The left thoracolumbar curve has been reduced to 70 degrees and the right thoracic curve to 47 degrees.

spinal instrumentation with a Dwyer or Zielke system may be used in thoracolumbar and lumbar curves. Anterior discectomy and fusion is preferred for thoracic curves. The posterior spinal fusion and instrumentation may be performed the same day, or performed 1 or 2 weeks later. Leong et al. (382) and others (381, 383) have demonstrated that combined anterior and posterior spinal fusions provide excellent correction for postpoliomyelitis spinal deformity, including the associated pelvic obliquity (Fig. 16-14). Rarely is preoperative traction, or traction between staged anterior and posterior procedures, necessary for additional correction. Fusion to the pelvis or sacrum is usually necessary in patients with severe pelvic obliquity (384, 385).

POSTPOLIOMYELITIS SYNDROME

Postpoliomyelitis syndrome is a true entity occurring in adults, and is a sequela to poliomyelitis. Reactivation of the poliomyelitis virus has been mistaken for amyotrophic lateral sclerosis. Postpoliomyelitis syndrome is thought to be an overuse syndrome (386). Diagnosis is based on five criteria and is essentially a diagnosis of exclusion. The criteria include

1. A confirmed history of previous poliomyelitis
2. Partial to fairly complete neurologic and functional recovery
3. A period of neurologic and functional stability of at least 15 years' duration
4. Onset of two or more of the following health problems since achieving a period of stability: unaccustomed fatigue, muscle and joint pain or both, new weakness in muscles previously affected or unaffected, functional loss, intolerance to cold, and new atrophy
5. No other medical diagnosis to explain the aforementioned health problems

Postpoliomyelitis syndrome is more likely to develop in those with onset later than the age of 10 years, because older children are more likely to have severe poliomyelitis. Management of these patients is conservative and consists of muscle strengthening, decreasing the duration of effort, and orthotics (386). Reconstructive surgery is rarely indicated or necessary.

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