Introduction
The 2006 definition of cerebral palsy (CP) has been widely accepted and is recommended as the most useful operational definition of CP (Rosenbaum et al. 2007). This definition includes the term ‘secondary musculoskeletal problems’ as part of the spectrum of features seen in CP. This recognizes the impact of musculoskeletal pathologies on functioning for persons with CP. The focus of this section will be the effects of the brain lesion on the motor function of the lower limbs, pelvis, and spine. The authors work together in a gait laboratory and hip surveillance clinic with a commitment to provide clinical services and to improve the evidence base by clinical research. The framework for this section will be based on the World Health Organization International Classification of Functioning (ICF) and the Gross Motor Function Classification System (GMFCS) (Palisano et al. 1997, World Health Organization 2001).

Classification: Gross Motor Function Classification System
The development of the GMFCS has for the first time given clinicians and parents a common language to communicate about cerebral palsy (Figs 27.1 and 27.2) (Palisano et al. 1997, 2008). The GMFCS is a classification system and it is essential when discussing gross motor function in children with CP. It should be used alongside the classification of upper limb function (Manual Ability Classification System) and communication abilities (Communication Function Classification System) to provide the essential context for considering the individual child’s prognosis, goal setting, and management (Eliasson et al. 2006, Hidecker et al. 2011). For example, a child classified in GMFCS level IV aged between 6 and 12 years may perform some stepping with a heavily adapted walker, under the supervision of a therapist or parent. However, following the pubertal growth spurt, useful walking is not sustained. It would be inappropriate to offer such children invasive treatments to improve or prolong walking because these will not be successful in the long term. A more appropriate goal would be to maintain standing transfers.

The GMFCS has strong predictive value in other domains. Certain musculoskeletal features and deformities are closely related to GMFCS level. The shape of the proximal femur shows a strong correlation with GMFCS level. Femoral neck anteversion (FNA) increases from GMFCS level I to level III and then plateaus at a mean of 40 degrees in GMFCS levels III, IV and V. Mean neck shaft angle, increases stepwise from GMFCS level I through to GMFCS level V (Robin et al. 2008). The incidence and severity of hip displacement is directly predicted by GMFCS level. In our population-based study, children in GMFCS level I showed no hip displacement and those in GMFCS level V had a 90% incidence of having a migration percentage in excess of 30% (Soo et al. 2006). The relationship between GMFCS and hip displacement has implications for screening and management protocols.

Knowing a child’s GMFCS level is fundamental in establishing gross motor prognosis and monitoring changes (Rosenbaum et al. 2002). Changes in GMFCS levels should be carefully documented. The GMFCS may not be stable in the very young child. However, the most common reason for a change in GMFCS is an error in interpretation of the previous or current examination. Given that the GMFCS is a categorical grading system, true changes in GMFCS level sometimes occur and these may occur in both directions, that is improvement or deterioration. After major intervention such as selective dorsal rhizotomy (SDR) or Single Event Multilevel Surgery (SEMLS), a small number of children move up a level. This is uncommon and should not be expected in more than 5% to 10% of children (Rutz et al. 2012b). Deterioration in GMFCS level is more common. For example, lengthening of the Achilles tendons in children in GMFCS level II can result in progressive crouch gait, and the need for assistive devices. For these children, their gait and function deteriorates and GMFCS level changes from II to III (Rodda, Graham, and Galea 2006).

Motor curves and cerebral palsy
The development of gross motor function in children with CP can be described by a series of curves (Rosenbaum et al. 2002). Understanding the position of a child’s development in relation to their gross motor curve provides a rational basis for the understanding of management strategies, goal setting, and long-term gross motor function (Hanna et al. 2008). For example, a 2-year-old child in GMFCS level II with signs of bilateral spastic CP, is treated with a physiotherapy programme, ankle–foot orthoses (AFOs), and injections of botulinum neurotoxin-A (BoNT-A) to the gastrocsoleus and hamstring muscles. Within 3 months, the child is noted to have progressed
from standing with support to independent walking. Whilst the intervention programme may well have contributed to these gains in gross motor function, the child is at the stage of rapid acquisition of gross motor function with or without intervention. This underlines the need for intervention studies in the first 6 years of life to be controlled. The popularity of many forms of intervention in early childhood in children with CP is the mistaken attribution of improvements in gross motor function to the intervention, when natural history has such a large effect. Association is not causation.

In most children gross motor function reaches a plateau between 3 and 6 years with some regression in later childhood.
Fig. 27.2. Gross Motor Function Classification System (GMFCS) E & R between 12th and 18th birthday: descriptors and illustrations.

GMFCS Level I
Youth walk at home, school, outdoors and in the community. Youth are able to climb curbs and stairs without physical assistance or a railing. They perform gross motor skills such as running and jumping but speed, balance and coordination are limited.

GMFCS Level II
Youth walk in most settings but environmental factors and personal choice influence mobility choices. At school or work they may require a hand held mobility device for safety and climb stairs holding onto a railing. Outdoors and in the community youth may use wheeled mobility when traveling long distances.

GMFCS Level III
Youth are capable of walking using a hand-held mobility device. Youth may climb stairs holding onto a railing with supervision or assistance. At school they may self-propel a manual wheelchair or use powered mobility. Outdoors and in the community youth are transported in a wheelchair or use powered mobility.

GMFCS Level IV
Youth use wheeled mobility in most settings. Physical assistance of 1-2 people is required for transfers. Indoors, youth may walk short distances with physical assistance, use wheeled mobility or a body support walker when positioned. They may operate a powered chair, otherwise are transported in a manual wheelchair.

GMFCS Level V
Youth are transported in a manual wheelchair in all settings. Youth are limited in their ability to maintain antigravity head and trunk postures and control leg and arm movements. Self-mobility is severely limited, even with the use of assistive technology.

(Fig. 27.3). One of the causes for this regression in gross motor function is progressive musculoskeletal pathology (Graham 2004).

After age 6 years, gait parameters deteriorate as contractures and bony deformities increase. Changes in gross motor function and gait during the plateau/early decline phase, can be more realistically attributed to intervention. Longitudinal cohort studies are less liable to misinterpretation than in the birth to 6 years age group.

Sagittal gait patterns: unilateral spastic cerebral palsy
In 1987, Winters, Gage, and Hicks classified the sagittal gait patterns in unilateral spastic CP (hemiplegia) in a cross-sectional study (Winters, Gage, and Hicks 1987). Their four
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Sagittal gait patterns: bilateral spastic cerebral palsy
Sagittal gait patterns in bilateral spastic CP (diplegia), can be classified as true equinus, jump gait, apparent equinus, and crouch gait (Rodda et al. 2004) (Fig. 27.5). There is a group of patients in whom the gait deviations in the sagittal plane are minimal but who have substantial transverse plane issues, usually internal hip rotation. This gait pattern has been described as ‘mild gait’.

True equinus
True equinus is characterized by walking on tip toe with the knees and hips extended. It is commonly seen in younger children with bilateral spastic CP when they first learn to walk. The plantarflexion-knee-extension couple is overactive and the ground reaction force (GRF) is in front of the knee throughout the stance phase of gait.

Jump gait
Jump gait is characterized by equinus at the ankle associated with incomplete extension at the knee and hip in mid-stance. There may be excessive flexion at initial contact with rapid extension in later stance to near normal range. In other children, there is more severe knee flexion throughout stance, combined with incomplete hip extension. This is the most common pattern in the pre-adolescent.

Apparent equinus
Apparent equinus is characterized by toe walking but with near normal ankle range of motion. There is flexion present at the knees and hips. The recognition of ‘apparent equinus’ in group classification has been extensively used by clinicians as a template to guide clinical management, the prescription of orthoses, spasticity management by injection of BoNT-A, and musculoskeletal surgery (Fig. 27.4).

Type I hemiplegia
In type I hemiplegia there is a drop foot in the swing phase of gait which is due to loss of selective motor control and/or weakness in tibialis anterior. There is no contracture of the gastrosoleus and the second rocker in gait is relatively normal.

Type II hemiplegia
In type II hemiplegia, there is equinus in stance phase and foot drop in swing phase. There is spasticity in the gastrosoleus which gradually becomes fixed resulting in a contracture.

Type III hemiplegia
In type III hemiplegia, there is equinus at the ankle, with reduced range of motion at the knee and co-contraction of the hamstrings and rectus femoris.

Type IV hemiplegia
In type IV hemiplegia, there is equinus at the ankle, a flexed, stiff knee, and involvement at the hip, with incomplete hip extension. In the coronal plane there is excessive hip adduction and in the transverse plane, excessive internal rotation and pelvic retraction. Contractures are present as seen in type III with the addition of hip adductor and hip flexor contracture and the risk of hip dysplasia.

Fig. 27.3. Gross motor curves in children with cerebral palsy and the five levels of the Gross Motor Function Classification System (GMFCS) modified from Hanna (2008).
Lower Limb Function

Cerebral—Cerebral Palsy

Patients with a posterior pelvic tilt. When the pelvis is in the neutral range, the hamstrings are of normal length and when the pelvis is anteriorly tilted, the hamstrings are excessively long. Without the use of IGA and the modelling of muscle lengths, it is very difficult to appreciate these findings. The popliteal angle is decreased, the hamstrings feel tight and are therefore incorrectly assumed to be short (Rodda, Graham, and Galea 2006).

Assessment/measurement (see also Chapter 18)

The World Health Organization’s ICF describes health conditions in several domains, including body structure and function, activities and participation (World Health Organization 2001). These domains are influenced by environmental factors and personal factors. Various tools exist to measure parameters relevant to CP in the ICF domains and new measurement tools are being developed. When considering measurement of the lower limb in children with CP it is important to consider all of the components of the ICF. There are valid and reliable tools to classify and measure some aspects of gross motor function in the lower limbs (Fig. 27.6).

Crouch gait

Crouch gait is characterized by excessive knee flexion in stance phase, incomplete extension at the hip and excessive ankle dorsiflexion (calcaneus). Knee stiffness in swing is common. The soleus is excessively long and usually weak. This is a very common gait pattern in adolescence and may be part of the natural history of bilateral spastic CP but is more often caused by isolated tendo Achilles lengthening (TALs) (Rang 1990, Rodda, Graham, and Galea 2006, Stout et al. 2008, Vuillermin et al. 2011). A key feature of true Crouch Gait is that the majority of muscle-tendon-units (MTU) are excessively long. This is by definition true for all of the one-joint muscles such as soleus, vasti, and gluteus maximus and often for the two-joint hamstrings. The only consistent contractures are of the iliopsoas. In crouch gait, the hamstrings are short only in patients with a posterior pelvic tilt. When the pelvis is in the neutral range, the hamstrings are of normal length and when the pelvis is anteriorly tilted, the hamstrings are excessively long. Without the use of IGA and the modelling of muscle lengths, it is very difficult to appreciate these findings. The popliteal angle is decreased, the hamstrings feel tight and are therefore incorrectly assumed to be short (Rodda, Graham, and Galea 2006).

It is important to choose the correct measurement tool to use at any given time or following an intervention. Choice of measurement tool should be based on the psychometric properties of the tool, the aspect of the ICF being measured as well...
as the age and GMFCS level of the child. A detailed discussion of measurement tools is beyond the scope of this chapter. Some of the tools that we use commonly are discussed below.

**Body structure and function**

**Instrumented gait analysis**

Evaluation of gait and functioning in children with CP can be considered in the format of a diagnostic matrix (Davids et al. 2003). The role of IGA is crucial to the evaluation of gait dysfunction, especially in relation to planning and assessing the outcome of major interventions such as SDR and SEMLS. As IGA becomes more reliable, cheaper, and more accessible, it is anticipated that assessment quality for children with CP and the outcomes based on such assessments, will continue to improve (Thomason et al. 2012).

**Video gait analysis**

Video gait analysis (VGA) is a central part of the diagnostic matrix. A visual record of a child’s gait and functioning on digital video can be of much greater value than observational gait analysis and a written report. Digital video can be archived in a permanent fashion, is objective and can be shared by multiple observers over a long period of time. It allows observation and recording of gait from multiple viewpoints, can be replayed in slow motion and can be reviewed repeatedly. In an effort to quantify and objectify the outcome of observational gait analysis, a number of gait scores have been developed of varying degrees of complexity, sophistication, and reliability. These include the Physician Rating Scale, the Observational Gait Scale and the Edinburgh Visual Gait Score (Koman, Mooney, and Smith 1993, Mackey et al. 2003, Read et al. 2003, Wren et al. 2005).

**Longitudinal assessments with radiology: hip surveillance**

Mercer Rang suggested many years ago that all children with CP should have regular hip examinations and radiographs (Rang 1990). The goal was to prevent dislocation by early detection and early preventive (adductor release) surgery. Several centres in Europe and Australia have developed these concepts into formal ‘hip surveillance programmes’ (Dobson et al. 2002, Hagglund et al. 2005, Kentish et al. 2011). Children with a confirmed diagnosis of CP are offered regular clinical and radiographic examination of their hips and access to both preventive and reconstructive surgery. In both Victoria, Australia and southern Sweden, the prevalence of late dislocation has
In children with CP, the hip is normal at birth and then displaces because of limitations in activity, accompanied by soft tissue contractures and bony deformities. Factors which may contribute to hip displacement include increased muscle forces across the hip, which have been modelled to be increased six-fold (Miller et al. 1999). The shape of the proximal femur is also important in terms of torsion (femoral neck anteversion, (FNA) and neck shaft angle (NSA)) (Robin et al. 2008).

The most useful radiographic index for measuring hip displacement in children with CP is the migration percentage of Reimers (1980). This measures the percentage of the femoral head which lies outside the acetabulum. Migration percentage can be reliably measured from hip radiographs, taken in supine with good positioning and a standardized technique (Parrott et al. 2002). The measurement error should be less than 10% and serial measurement of migration percentage is the most useful means to study hip displacement in children with CP. It is the key index for making decisions regarding surgical management and to monitor hip displacement both before and after operative intervention. In children with CP, the migration percentage increases by 2% to 10% per year, depending on GMFCS level, until the migration percentage reaches about 50%. At this point the displacement increases rapidly and is associated with progressive deformities of the femoral head and acetabulum, followed by loss of articular cartilage and degenerative arthritis (Graham 2004). The incidence of hip displacement (migration percentage >30%) is 35% of children with CP in population-based studies and is directly related to the child’s GMFCS level (Soo et al. 2006, Hagglund, Lauge-Pedersen, and Wagner 2007, Connelly et al. 2009). Early hip displacement is silent and formal screening by radiographs of the hips, with careful positioning is advised. The frequency of such radiographs should be directly related to the risk of hip displacement, which is in turn related to the child’s GMFCS level. In GMFCS level I the risk of hip displacement is very low and radiographs are only required if there are findings on clinical examination raising concerns. More regular radiographs are required in GMFCS levels II and III. Radiographs every 6 to 12 months decreased and the need for salvage surgery has been reduced (Dobson et al. 2002, Hagglund et al. 2005).

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may be required in GMFCS levels IV and V to monitor progressive hip displacement. Evidenced-based recommendations on hip surveillance in children with CP have been published and can be downloaded from www.ausacpdm.org.au (Wynter et al. 2011).

**Activity**

**FUNCTIONAL MOBILITY SCALE** (see APPENDIX 5)
The Functional Mobility Scale (FMS) describes the level of assistance a child requires to mobilize over three different distances, in three different environments: the home (5m), school (50m), and the community (500m) (Graham et al. 2004). Three numbers are assigned depending on the level of assistance required in each of these settings. For example, a child in GMFCS level III is frequently capable of independent walking in a sheltered familiar environment such as the home. The same child may require the use of elbow crutches to move around in the school environment but these may be too slow to keep up with the rest of the family during trips to the shopping mall, when a wheelchair may be preferred. The FMS grading for such a child is 5,3,1. The FMS was designed as an outcome measure and is sensitive to change (Harvey et al. 2007, Harvey et al. 2009). For example, children in GMFCS level III often require a posterior walker to ambulate, prior to multilevel surgery. After optimum biomechanical realignment and correction of spastic contractures, these children can often progress to lesser levels of support. Some will be able to walk increasing distances independently; others will require crutches or sticks when previously they were dependent on a posterior walker. These important changes can be monitored and reported using the FMS.

**FUNCTIONAL ASSESSMENT QUESTIONNAIRE**
The Functional Assessment Questionnaire (FAQ) is a 10-level, parent report walking scale, which describes a range of walking abilities across the entire spectrum of CP, from non-ambulatory to independent ambulation at a high level (Novacheck, Stout, and Tervo 2000). In addition to the 10-level walking scale, there is an additional list of 22 items describing a variety of higher level functional activities requiring varying degrees of walking ability, balance, strength, and coordination. The FAQ is a valid and reliable scale and has been shown to be sensitive to change. It is a simple scale, which can be quickly completed by parents or care-givers and provides an excellent longitudinal view of the child’s gross motor and walking abilities.

The FMS and FAQ are complementary scales and are both gaining increasingly widespread acceptance and use in assessing children with CP as baseline measures, longitudinal measures and as outcome measures after intervention.

**GROSS MOTOR FUNCTION**
The Gross Motor Function Measure (GMFM) (Russell et al. 1989) and the Pediatric Evaluation of Disability Inventory (PEDI) (Haley 1997) are measures frequently used to assess motor function. The PEDI may be a more appropriate tool for use with children in GMFCS levels IV and V.

**Management**
CP is the most common cause of the upper motor neurone syndrome (UMNS) in childhood, with positive features such as spasticity, hyper-reflexia, and co-contraction and negative features such as weakness, loss of selective motor control, sensory deficits and poor balance (Burke 1988). The negative features have a greater influence on locomotor prognosis (Hutchinson and Graham 2008). Weakness and loss of selective motor control determine when or if a child will walk. Weakness and balance deficits may dictate long-term dependence on a walking aid. The CP brain lesion is a ‘static encephalopathy’. This is in contrast to musculoskeletal pathology in the limbs, which is progressive and constantly changing during growth and development (Graham 2004).

In the absence of biological therapies to correct the brain lesion, management of children with CP is directed to reducing the effect of the positive features of the UMNS such as spasticity and to assist the child to compensate for the negative effects such as weakness. Treatment is also aimed at reducing the effects of the progressive musculoskeletal deformities which result from growth and maturation.

**PROGRESSIVE MUSCULOSKELETAL PATHOLOGY**
In children with CP the musculoskeletal pathology is progressive. Chronic neurological impairment affects the growth and development of muscles and bones. The key feature of the musculoskeletal pathology in CP is failure of longitudinal growth of skeletal muscle, ‘short muscle disease’ (Graham and Selber 2003, Graham 2004). The conditions for normal muscle growth are regular stretching of relaxed muscle, under physiological loading conditions and normal levels of activity. In children with CP, skeletal muscle does not relax during activity because of spasticity and the children have greatly reduced levels of activity because of weakness and poor balance. The newborn child with CP does not have contractures or lower limb deformities and most do not show signs of spasticity. With time spasticity develops, activity levels are reduced, the growth of muscle-tendon-unit (MTU) lags behind bone growth and contractures develop. Although the MTU is often short in CP, muscle fibres may not be short. Paradoxically in teenagers with crouch gait, the majority of lower limb the muscle-tendon-units are excessively long. Only the ilioptasas and occasionally the hamstrings are short. The soleus, vasti, and hip extensors are excessively long indicating that disordered biomechanics play a profound role in the relationship between MTU length and bone length (Graham and Selber 2003).

Torsional deformities develop in the long bones and instability of joints including the hip and subtalar joint may develop, secondary to growth abnormalities and disordered
biomechanics. Eventually premature degenerative arthritis may develop. Torsional deformities in long bones, hip subluxation and midfoot breaching are referred to as lever arm deformities. Muscles act on bony levers to produce a moment which, if great enough, will induce movement about the joint. If the lever is mal-directed (tibial torsion) or the fulcrum unstable (hip subluxation) the moment generating ability of the muscle is reduced. Lever arm deformities may then result in lever arm disease. In the lower limbs, external tibial torsion combined with pes valgus may impair the plantarflexion moment of the gastrosoleus. This may contribute to defective plantarflexion-knee-extension coupling and crouch gait (Graham 2010). A management algorithm is represented in Fig. 27.7. An important therapeutic window exists for spasticity management before the development of fixed contractures (Hutchinson and Graham 2008). A second therapeutic window exists for the correction of fixed musculoskeletal deformities, before the onset of decompensation (Rang 1990). There are three important longitudinal studies of gait in children with bilateral spastic CP, which confirm that the musculoskeletal pathology and the attendant gait disorder are progressive during childhood (Johnson, Damiano, and Abel 1997, Bell et al. 2002, Gough et al. 2004). These studies provide an important insight into natural history and a framework to interpret the results of management strategies in the lower limbs.

**Physiotherapy in Multidisciplinary Management of the Lower Limb in Cerebral Palsy**

Management of children with CP is multidisciplinary with physiotherapists, occupational therapists, speech pathologists, psychologists, and teachers, working together with physicians and surgeons to optimize the potential of the individual child (Rang 1990). Physiotherapy is the most popular and widely used management strategy for the lower limb in children with CP and is highly valued by the parents. It involves the use of a variety of interventions. The physiotherapy management of children with CP has been based on a variety of theoretical perspectives. Physiotherapists use biomechanical approaches to...
maintain range of motion and muscle length. Techniques used include passive and active ranging of joints, stretching of muscles, splinting, and casting. Serial casting can be combined with BoNT-A injections for dynamic contractures (Hutchinson and Graham 2008). The introduction of a suitable AFO is often a critical step in providing an improved base of support and achieving progress in a child’s ability to stand and walk.

Physiotherapists use approaches such as neurodevelopmental treatment based on the work of Dr and Mrs Bobath, motor learning and conductive education (Hari and Akos 1988, Valvano and Long 1991, Catanese et al. 1995, Shepherd 1995). Physiotherapists have also begun to move away from passive interventions towards activity-focused interventions which reflect recent views of motor learning theories. The importance of activity-based interventions is increasing in focus (Damiano 2006). More recently, Progressive Resistance Strength Training (PRST) has been used to increase muscle strength and endurance (Damiano, Dodd, and Taylor 2002, Dodd, Taylor, and Graham 2003, Verschuren et al. 2011). Treadmill training is becoming an increasingly popular intervention to improve walking speed and endurance (Damiano and DeJong 2009, Mutlu, Krosschell, and Gaebler-Spira 2009, Willoughby et al. 2010). These modalities are rarely utilized in isolation. Spasticity management with BoNT-A, intrathecal baclofen (ITB), and SDR may also improve outcomes (McLaughlin et al. 2002, Albright 2008, Ward 2009). It is increasingly difficult to determine which combinations are best for children with CP. The approaches used by physiotherapists will be influenced by many factors and must be evidenced based. Intervention requires sensitivity to the child’s age, cognitive, sensory, and perceptual factors as well as type and severity of CP. The treatment setting, whether based in a hospital, community centre, at school or home, and the focus of these services are also important factors. The child’s environment, including family, cultural, and contextual factors must be considered. Interventions will be less effective if they are not carried over into the child’s everyday environment at home. Interventions need to be planned using a family-centred, problem-based approach, clinical reasoning, and best available evidence. Management plans should be negotiated with the child and their family/careers and, most importantly, outcomes of the intervention should be evaluated.

Physiotherapy programmes also provide education and emotional support to parents coping with the diagnosis of CP and starting the journey through the uncharted waters of raising a child with a life-long physical disability (Rang 1990). Coordination of access to other services including physical medicine and rehabilitation, orthotics, and orthopaedic surgery are also integral to the role of the physiotherapist. Parents will often seek the view of the child’s therapist on recommendations for spasticity management, the type of orthosis and the timing and type of surgical intervention. The need for clear communication and teamwork within the multidisciplinary team is obvious. When major interventions are scheduled, therapy needs to be carefully planned with a team approach involving the child’s community therapist. Additional therapy may be provided within the tertiary hospital, rehabilitation centre or, where possible, the child’s home.

Movement disorder management and the spasticity compass

The ‘spasticity compass’ can be used to classify and compare interventions for spasticity management as focal or generalized in their effect and as temporary or permanent (Fig. 27.8). Each intervention can then be located in the appropriate quadrant. For example, oral medications are general (all nerves or all muscles in all body areas) but temporary in effect (Ward 2009). Selective dorsal rhizotomy (SDR) is a neurosurgical procedure in which 30% to 50% of the dorsal rootlets between L1 and S1 are transected for the permanent relief of spasticity in a highly selected group of children with bilateral spastic CP (McLaughlin et al. 2002, Albright 2008). The principal effects are on the lower limbs although there may be minor effects on the upper limbs. The position on the grid is therefore permanent and half way between general and focal.

ITB is the most effective current method available for the management of severe spasticity, dystonia and mixed movement disorders in CP and has been reviewed extensively in several recent publications (Butler and Campbell 2000, Albright 2008).

Chemodenervation is invaluable in the management of focal spasticity and dystonia. Phenol neurolysis was much more widely utilized before the introduction of BoNT-A. The principal limitation on its use is pain at the site of injection and post injection dysesthesia. This is because phenol is not selective and has the same effect on sensory nerve fibers as motor fibres. Hence its use in mixed nerves in children with CP is very limited. However, in the lower limb in CP the principal application is neurolysis of the obturator nerve for adductor spasticity as these nerves have such limited sensory

Fig. 27.8. The spasticity compass for children with cerebral palsy.
distribution and precautions for use of Phenol do not apply (Khot et al. 2008).

**Botulinum Neurotoxin-A in the Management of the Lower Limb in Cerebral Palsy**

Injection of skeletal muscle with BoNT-A results in a dose-dependent, reversible chemodenervation, by blocking presynaptic release of acetylcholine at the neuromuscular junctions. Because of the neurotoxin’s rapid and high affinity binding to receptors at the neuromuscular junctions of the target muscle, little systemic spread of neurotoxin occurs. Neurotransmission is restored initially by sprouting of new nerve endings, but these are eliminated at about 3 months when the original nerve endings regain their ability to release acetylcholine (de Paiva et al. 1999). BoNT-A may be useful in children with CP to manage dynamic gait problems and to delay the need for orthopaedic surgery until the child is older (Koman, Mooney, and Smith 1993).

The most common and most important indication for BoNT-A therapy in ambulatory children with CP is the injection of the gastrocsoleus for spastic equinus (Graham et al. 2000). Before widespread use of BoNT-A for spastic equinus, the majority of children with CP who walked on their toes had a lengthening of their Achilles tendons by age 4 to 6 years. This resulted in progressive crouch gait which was much more disabling than the original equinus gait (Vuillermin et al. 2011). A non-operative programme of care utilizing BoNT-A should be viewed as complementary to orthopaedic surgical reconstruction and not as an alternative. Information about dosing, dilution, muscle targeting, and safety have been published elsewhere (Cosgrove, Corry, and Graham 1994, 1999, Graham et al. 2000, Naidu et al. 2010).

Injection of BoNT-A for spastic equinus increases the dynamic length of the gastrocsoleus with improvements in ankle dorsiflexion during gait, as determined by the Physician Rating Scale (Cosgrove, Corry, and Graham 1994, Koman et al. 1994, 2000, Boyd and Graham 1997). Improvements have been reported in studies using instrumented gait analysis, including kinematics and electromyography (Bjornson et al. 2007). This may lead to small but important gains in gross motor function. The evidence base supporting the use of BoNT-A in CP is quite good as confirmed in several randomized controlled trials and systematic reviews. However, the size of the treatment effect is small and often short-lived (Desloovere et al. 2001, Bjornson et al. 2007, Simpson et al. 2008).

In non-ambulant children with CP, BoNT-A may help reduce adductor spasticity but does not prevent hip displacement (Graham et al. 2008, Willoughby et al. 2012).

**Adverse Events and Botulinum Neurotoxin Therapy in Cerebral Palsy**

BoNT-A is generally safe in children with CP. Most adverse events are localized, minor and self-limiting. Systemic side effects including temporary incontinence and dysphagia have been reported. Dysphagia, aspiration, and chest infection are the most serious complications after injection of BoNT-A and if unrecognized or inadequately treated could lead to death from asphyxia (Naidu et al. 2010).

Recent concerns from studies in animal models and from clinical studies in children have raised concerns about denervation atrophy (Fortuna et al. 2011). The mechanism of action of BoNT-A dictates that a clinically successful injection will be followed by a period of muscle weakness and muscle atrophy. What is not yet understood is the duration of atrophy and the long-term implications for muscle growth and function. In adolescents, the management of weakness is a much greater challenge than the management of spasticity, in GMFCS levels II and III (Gough, Fairhurst, and Shortland 2005). Until the long-term implications of denervation atrophy are more clearly understood, it would be prudent to limit the use of BoNT-A in the antigravity muscles of ambulant children with CP. Both the dose and frequency of injections should be reduced to the absolute minimum required to achieve the desired functional goals.

**Botulinum Neurotoxin-A as an Analgesic Agent in Cerebral Palsy**

BoNT-A can be used to treat muscle spasm following operative procedures, such as adductor release surgery. Injection of BoNT-A can be useful for short-term relief of pain associated with hip displacement. Target muscles include the hip adductors, medial hamstrings, and hip flexors. Pain relief is associated with a decrease in spastic adduction and scissoring postures (Barwood et al. 2000). Some children with neglected hip displacement have limited life expectancy and may not survive salvage surgery. BoNT-A may provide useful palliation in such circumstances. Better still is to prevent painful hip displacement.

**Orthopaedic Surgical Management of the Lower Limb in Cerebral Palsy**

**The ambulant child**

Surgery for children with bilateral spastic CP used to start at the ankles with TALs for equinus gait and then move up to the knee and then to the hip. Mercier Rang caricatured this approach as the ‘Birthday Syndrome’ (Fig. 27.9). Children spent most of their birthdays in hospital, in casts or in rehabilitation. The current concept for the management of musculoskeletal deformities is Single Event Multilevel Surgery (SEMLS).

In a recent systematic review of SEMLS, evidence was found for large improvements in gait dysfunction, moderate improvements in health related quality of life and only small changes in gross motor function (McGinley et al. 2012). In the first randomized clinical trial of SEMLS a 50% improvement in gait function (Gillette Gait Index, GGI) and a 4.9% improvement in gross motor function (GMFM-66) was reported.
against their will or without their full consent is likely to be resentful, may develop depression and struggle with rehabilitation. Careful preoperative discussions about setting realistic goals, helps to ensure that patient’s, parents’, and surgeon’s goals are consistent and achievable (Thomason and Graham 2013).

A comprehensive plan is then developed for the correction of all muscle tendon contractures, torsional malalignments, and joint instabilities in one operative session. Rehabilitation requires at least 1 year and improvements continue into the second year, postoperatively (Thomason and Graham 2013, Thomason, Selber, and Graham 2013).

The principal components of a successful SEMLS programme are as follows:
1. Planning based on the diagnostic matrix, including instrumented gait analysis.
2. Preparation and education of the child and family.
3. Optimal perioperative care, including epidural analgesia.
4. Carefully planned and supervised rehabilitation.
5. Appropriate orthotic prescription.
7. Follow-up gait analysis at 12 to 24 months after the SEMLS.
9. Follow-up until skeletal maturity, for new or recurrent deformities (Thomason and Graham 2013).

The surgical team should consist of two experienced surgeons and two experienced assistants. Expert anaesthesia and pain management is essential. Postoperative nursing care must be vigilant. The use of epidural analgesia carries risks of masking the signs of compartment syndromes and nerve stretch palsies.

The surgery is a series of steps which correct deformity (Fig. 27.10). However, for 6 to 9 months after surgery, children are more dependent and less functional than they were prior to surgery. A child who walks into hospital with a typical CP gait pattern leaves hospital in a wheelchair with straighter legs, but may be unable to walk independently for weeks or even months. (Thomason et al. 2011). The 5-year results of this clinical trial show that these improvements were largely maintained at 5 years post-SEMLS (Thomason, Selber, and Graham 2013).

In the SEMLS approach, the gait pattern is identified and evaluated by IGA as part of the diagnostic matrix. SEMLS in bilateral spastic CP can be considered to be an exercise in correcting anatomical deformities based on the clinical findings from the diagnostic matrix assessments. It is necessary to consider all components of the matrix so that surgical planning is optimized for the individual child (Davids et al. 2003). For example, muscle weakness is an impairment which is easily overlooked and which may have a greater impact on energy cost of walking and function in the community than multiple musculoskeletal deformities.

It is essential to also consider the child in the context of participation, psychological and environmental factors, which may make successful surgical outcomes less predictable. It is important to have a frank discussion around the family and child’s goals and aspirations. This requires a multidisciplinary approach with the involvement of the family and child, the rehabilitation team as well as community therapists. For a child in GMFCS level III, independent ambulation is rarely achievable and it is essential to have these discussions ahead of the surgery and rehabilitation. A detailed examination of the child’s level of activity and participation, using measures such as the Canadian Occupational Performance Measure, Children’s Assessment of Participation and Enjoyment, or the Activity Scale for Kids (Law et al. 1990, Young et al. 2000, King et al. 2004) may be useful.

It is crucial to distinguish between the needs of children and adolescents. The decision to proceed with SEMLS for younger children is largely made by their parents. However, adolescents must be given the freedom to make their own informed decisions regarding surgery and rehabilitation. An adolescent who feels that they have been forced into SEMLS against their will or without their full consent is likely to be resentful, may develop depression and struggle with rehabilitation.
Lower Limb Function

Only a carefully tailored and carefully monitored rehabilitation programme can ensure that the child will reach a higher level of function.

The child may commence full weight bearing once they are comfortable. A day or two after soft tissue surgery. Weight bearing can commence after 2 to 3 days if the child has had a femoral osteotomy with stable internal fixation, or after a maximum of 1 to 2 weeks if there has been more extensive reconstructive surgery at the foot–ankle level. Casts are only required after foot and ankle surgery. Removable extension splints may be used at the knee level after hamstring-rectus surgery. The goal is to achieve full extension of the knee, combined with regaining full flexion, so that the transferred rectus femoris does not become scarred and adherent in its new site. New AFOs must be prepared for immediate fitting after cast removal, usually 6 weeks after surgery. The initial postoperative brace is usually a solid AFO. The orthotic prescription must be carefully monitored throughout the first year after surgery. A less supportive AFO, such as a hinged or posterior leaf spring, may be introduced when the sagittal plane balance has been restored and the plantar-flexion-knee-extension couple is competent. Functional recovery and orthotic prescription can be monitored by a gait laboratory visit every 3 months for the first year after surgery and yearly thereafter. Our approach to SEMLS rehabilitation has been described in more detail elsewhere (Thomason and Graham 2013).

The non-ambulant child
As children spend less time weight bearing and walking, and more time in seated postures, flexion deformities at the hip, knee may develop. Managing ankle and foot deformities is important to allow bracing, enable the child to wear typical footwear and to have their feet rest comfortably on the footplate of a wheelchair. Correction of severe external tibial torsion by supramalleolar osteotomy of the tibia may be necessary (Selber et al. 2004). Where children are able to participate actively in standing transfers, achieving stable and pain-free feet and ankles can be important. Stabilization of the foot for pes valgus is more reliably achieved by a subtalar fusion than by os calcis lengthening (Shore et al. 2013). Correction of hallux valgus and dorsal bunion by soft tissue balancing and fusion of the first metatarsophalangeal joint is effective for deformity correction, pain relief, and comfortable shoe wear (Davids et al. 2001).

Surgery for hip displacement. The risk of developing progressive hip displacement is very high for non-ambulant children. Hip displacement may be managed by preventive or reconstructive surgery or, for many children, a combination of both (Fig. 27.11) (Miller, Dabney, and Rang 1995). The aim of hip surgery is to achieve and maintain a pain-free, enlocated hip to maintain comfortable sitting, not to improve gross motor function.

Preventive hip surgery. Preventive surgery (Fig. 27.12) aims to facilitate proximal femoral and acetabular development by correcting adduction and flexion contractures. Normalizing the range of hip abduction is crucial to normal hip development. Preventive surgery involves lengthening of the hip adductors and is typically advised when the migration percentage of one or both hips exceeds 30% to 40% and hip abduction is less than 40 degrees on one or both sides (Presedo et al. 2005). Phenol neurolysis of the anterior branch of the obturator nerve is helpful in addressing both adductor spasticity and pain from muscle spasm post-surgery (Khot et al. 2008). Painful spasms in the lengthened muscles can be very distressing to both the child and their carers. Postoperatively, analgesia and muscle relaxants can assist in managing pain. A ‘broomstick’ or ‘A’ frame cast is often used to maintain the child’s legs in abduction and can complement pain management strategies. Children can, and should, be encouraged to continue with many daily activities while wearing the plaster, including prone lying, long-sitting, and supported standing.
Reconstructive surgery consists of three main components: adductor release, femoral osteotomy and pelvic osteotomy. Firstly, abduction range is restored by a revision adductor release. Correction of the shape of the femur is achieved by varus derotation osteotomy of the proximal femur. Shortening of the proximal femur is also an effective way to reduce soft tissue tension and restore range of motion and symmetry about the hips. In windswept deformities, symmetry can be achieved by a combination of asymmetrical soft tissue releases and adjusting the amount of rotation in each osteotomy (Fig. 27.13). Stable internal fixation is achieved by using a fixed angle blade plate, avoiding the need for a hip spica in most children. Significant acetabular dysplasia should be corrected by a San Diego pelvic osteotomy and older children and teenagers may benefit from a periacetabular osteotomy (Clohisy et al. 2006).

After reconstructive surgery, there are no restrictions to weight bearing or movements of the hips, apart from consideration of the child’s level of comfort. Correction of the neck shaft angle can produce a ‘widening’ at the child’s thighs and therapists supporting the family may need to consider modifications to wheelchair seating to accommodate the increase in hip width. Blade plates are usually removed about 12 months after surgery.

One stage correction of hip displacement by bony reconstruction is a very effective and reliable method of stabilizing the severely subluxated or dislocated hip in CP (Miller et al. 1997b, McNerney, Mubarak, and Wenger 2000). The radiological status of most hips remains satisfactory in the short and longer term. Pain is prevented or relieved and sitting tolerance is usually dramatically improved. Radiological monitoring of hip development should continue at least until skeletal maturity. The single biggest threat to hip status after successful hip reconstruction is progression of scoliosis and pelvic obliquity. It is very difficult to maintain hip stability on the high side of an oblique pelvis.

It is important to note that most studies of adductor releases report a high failure rate in children who are non-ambulant and who are followed up for more than 3 to 5 years (Miller et al. 1997a, Shore et al. 2012). The majority of these children will need bony reconstructive surgery, 2 to 10 years after preventive surgery.

Reconstructive hip surgery. The most common indication for reconstructive surgery is a persistently high migration percentage after adductor surgery. If the migration percentage remains >40%, at >12 months after adequate adductor releases and the child is >4 years with little or no degenerative changes, reconstructive surgery is indicated (Miller et al. 1997b, McNerney, Mubarak, and Wenger 2000). Reconstructive surgery is also advised as the index surgery in children >8 years presenting with migration percentage >40% (Miller, Dabney, and Rang 1995).

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Referral to a pain management service is important as a number of adolescents can be managed non-operatively, in the short term. ITB may also be considered for optimizing tone management prior to salvage surgery.

**Spinal Deformity and Scoliosis Surgery**

*Natural history of scoliosis in cerebral palsy*

GMFCS level is the single strongest predictor of severe scoliosis (Cobb angle >40 degrees) in children with CP (Persson-Bunke et al. 2012). Scoliosis may present as early as age 4 to 6 years, and occasionally even younger. The rate of progression accelerates when the curve reaches 40 to 50 degrees and as the child enters the pubertal growth spurt (Fig. 27.15). This acceleration in the rate of progression may catch parents, pediatricians and unaware. In the space of 1 to 2 years it is possible for a curve to progress from a moderate flexible curve, easily correctible in single stage posterior surgery with moderate risks, to a severe rigid curve requiring anterior and posterior surgery, which has increased risks of morbidity and mortality (Miller 2005). A ‘point of no return’ may be reached where the magnitude of the
Parents and caregivers need instructions regarding protection of the fusion when the child is transferring to and from their wheelchair, and by limiting hip flexion in the short term. Review of wheelchair seating and postural supports is often required as ‘seat to shoulder’ height typically increases with correction of the scoliosis.

Curve progression after successful fusion is usually <10 degrees although this may be greater in immature individuals with growth potential. Spinal fusion in children with CP improves sitting position and appears to improve upper limb function, eating and respiratory function (Tsirikos et al. 2004, Miller 2007). It may also prolong life and improve the quality of life (Narayanan et al. 2006, Mercado, Alman, and Wright 2007).

Kyphosis and lordosis in cerebral palsy
Kyphosis in the dorsal spine is very common in younger children with weak paraspinal muscles and is best managed by having the wheelchair seat slightly reclined, the use of chest straps and occasionally a Lyre ‘upsuit’ or thoraco-lumbar-sacral orthoses (TLSO). With advancing age, the thoracic kyphosis and the secondary cervical lordosis may become more fixed. Cervical pain in adults with CP is common.

Kyphosis in the lumbar spine may be related to severe contractures of the hamstrings. Proximal hamstring recession at the time of adductor releases may be beneficial. Lordosis in the lumbar spine is much more common and is frequently related to hip flexion contractures. Lengthening of the hip flexors before the lordosis becomes excessively severe or fixed may be appropriate (Miller 2005).

Management of the lower limb in cerebral palsy
by sagittal gait pattern
It is helpful to consider the sagittal gait pattern in both unilateral and bilateral spastic CP. The classifications are useful as they provide insight into which levels of the lower limbs are affected, the extent of involvement and the biomechanical principles which need to be considered when planning management. The classifications do not provide recipes for management but highlight important aspects which are useful in the decision making process (Figs 27.4 and 27.5).

Sagittal gait patterns: unilateral spastic cerebral palsy
TYPE I HEMIPLEGIA
The prominent impairment is a drop foot in the swing phase of gait. There is no contracture of the gastrocsoleus. Neither spasticity management nor musculoskeletal surgery is necessary. Gait and function can be improved by the use of an AFO, usually a leaf spring AFO or a hinged AFO.

TYPE II HEMIPLEGIA
In type II hemiplegia, there is spasticity in the gastrocsoleus which gradually becomes fixed resulting in a contracture.
and equinus gait. Management requires correction of fixed contracture in the gastrocsoleus (to correct second rocker) and provision of an AFO (to provide heel strike, swing phase clearance, and appropriate pre-positioning of the foot during pre-swing).

**Type III Hemiplegia**
In type III hemiplegia there is a contracture of the gastrocsoleus at the ankle plus knee involvement with co-contraction of the hamstrings and rectus femoris. Children in this transitional group may benefit from lengthening of the medial hamstrings and rectus femoris transfer, in addition to gastrocsoleus lengthening and a hinged AFO.

**Type IV Hemiplegia**
In type IV hemiplegia, all levels of lower limb are involved and there is involvement in the sagittal, coronal, and transverse planes at the hip. Hip dysplasia is common and often presents late. In addition to the surgery outlined for type III hemiplegia, correction of type IV hemiplegia includes lengthening of the adductor longus and the psoas over the brim of the pelvis as well as a proximal femoral derotation osteotomy (Winters, Gage, and Hicks 1987, Dobson et al. 2005).

**Sagittal gait patterns in bilateral spastic cerebral palsy**

**True Equinus**
Sagittal plane: ankle equinus, knees and hips extended
True equinus can be managed in the younger child by injections of BoNT-A to the gastrocsoleus and the provision of hinged AFOs. By the time children develop fixed contractures and require surgery, true equinus is rare. When it persists, there are usually occult contractures of the hamstrings and iliopsoas. Single level surgery (gastrocsoleus lengthening) is almost never the correct strategy in bilateral spastic CP, no matter how tempting it may appear on observational gait analysis.

**Jump Gait**
Sagittal Plane: ankle equinus, knees and hips incomplete extension in mid-stance
Many children require SEMLS for appropriate management. This is discussed in detail under orthopaedic surgical management.

**Apparent Equinus**
Sagittal plane: ankle plantargrade, knees and hips flexed
Many children with bilateral spastic CP who walk on their toes, never achieving heel contact, have an ankle range of motion close to the normal range. Such children are at risk of inappropriate management with injections of BoNT-A to the gastrocsoleus or even worse, lengthening of the gastrocsoleus. These important contractures are more proximal, at the level of the knee and hip. The recognition of ‘apparent equinus’ in contradiction to ‘true equinus’ is very important to avoid inappropriate lengthening and weakening of the gastrocsoleus with further deterioration in gait and functioning. These children may require SEMLS at proximal levels and IGA is essential for planning the appropriate surgical interventions.

**Crouch Gait**

Sagittal plane: excessive ankle dorsiflexion and knee flexion, incomplete hip extension
In crouch gait, the iliopsoas is usually contracted. The hamstrings are short only in patients with a posterior pelvic tilt. When the pelvis is in the neutral range, the hamstrings are of normal length and when the pelvis is anteriorly tilted, the hamstrings are excessively long. Without the use of motion analysis and the plotting of muscle lengths, it is very difficult to appreciate these findings (Thomason et al. 2012). Consequently the majority of children with crouch gait are managed by excessive hamstring lengthening to improve knee extension when in fact the hamstrings are of normal length or excessively long. Such surgery results in increased anterior pelvic tilt which may lead to recurrent crouch, back pain and spinal instability (spondyloysis and spondylolisthesis) (Roddia, Graham, and Galea 2006).

Severe crouch gait can be defined as knee flexion >30 degrees throughout stance, with excessive ankle dorsiflexion and incomplete hip extension (Roddia et al. 2004). It can be part of the natural history of gait in bilateral spastic CP but the majority of affected individuals have had lengthening of the Achilles tendons (Stout et al. 2008, Vuillermin et al. 2011). There is often a delay between lengthening of the gastrocsoleus and the development of crouch gait. The Achilles tendons are often lengthened in children with bilateral spastic CP between the age of 3 and 6 years. It may take another 3 to 6 years before crouch gait becomes a significant functional problem and it is often not until the adolescent growth spurt when the maximum deterioration in gait and functioning occurs. Instead of ‘growing up’ the adolescent with progressive crouch gait ‘sinks down’, with an inability to maintain an extension posture at the hip and knee during the stance phase of gait (Vuillermin et al. 2011). Contributing factors seem to be a progressive mismatch between the strength of the one-joint muscles contributing to the body support moment (gluteals, vasti, and soleus) and increased demand because of rapid increases in height and weight at the pubertal growth spurt. This typically occurs in conjunction with progressive bony deformities known as lever arm disease. Around the time of the pubertal growth spurt, increasing patella alta (sometimes with fractures of the patella or avulsions of the inferior pole), increasing external tibial torsion and breakdown of the midfoot with severe pes valgus, all contribute to increasing crouch, fatigue and decreasing ability to walk. Understanding the biomechanics of severe crouch gait has led to improved surgical management in recent years with the development of more effective techniques to achieve lasting correction (Ma et al. 2006, Stout et al. 2008).
Management should be based on the findings of IGA and the hamstrings should only be lengthened when found to be short. Surgery may include iliopsoas lengthening, semitendinosus transfer, distal femoral extension osteotomy, patellar tendon shortening, and correction of pes valgus and external tibial torsion. Before skeletal maturity, growth plate surgery is an option to correct small, residual knee flexion deformities (Young et al. 2010).

Management of the lower limb and spine in cerebral palsy by Gross Motor Function Classification

System level
Management of the child or adolescent with CP should be considered within the context of their GMFCS level, functional mobility level, and the biomechanics of the gait pattern or movement pattern. Management may include non-surgical and surgical options at different times and in different combinations. Gait correction surgery is an option for many children with CP in GMFCS levels I to III but with important differences at each level.

GMFCS level I Children at this level have the ability to participate in recreational physical activities with no or minimal adaptations.

Function: FMS 6,6,6 or 6,6,5; FAQ 9 to 10
Sagittal gait pattern:
Unilateral spastic cerebral palsy: type I or II hemiplegia
Bilateral spastic cerebral palsy: true equinus, mild jump gait

Musculoskeletal:
Lower limb: there is usually more distal than proximal involvement with mild spasticity and occasionally dystonia. Gait disturbances such as equinus in stance and foot drop in swing are the most likely concerns for the child and family. These may indicate a combination of impaired selective motor control, weakness in tibialis anterior, and either dynamic tightness or mild contracture in the gastrocnemius. There may be mild involvement at the knee and hip level as the child becomes older, particularly in children with bilateral spastic CP.

Hips: Mean femoral neck anteversion: 30°
Mean neck shaft angle: 136°

Hip disease is rare and is usually a mild developmental dysplasia.

Spine: scoliosis is seen in <20% of adolescents and the curve is small (10–25°) and does not progress or require surgery. If a spinal curvature develops, it will be an adolescent idiopathic type curve. Incidence is similar to children who are typically developing.

Management:
Younger child: physiotherapy will be the mainstay of management with emphasis on a family and task/context focused approach. A leaf spring AFO or hinged AFO is useful for dynamic equinus and can improve the base of support and aid gait training. The movement disorder is mild and easily managed by injections of BoNT-A, most often into the gastrocnemius muscles (Graham et al. 2000). Neither selective dorsal rhizotomy nor ITB are appropriate choices because the spasticity is mild and focal.

Older child: children with type I hemiplegia rarely need orthopaedic surgery. Equinus contracture may develop in children with type II hemiplegia and lengthening of the gastrosoleus is very helpful. Surgery can usually be deferred until age 4 to 6 years by the use of an AFO combined with injections of BoNT-A and a programme of physiotherapy. The choice of lengthening procedure is based on a careful Silfverskiold test to determine the amount of contracture in the gastrocnemius and soleus respectively (Graham 2010).

In bilateral spastic CP, some children develop a mild contracture, usually involving only the gastrocnemius. Careful assessment by instrumented gait analysis is essential to identify proximal involvement which would require correction. Isolated, single level surgery for equinus in bilateral spastic CP is rarely indicated and is associated with a 40% risk of severe crouch gait, in long-term follow up (Borton et al. 2001).

Adolescent: maintaining high level sporting activities may become more difficult. Maintaining muscle length and strength through PRST gym-based programmes can be very helpful.

GMFCS level II Children manage walking on level surfaces but uneven terrain, steps/stairs, long distances present difficulties. An assistive device or wheelchair may be required for community distances particularly when older.

Function: FMS 6,5,5 to 5,5,1; FAQ 8 to 9
Sagittal gait pattern:
Unilateral spastic cerebral palsy: type II to IV hemiplegia
Bilateral spastic cerebral palsy: jump gait, apparent equinus, crouch gait

Musculoskeletal:
Lower limb: Type IV hemiplegia: there is involvement of the entire lower limb in type IV hemiplegia. The usual pattern is equinus at the ankle, a stiff flexed knee, a hip that is internally rotated, adducted and flexed and a pelvis which is retracted, anteriorly tilted and oblique in the coronal plane. The foot may be equinovarus or equinovalgus (Michlitsch et al. 2006, Graham 2010). Evaluation should include IGA including dynamic EMG, pedobarography, and standardized radiographs in the weight bearing position (Davids, Gibson, and Pugh 2005). Malalignment is present when there is internal rotation of the femur combined with external tibial torsion. Long-term reliance on the ‘sound’ leg for push off may result in excessive external tibial torsion. It is difficult to evaluate the external tibial torsion on the ‘sound side’ without gait analysis but it rarely requires correction. Limb length discrepancy is often significant and may require correction by growth plate surgery, in selected children (contralateral epiphysiodesis). Dystonia
may be present particularly in the upper limb. It is important to note that type IV hemiplegia is associated with progressive hip displacement in some children (Rutz et al. 2012a). This is clinically silent, in the initial stages and radiological surveillance is required.

Bilateral spastic cerebral palsy: the movement disorder is usually spastic, especially in those born preterm. The natural history of deformities in the lower limbs in GMFCS level II is for gradual progression during childhood with more rapid deterioration during the adolescent growth spurt. The natural history of gait is progressive deterioration including increasing stiffness throughout the lower limb joints and increasing tendency to flexed knee gait and ultimately crouch gait (Johnson, Damiano, and Abel 1997, Bell et al. 2002, Gough et al. 2004). The transition from equinus gait to crouch gait is often accelerated by procedures, which weaken the gastrocnemius, especially lengthening of the Achilles tendons (Vuillermin et al. 2011). The principal gait dysfunctions in bilateral spastic CP are stiffness and excessive flexion.

Musculoskeletal pathology in bilateral spastic CP, GMFCS level II, includes increased femoral neck anteversion, and contractures of the two joint muscles, the psoas, hamstrings and gastrocnemius (Graham 2004) (Fig. 27.16). There is usually pes valgus and in adolescents hallux valgus. There is sometimes excessive external tibial torsion resulting in lower limb malalignment. In asymmetric bilateral spastic CP pelvic retraction may make clinical estimation of rotational malalignment during gait very difficult. Occasionally in bilateral spastic CP varus may be present but is more apparent than real because of excessive FNA and ‘rollover varus’. If present, varus is usually mild and flexible.

Hips: Mean femoral neck anteversion: 36°
Mean neck shaft angle: 141°
Risk of hip displacement (migration percentage >30%): 15%

In bilateral spastic CP, GMFCS level II, the mean femoral neck anteversion is increased at 36 degrees and there is a 15% risk of hip displacement. The hip displacement is generally mild and progresses slowly.

Spine: small curves (10–25°) are seen in <20% of adolescents but they do not progress and do not require surgery.

Management:
Younger child: early management will be similar to GMFCS level I but with more frequent physiotherapy and BoNT-A injections as indicated by functional limitations, together with use of hinged or solid AFOs. If the spasticity is mild/moderate and at multiple levels, it can be managed by multilevel injections of BoNT-A repeated at 12 month intervals. Selective dorsal rhizotomy is a better option when the spasticity is severe, generalized, and adversely affecting gait and function (McLaughlin et al. 2002).

Older child: this is the ideal time (6–12y) for SEMLS. SEMLS is rarely needed before age 6 years. All surgery and rehabilitation should be completed before the child leaves primary school. Teenagers do not cope well with SEMLS and rehabilitation (Thomason and Graham 2013).

Type IV hemiplegia: unilateral multilevel surgery is usually required between the ages of 6 and 12 years. Progressive subluxation of the hip is an indication to proceed with unilateral multilevel surgery in which stabilization of the hip and correction of the limb deformities are combined (Dobson et al. 2005, Rutz et al. 2012a). IGA is essential in type IV hemiplegia because the number of gait deviations is considerable. It is very important to differentiate between primary deviations, secondary compensations and tertiary coping mechanisms.

Correction of soft tissue contractures in the sagittal plane will most likely be accompanied by external rotation osteotomy of the femur and internal rotation osteotomy at the supramalleolar level of the tibia and fibula to correct malalignment (Fig. 27.10). Equinovarus deformities are variable in severity and
more resistant to surgical correction than in bilateral spastic CP. In younger children with documented overactivity in the tibialis posterior, both intramuscular recession and Split Posterior Tibial Tendon (SPOTT) transfer are good options (Graham 2010). Ideally this should be undertaken before deformities become fixed, thus avoiding the need for bony surgery. In children with documented overactivity in both the tibialis anterior and tibialis posterior, a combination of Split Anterior Tibial Tendon (SPLATT) transfer and intramuscular recession of the tibialis posterior, gives good long-term results (Graham 2010).

A number of children with unilateral spastic CP benefit from contralateral epiphysiodesis to reduce limb length discrepancy. In these children, bone age is often well ahead of chronological age. Children with type IV hemiplegia rehabilitate quickly and easily because surgery is unilateral and the sound side helps with rapid mobilization.

**Bilateral spastic cerebral palsy:** Preventive surgery for hip displacement consisting of lengthening of the hip adductors is effective (Shore et al. 2012). Hip flexion contractures are dealt with by lengthening of the psoas tendon at the brim of the pelvis. This is a stable lengthening and does not require immobilization. Prone lying is required postoperatively to encourage hip extension. Femoral antversion is corrected to 5 to 10 degrees, leaving only 10 to 20 degrees of internal rotation at the hip. The proximal osteotomy effectively lengthens the psoas and is the preferred technique.

At the knee, hamstring contracture and mild dynamic deformity may be treated by distal hamstring lengthening without any fixed flexion contracture at the knee. Distal hamstring lengthening is ineffective when knee flexion contracture exceeds 5 to 10 degrees (Young et al. 2010). Recurvatum is sometimes seen after excessive hamstring lengthening and a persistent equinus contracture. When hamstrings are lengthened in cases of normal hamstring function (normal muscle length and velocity in swing), excessive anterior pelvic tilt and pelvic range of motion may develop (Rodda et al. 2006). Hamstring lengthening should either not be considered or at least should be done cautiously and include management to treat the anterior pelvic tilt (Young et al. 2010).

The main complication of surgery for equinus is gradual failure of the plantarflexion-knee-extension couple, leading to calcaneus and crouch gait. This is much more disabling and difficult to treat than the original equinus gait. In bilateral spastic CP a little equinus is better than calcaneus’ (Rang 1990, Firth et al. 2013). The ‘over-lengthening’ is mediated by biomechanical changes and growth, not surgical imprecision. When the GRF falls behind the knee, the soleus responds to the continual stretch by adding more sarcomeres in series. In time, the soleus becomes functionally too long, biomechanically incompetent and calcaneus-crouch progresses rapidly. Deferring the surgery until age 6 to 8 years reduces the risks of both recurrence and over correction. The more proximal operations on the gastrocsoleus are the most stable and safest in terms of avoiding calcaneus (Shore, White, and Graham 2010, Firth et al. 2013).

Equinus leads to excessive loading of the forefoot and with time may cause breaching of the midfoot. A series of complex segmental malalignments of the midfoot, hindfoot, and forefoot develops referred to as ‘pes valgus’ (Graham 2010). Symptoms may include pain and callosities over the collapsed medial arch, particularly the head of the talus. This leads to discomfort in shoes and inability to wear AFOs (Fig. 27.17). Evaluation includes the usual components of the diagnostic matrix with special emphasis on weight bearing radiographs of the feet and ankles, rather than three dimensional motion analysis (Davids, Gibson, and Pugh 2005). Factors affecting the choice of operative procedure include the age of the patient and the clinical and radiographic severity of the deformity. The midfoot can be stabilized and deformity corrected by lengthening of the lateral column of the foot (os calcis lengthening) or extra-articular fusion of the subtalar joint. The indication for os calcis lengthening is a flexible valgus deformity of the heel in association with an abductus deformity of the forefoot, in a patient who walks independently, GMFCS levels I or II (Mosca 1995). Arthrodesis of the subtalar joint is a reliable means of correcting hindfoot valgus and with secondary correction of the midfoot. It is useful for more severe deformities in patients who require assistive devices and long-term orthotic support, GMFCS levels III and IV (Shore et al. 2012).
Fusion of the talonavicular joint is a third option (de Coulon et al. 2011).

Management of equinovarus by intramuscular recession of tibialis posterior, combined with correction of femoral torsion, as part of SEMLS gives good results. In children with bilateral spastic CP, over correction to valgus is common.

External tibial torsion may occur in isolation or in conjunction with medial femoral torsion. In isolation, external tibial torsion results in an external foot progression angle and ‘lever arm disease’ because the foot lever is effectively shortened and mal-directed, in relation to the line of progression. However, when external tibial torsion and medial femoral torsion coexist the foot progression angle may be relatively normal but the knees face inwards and there is still very significant lever arm disease (malignant malalignment syndrome). Supramalleolar osteotomy of the tibia is an effective means of addressing this problem. External foot progression angle is usually the result of combined pes valgus and external tibial torsion. The decision to perform os calcis lengthening, supramalleolar osteotomy (SMO) of the distal tibia, combination requires a very careful assessment using all components of the diagnostic matrix.

Hallux valgus is commonly associated with deformities in the hindfoot, midfoot, and proximal gait deviations, such as stiff-knee gait, which causes toe scuffing. The most reliable procedure is fusion of the first metatarsophalangeal joint, either in conjunction with, or after correction of the proximal deformities (Davids et al. 2001).

Adolescent: the time for SEMLS and intensive rehabilitation has passed. The emphasis moves to maintenance of function and mobility via strengthening programmes within the home, school or gym environment. Minor surgery for recurrent deformities or minor gait deviations may be required.

GMFCS level III Children walk using an assistive device in most situations but may use a wheelchair for community distances.

Function: FMS 5.4.4 to 2.2.1; FAQ 6 to 8

Sagittal gait pattern:

Unilateral spastic cerebral palsy: not applicable unless other comorbidities

Bilateral spastic cerebral palsy: jump gait, apparent equinus, crouch gait

Musculoskeletal:

Lower limb: the predominant movement disorder in GMFCS level III is spasticity but some children have dystonia or a mixed movement disorder. Weakness of the major lower limb muscles, particularly those contributing to body support is a major feature. Flexed knee gait patterns predominate and weakness is usually the primary determinant of long-term gait and community function rather than spasticity. It is important to differentiate between those individuals who are being ‘pulled down’ by spasticity and those who are ‘falling down’ because of weakness. The strength and selective motor control of the muscle groups which contribute to the body support moment, the gastrocsoleus, quadriceps, and hip extensors are crucial.

The musculoskeletal pathology in GMFCS level III is similar to that in GMFCS level II but the contractures of the muscle-tendon-units are usually more severe and the deformities in the bony levers (femur and tibia) and joint instability (hip and foot) are more pronounced. Severe ‘lever arm deformities’ are common in GMFCS level III with increased femoral neck anteversion, marked external tibial torsion and pes valgus (Fig. 27.18).

Severe crouch gait can be defined as knee flexion >30 degrees throughout stance, with excessive ankle dorsiflexion and incomplete hip extension (Rodda et al. 2004). crouch gait may occur in GMFCS level I but is invariably mild because children in GMFCS level I have good strength and selective motor control. Severe crouch gait may occur in GMFCS level IV, but given that sustained ambulation is not feasible in adult life, correction by invasive surgery is not appropriate. Severe crouch gait is a major functional issue in GMFCS levels II and III.

There is often a delay between lengthening of the gastrocsoleus and the development of crouch gait. Instead of ‘growing up’ the adolescent with progressive crouch gait ‘sinks down’, with an inability to maintain an extension posture at the hip and knee during the stance phase of gait. Most severe crouch gait is iatrogenic and therefore preventable (Vuillermin et al. 2011). Contributing factors seem to be a progressive mismatch between the strength of the one-joint muscles contributing to the body support moment (gluteals, quadriceps, and gastrocsoleus) and increased demand because of rapid increases in height and weight at the pubertal growth spurt. This typically occurs in conjunction with progressive bony deformities known as lever arm disease. Around the time of the pubertal growth spurt, increasing patella alta (sometimes with fractures of the patella or avulsions of the inferior pole), increasing external tibial torsion and breakdown of the midfoot with severe pes valgus, all contribute to increasing crouch, fatigue, and decreasing ability to walk.

Hips: Mean femoral neck anteversion: 40°

Mean neck shaft angle: 149°

Risk of hip displacement (migration percentage >30%): 41%

Spine: small curves (10–35°) are seen in 20% of adolescents but they do not progress and do not require surgery.

Management:

Younger child: the focus in the early years is on the development of gross motor function and mobility with emphasis on prevention of contractures and developing strength. Physiotherapy is combined with orthotics and the judicious use of BoNT-A injections as an adjunct to therapy.

Hip displacement in children with CP cannot be prevented by non-operative measures including physiotherapy, abduction bracing and injections of BoNT-A (Graham et al. 2008, Lundy, Doherty, and Fairhurst 2009). Hip surgery for children with
CP can be classified as preventive, reconstructive, and salvage (Miller, Dabney, and Rang 1995). Surgery to prevent hip displacement refers to soft tissue releases incorporating open lengthening of the adductor longus and gracilis and lengthening of the psoas over the brim of the pelvis to prevent or reverse early hip displacement in younger children. Because the outcome of preventive surgery depends on the age of the child (younger children have better results) and the initial migration percentage (migration percentage <40%), early and regular hip surveillance is recommended. The results in children in GMFCS level III, who are walking with external support are very good. Several studies have reported that the outcome of preventive surgery is much better in ambulators than in non-ambulators (Miller et al. 1997a, Presedo et al. 2005). The effectiveness of adductor surgery is predicted by GMFCS level (Shore et al. 2012).

Older child: SEMLS using the principles and techniques described for children with a GMFCS level II is appropriate. Surgery for crouch gait has been revolutionized in recent years by improved understanding of the causes, biomechanics and by the introduction of more effective surgical procedures and rehabilitation (Stout et al. 2008). Most severe crouch gait is caused by single level surgery for equinus gait. When this is eliminated in a population, crouch gait becomes less common, less severe and more easily managed. Traditional surgery with over reliance on hamstring lengthening is not very effective (Rodda, Graham, and Galea 2006, Young et al. 2010). If the knee flexion deformity is between 5 and 10 degrees, semitendinosus transfer to the adductor tubercle is the technique of choice but if the deformity is between 10 and 25 degrees and the child is pre-pubertal, then guided growth at the anterior physis of the knee by '8' plates can be included (Ma et al. 2006, Young et al. 2010). If the child is at skeletal maturity and the knee flexion deformity is 10 to 30 degrees, a distal femoral extension osteotomy with patella tendon shortening is most likely to assist in achieving better knee extension and lasting correction of crouch gait (Stout et al. 2008).

Adolescent: Ideally SEMLS will have been undertaken prior to adolescence. The ongoing management of weakness and muscle tightness will be emphasized in a physiotherapy programme and ideally in a community setting such as a gym. Both PRST and aerobic exercise for fitness and weight control are important (Thomason and Graham 2013).

GMFCS level IV: At this GMFCS level, children may have limited walking (requiring physical assistance) within the home or classroom but will use wheeled mobility at other times. Adolescents will most likely use a manual or powered wheelchair in all settings.

Function: FMS 2,1,1 to 1,1,1; FAQ 1 to 5

Sagittal gait pattern:

Bilateral spastic cerebral palsy: jump gait, apparent equinus, crouch gait

Musculoskeletal:

Lower limbs: Flexion deformities at the hip and knee are very common as are deformities at the foot and ankle, especially external tibial torsion and pes valgus. Hallux valgus and dorsal bunions are also quite common.

The majority of children in GMFCS level IV have mixed tone or ‘spastic-dystonia’. In children and adolescents with severe, generalized hypertonia, ITB by implanted pump offers the most reliable method of sustained tone reduction (Albright

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Fig. 27.18. Severe jump gait in Gross Motor Function Classification System level III prior to surgery. Post SEMLS. Post growth plate surgery to the knees. The goals of growth plate surgery are sagittal plane balance and the ability to tolerate ankle-foot-orthoses (AFOs) which together improve gait and functioning. Used with permission from Lippincott Williams and Wilkinson/Wolters Kluwer Health: Lovell and Winter Pediatric Orthopaedics. © 2014 Lippincott Williams and Wilkinson.
Lower Limb Function

2008). Weakness of the trunk and paraspinal muscles results in a postural kyphosis and the incidence of scoliosis is high (Persson-Bunke et al. 2012).

**Hips:**  
Mean femoral neck anteversion: 40°  
Mean neck shaft angle: 155°  
Risk of hip displacement (migration percentage >30%): 69%  

**Spine:** Severe curves (>40°) are seen in 25% of adolescents. Progressive scoliosis is common in GMFCS level IV. The majority of children will require surgical correction. Postural kyphosis is also common in GMFCS level IV owing to the effects of paraspinal weakness and impairments of posture and balance. Management of spinal deformities is considered in more detail in the section on GMFCS level V.

**Management:**  
In GMFCS level IV, management goals are based on a realistic appraisal of long-term motor prognosis including standing and assisted walking in early childhood. In later childhood maintenance of comfortable sitting by detecting and treating early hip displacement is important. Later, monitoring of spinal deformity with appropriate treatment and provision of custom seating are the most important issues.

**Younger child:** Younger children may enjoy supported standing and assisted ambulation. It may be appropriate to employ some of the procedures described for children in GMFCS level III to assist with this. While physiotherapy and orthotic prescription, combined with BoNT-A or ITB, are appropriate forms of management, attainment of standing and walking will be limited and slow. Parents, carers, and therapists should recognize that sustained ambulation into adolescence and adult life is not achievable (Palisano, Rosenbaum, and Bartlett 2008), therefore extraordinary measures to maintain ambulation are contraindicated. Hip surveillance is essential owing to the high risk of progressive hip displacement (Soo et al. 2006).

**Older child:** Managing deformity of the foot and ankle is important to allow bracing and wearing of shoes. This can also allow the child’s feet to rest comfortably on the footplate of their wheelchair. Correction of severe external tibial torsion by supramalleolar osteotomy of the tibia and/or stabilization of the foot by a subtalar fusion may be necessary for correct foot positioning to allow the child to participate in assisted transfers (Selber et al. 2004, Shore et al. 2013). If pain and comfortable shoe wear is a problem for the child, hallux valgus and dorsal bunions can be corrected by soft tissue surgery and fusion of the first MTP joint (Davids et al. 2001).

Hip displacement may be managed by preventive or reconstructive surgery or, for many children, a combination of both. For children with reduced hip abduction range, preventive hip surgery is undertaken to lengthen the adductors. While the aim of preventive surgery is to slow the progression of hip displacement, an increase in abduction range can also assist carers with daily tasks such as dressing and bathing. It is important to remember that preventive surgery has a short-term effect for children in GMFCS level IV and many will go on to require reconstructive hip surgery (Shore et al. 2012).

Reconstructive hip surgery poses a major challenge to children in GMFCS level IV who often have complex comorbidities. Nutrition and respiratory status should be optimized before embarking on any major surgery, especially bilateral VDROs and left pelvic osteotomy the hips are enlocated (in joint) and the pelvis is more level.

![Windswept hips in a 10-year-old boy with cerebral palsy in Gross Motor Function Classification System level IV. Note the pelvic obliquity and severe hip displacement on the left side. Following bilateral VDROs and left pelvic osteotomy the hips are enlocated (in joint) and the pelvis is more level.](image)
a pelvic osteotomy at the time of bony reconstruction (Flynn and Miller 2002).

Following surgery, radiological monitoring of hip development and scoliosis should continue until skeletal maturity, at least. In GMFCS levels IV and V, the single biggest threat to hip status after successful reconstruction is progression of scoliosis and pelvic obliquity.

Progressive scoliosis is common in GMFCS level IV but differs from that seen in GMFCS level V. It tends to start a little later, is not so rapidly progressive and the outcomes of surgery are better because medical comorbidities are fewer and less severe. Management of scoliosis will be considered in more detail in the section on GMFCS level V.

**Adolescent:** Continued clinical and radiological screening of hip and spine status are paramount. Surgery as required according to the principles and techniques stated above.

**GMFCS level V**

Mobility is dependent on wheelchair use and usually the assistance of another person. There is immense difficulty with anti-gravity head and trunk movement and minimal upper and lower limb control.

**Function:** FMS 1,1,1; FAQ 1 at best 2.

**Sagittal gait pattern:** not applicable as children are non-ambulant.

**Musculoskeletal:**

**Lower limb:** The movement disorder can be dominated by spasticity or dystonia, or a combination of both, and is usually severe and generalized. ITB can help reduce discomfort and enhance day to day care. Physical activity is extremely limited and most of the day would be spent in a sitting position and some time in lying. Contraction of the hip flexors, knee flexors and the feet will tend to occur but the most serious problems are those posed by hip displacement and spinal deformity.

**Hips:**

- **Mean femoral neck anteverision (FNA):** 40°
- **Mean neck shaft angle (NSA):** 163°
- **Risk of hip displacement (migration percentage >30%):** 90%

**Spine:**

Severe curves (>40°) are seen in 50% of adolescents. They progress rapidly and surgical correction is usually required. The long ‘C’ shaped curves in cerebral palsy, present early in childhood, are likely to be progressive and can progress rapidly. Progression may continue after skeletal maturity if the curve is more than 40 degrees (Miller 2005).

**Management:** Management is for comfort, optimal function (despite being limited) and ease of care giving. Posture and alignment of the body in the wheelchair is paramount for comfort, therefore there is emphasis on the status and management of the feet, hips, and spine to ensure this.

**All ages:** Preventive hip surgery has a high failure rate and should be considered to be a temporizing measure for most children in GMFCS level V (Shore et al. 2012). Reconstructive surgery is technically easier and probably more successful in older children (Miller et al. 1997b). Scoliosis and pelvic obliquity are so prevalent that hip and spine management should be considered together.

If the opportunity for reconstructive surgery has been missed and hip salvage surgery is required, the degree of femoral head and acetabular deformity should be carefully evaluated in the context of the child’s health, functioning, and life expectancy (Flynn and Miller 2002). Referral to an appropriate pain management service should be considered as a number of teenagers can be managed non-operatively in the short term. Reflex spasms of the hip adductors and flexors are almost always part of the pain problem in dislocated hips. Short-term symptomatic relief can often be achieved by injecting the hip joint with bupivacaine and corticosteroid and injecting the hip adductors and flexors with BoNT-A. Open releases of the contracted hip adductors and phenolization of the obturator nerve may be helpful. These interventions have been reported to give short-term pain relief but no long-term studies have been reported (Lundy, Doherty, and Fairhurst 2009).

It is also important to optimize tone management prior to salvage surgery as the surgery is much easier to perform when global tone is reduced. ITB pump may be an appropriate choice for managing tone, and if so, should be done before hip surgery. In a few children a marked reduction in tone around the hips may reduce pain and postural deformities to such a degree that salvage surgery may not be required.

There is no single, reliable salvage surgery for the painful dislocated hip, therefore the best treatment is prevention. The need for salvage surgery is best avoided by early hip surveillance and appropriately timed preventive and reconstructive surgery.

Spinal deformity affects approximately two-thirds of children in GMFCS level V but is variable in its onset, severity, progression, and effects. Kyphosis in the dorsal spine is very common in younger children with weak paraspinal muscles and is best managed by having the wheelchair seat slightly reclined, the use of chest straps and occasionally a thoraco-lumbar-sacral orthosis (TLSO). Kyphosis in the lumbar spine is less common and may be related to severe contractures of the hamstrings. Proximal hamstring recession may be beneficial. Lordosis in the lumbar spine is much more common and is frequently related to hip flexion contractures. Lengthening of the hip flexors before the lordosis becomes excessively severe or fixed may be appropriate. An ITB pump may be helpful in the management of muscle imbalances about the hip that are causing secondary lumbar lordosis or kyphosis deformities.

A variety of options may be considered for managing scoliosis. Non-operative management such as physiotherapy, injections of BoNT-A and electrical stimulation have been tried and are not effective for scoliosis (McCarthy et al. 2006). Customized seating with moulded inserts may improve sitting balance and comfort, but do not slow curve progression. Bracing of scoliosis in cerebral palsy is poorly tolerated and is also ineffective in avoiding progression in the long term. It may be appropriate
to offer bracing or seating modifications in younger children, combined with careful clinical and radiographic monitoring. This gives parents and caregivers the opportunity to learn about the natural history of the curve in their child, and come to terms with the need for major spinal surgery. In one study, bracing was helpful in curves <40 degrees in ambulant children but these are not the typical curves seen in GMFCS V (Terjesen, Lange, and Steen 2000). Bracing in children in GMFCS V may, at best, slow curve progression in younger children with small curves and good compliance. Surgery may be postponed but will still be required for the majority of children (McCarthy et al. 2006).

The functional goal of scoliosis surgery in cerebral palsy is to improve sitting balance and ease the burden of care (Tspirikos et al. 2004). The biomechanical goal is to achieve a stiff, well balanced spine over a level pelvis with flexible, enlocated hips. In the majority of children, the surgical goal is a long posterior spinal fusion with the fusion limits from high in the dorsal spine to the pelvis. Spinal fusion in children with CP improves sitting position and appears to improve upper limb function, eating and respiratory function. It may also prolong life and improve the quality of life (Mercado, Alman, and Wright 2007).

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Cerebral—Cerebral Palsy

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