Hip Reconstruction in Children with Cerebral Palsy

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Abstract

Children with cerebral palsy who are not able to ambulate have a high frequency of developing hip subluxation and dislocation. Through early surveillance, many of these can be treated before there is pain or severe hip displacement and deformity. After the initial early detection, or if the problem is discovered later with more severe hip displacement, a full hip reconstruction is required. This procedure usually involved lengthening of the hip adductor muscles, femoral varus osteotomy. When there is hip subluxation or dislocation with acetabular dysplasia, a pelvic osteotomy is also required. It is usual to do bilateral, femoral osteotomies to prevent the problems of seating caused by very symmetric leg lengths, to treat the contra-lateral abducted hip to prevent it from causing...
seating problems and from driving the opposite hip back to adduction and recurrent dislocation. This reconstruction can usually be done without the use of casts, and the child can be up in the wheelchair in 2–4 days. Long-lasting correction of the hip displacement has approximately a 95% success; relief of pain when it is present before surgery occurs in more than 90% of children. Good results of reconstruction have been reported in young adults, although good outcomes are less common with very young children and in adults when the hip is completely dislocated.

**Keywords**

Hip subluxation · Hip dislocation · Pelvic osteotomy · Femoral osteotomy · Hip pain · Cerebral palsy

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**Introduction**

Hip subluxation and dislocation is common in children with cerebral palsy (CP), and it is most common in children with severe motor disability at GMFCS IV and V level of function. Subluxation primarily develops between ages 2 and 6 years old and complete dislocation developing between ages 5 and 12 years old. The current goal of management is to identify the subluxation at the early stage with the goal of preventing later complete dislocation. If the early prevention is missed or the preventive therapy fails, reconstruction is required. Reconstruction should occur before there is severe boney deformity of the femoral head or acetabulum. Also the reconstruction is technically easier and has a better outcome if it is done before the closure of the growth plates or when there is not a complete dislocation. Boney hip reconstruction has developed very widely accepted indications and similar techniques in almost every center around the world. There is much higher level of agreement on indications and techniques for hip reconstruction then for preventive treatment or palliative treatment. The current technique using femoral and pelvic osteotomy grew out of the experience of treating hips with developmental hip dysplasia but with the early recognition that the same protocol and procedures do not work for the hip in CP. The use of the varus osteotomy had a long-standing history in children with CP; however, there was still a high failure rate when it was used alone. The concept of peri-ileal osteotomy was developed in the late 1980s which was loosely modeled on the Dega osteotomy (Dega 1974). The procedure for the CP hip was developed independently in San Diego, Wilmington, and Edinburgh and has now come into widespread use with some minor modifications. This chapter will review the indications and technique for hip reconstruction in children with cerebral palsy.

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**Natural History**

The natural history of hip subluxation in the child with cerebral palsy is addressed in the previous chapter (“Natural History and Surveillance of Hip Dysplasia in Cerebral Palsy”). It should be noted that all children who develop subluxation in middle childhood which reaches migration percent (MP) of 50–60% will almost certainly proceed to go on to a dislocated hip and a large number of these will become painful. Some children appear to develop pain during subluxation, which then reduces as the hip dislocates; however, most of these will have recurrent pain as degenerative arthritis occurs. Due to the very ominous outcome of a dislocated hip in a child with cerebral palsy and the excellent outcome of surgical treatment, hip reconstruction is strongly recommended before the child’s hip becomes painful or dislocated.

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**Treatment**

Reconstructive treatment is required for those spastic hips whose secondary bone deformities are too severe for the body to recover without direct treatment. Reconstructive treatment is primarily directed at reducing the femoral head into the acetabulum, followed by reconstruction of the
acetabulum to correct its bony deformity. The goal of reconstruction is to leave children with an anatomically normal hip joint, with normal posture and normal range of motion. In this sense, reconstruction has the same goal as prevention treatment; however, reconstruction is a much more extensive surgical procedure with a longer rehabilitation. Using appropriate monitoring and screening, most children who are treated with soft tissue lengthening will not need reconstruction (chapter “Prophylactic Treatment of Hip Subluxation in Children with Cerebral Palsy”).

**Indications for Reconstructive Treatment**

For the spastic hip that subluxates or dislocates, the most typical direction is posterior superior and is the primary indication for reconstruction in a child whose hip has severe subluxation of greater than 60% or who has a dislocated hip. Any child whose hip MP is greater than 40%, and who is over age 8 years, is also indicated for reconstructive treatment (Case 1). Reconstructive treatment should not be considered in children with very severe degenerative arthritis of the hip joint and a severe deformity of the femoral head; however, this is very subjective and difficult to define. As the severity of the femoral head and acetabular deformity gets worse, the risk of failure increases, so another approach is to consider how much tolerance the family and surgeon have for failure of the procedure. It should also be considered that the outcome of a good reconstruction is always better than the outcome of a good palliative salvage procedure. In general, the femoral head should be relatively round, and the acetabulum should have a fairly good shape without an excessive amount of medial wall widening. Reconstruction works best for children who have severe subluxation or recent dislocation in whom the secondary acetabular deformity of excessive medial wall growth and of femoral head deformity has not occurred. For children with open triradiate cartilage and thickening of the medial wall or femoral head deformity, reconstruction is still an option. This area is not very clearly defined and depends somewhat on the experience of the surgeon, the willingness of children and parents to risk failure, and the level of discomfort and function of the children. In general, younger children, between 6 and 12 years of age, who are having pain from a severely subluxated or dislocated hip, can have the reconstructive treatment indications pushed harder because more remodeling capability remains (Case 2). Conversely, fully mature adults with a substantial triangular-shaped femoral head have less possibility of getting a good result from reconstruction because of more limited ability for remodeling. This limit however can be pushed extensively as has been shown by Brunner, who reconstructed many severely deformed hips with good results (Rutz et al. 2015).

**Recommended Surgical Reconstruction Approach**

Surgical reconstruction should include three major areas of the hip joint. First, it is important to correct the pathomechanics, which is the original etiology. The abnormal hip joint reactor force vector has to be corrected by adequate lengthening of the hip adductor muscles. The high-force environment that has caused this should be treated by adequate femoral shortening so that the hip joint is no longer under high force after reconstruction. The second major aspect of a reconstructive procedure is correction of the acetabular deformity, which is of such severity that it will not be able to remodel and needs to be corrected directly. The third major aspect of a reconstruction is making all attempts to leave children with symmetric movement of the hips and symmetric limb lengths.

The standard hip reconstruction involves open adductor lengthening, followed by a varus shortening derotational osteotomy of the femur and a reconstruction of the acetabulum using a peri-ilial acetabular osteotomy. The peri-ilial osteotomy and the Dega osteotomy are somewhat confusing terms, and the use of the Dega osteotomy for spastic hip disease was initially described as extending posteriorly into the sciatic notch (Mubarak et al. 1992). This sciatic notch approach
defined as the classic Dega procedure (Jozwiak et al. 2000) has now been altered (McNerney et al. 2000) so that the osteotomy is directed toward the posterior triradiate cartilage as was originally described in the peri-ilial procedure (Miller et al. 1997). The San Diego osteotomy continues to use the anterior approach to the hip capsule rather than the medial or lateral approach, which is advocated in the peri-ilial approach. Cast immobilization continues to be used after the pelvic osteotomy by some usually for a short period for pain control, as opposed to the immediate mobilization used after the peri-ilial osteotomy. However, outcomes of both procedures are very similar.

An extremely important aspect of the reconstruction procedure is to make sure the hip is reduced into the true acetabulum before one attempts to do the acetabular osteotomy. If the hip is not reduced first by decompression with the varus shortening osteotomy, a medial and anterior capsulotomy is needed. This should allow Shenton’s line to normalize and even better if it is over reduced by bringing the femur lower then Shenton’s line. This will allow the acetabulum to be turned down without resistance from the femoral head. The capsulotomy maybe performed from the medial approach through the adductor lengthening incision, or through the lateral femoral osteotomy site, or some surgeons prefer the anterior approach. The simplest and most direct approach is through the lateral femoral osteotomy site. Once the femoral head is brought down to at least Shenton’s line, it should also be brought medially against the medial wall of the acetabulum. In long-standing dislocations, there may be a medial ridge of cartilage or bone where the triradiate cartilage has grown out because there was no pressure from the femoral head (Case 3). If the hip is not too far lateral, this maybe left and the acetabulum will usually remodel if the hip stays reduced, although there may be a period of pain (Case 4). Another option is to directly perform curettage on some of the cartilage and bone, or one can do the pelvic osteotomy and curettage on the triradiate cartilage through the osteotomy site and then impact the ridge with a ball impactor. I usually use a total hip acetabular impactor of approximately the correct size. Although these hips may sit lateral for some time, if the child has muscle tone and the hip can locate, it will gradually reduce (Case 3).

**Outcome of Reconstruction Treatment**

The outcome of reconstruction treatment is excellent and very predictable, as long as the indications are not pushed too hard in children who have closed growth plates and more severe degenerative arthritis and deformity (Case 1). Two centers have reported that 95% of hips should have an essentially normal reduction and function (Miller et al. 1997; McNerney et al. 2000). There have continued to be further reports from many centers documenting the excellent outcomes of the one-stage reconstruction (Braatz et al. 2014, 2015; Krebs et al. 2008; Oetgen et al. 2015; Rutz et al. 2015; Sankar et al. 2006). This reconstruction is a onetime procedure with results that last a lifetime. Range of motion continues to be excellent, with hip flexion of more than 90% near full extension in almost all patients and abduction of at least 20° or 30°. Many children will have some limitation of hip internal and external rotation, and some children will develop progressive, recurrent hip adduction contractures. As these adduction contractures develop, it is important to not let them become very severe because there is a tendency for windblown deformities to develop in adolescence. These early windblown deformities are more easily treated with recurrent soft tissue lengthening than by waiting for them to become too severe.

Pain was a major problem for some children before reconstruction. In 18 patients, there were 23 painful hips before reconstruction, and of these 23 hips, one child continued to have some discomfort requiring occasional analgesia at a final follow-up of more than 2 years, and one hip failed at 9 months, requiring reconstruction (Miller et al. 1997). Therefore, the treatment of painful dislocated hip has a 90% success rate. Both these hips that continued to have pain were hips in which the triradiate cartilage was closed, and the indication for this procedure was pushed a little beyond its limit. Patients with more hip
deformity such as more femoral head deformity, displacement of Shenton’s line, and acetabular deformity had a less positive long-term outcome (Oh et al. 2007). Also hips in younger children under age 6 and those who have had a failed reconstruction have a higher risk of long-term failure (Dhawale et al. 2013). There is data however from another series showing that the degree of femoral head deformity was not related to the poor outcome. Of 168 hip reconstructions in 121 patients, only the preoperative migration percent was correlated with outcome assessed with pain evaluation, MCPHCS grade, and GMFCS level (Rutz et al. 2015). The difference in the data between studies may be related to the better accounting of comorbidity of migration percent and femoral head shape, or it may be due to better surgical technique. These reconstructions are technically demanding and should be done in centers with high volume to gain the required experience.

Other Reconstructive Treatment Options: Varus Osteotomy Without Acetabular Osteotomy

There have been many reports (Hoffer et al. 1985; Bagg et al. 1993; Herndon et al. 1992) that suggest using varus osteotomy plus adductor lengthening in the treatment of hip subluxation. A more recent review of a large number of varus osteotomies with 8-year mean follow-up found 37% failure rate. Some of these also had pelvic osteotomies, but the identified factors relating to failure were lack of adductor lengthening, low surgeon case volume, and increasing GMFCS level. All these reports found 20–30% failure rates and none has very clear inclusion criteria. The failures are almost all dislocations. One report evaluating adductor lengthening versus femoral varus osteotomy reported very similar outcomes (Schmale et al. 2006). Some of these reports use the archaic pins and plaster technique for doing hip osteotomies, which tends to leave children with severe torsional malalignments as one hip goes into internal rotation and the other hip into external rotation (Bagg et al. 1993). Varus osteotomy alone to address hip subluxation likely yields similar outcomes as hip adductor lengthening in children who meet very stringent criteria. There is, however, no data to support the relative outcome of a 5-year-old spastic child with GMFCS V function with 50% hip subluxation to recommend soft tissue-only procedure versus soft tissue and varus osteotomy versus varus osteotomy only. Developing the data will require strict inclusion criteria of young children, less than 8 years of age, having a hip subluxation that is less than 40%, and having a normal sourcil or a type I sourcil of the acetabulum. However, if these criteria are not met, the long-term failure rate of varus osteotomy alone is high, using the criteria of success as less than 25% migration index with a normal acetabulum (Cases 4 and 5). Under these rigid criteria of good outcome by which reconstructive procedures are assessed, the failure rate for varus osteotomy would be 70 or 80%. Based on these data and understanding, a varus osteotomy should not be performed without a concomitant acetabular procedure in any child who does not meet the criteria of being less than 8 years, having less than 40% migration index, and having a normal sourcil at the acetabulum. The major indication for using varus osteotomy alone in the reconstructive procedure is doing varus shortening derotational osteotomy of a limb to bring symmetry to patients who do not have hip subluxation. This procedure should be done on the normal side in almost all unilateral hip subluxations of patients undergoing full reconstruction, especially in those who have any degree of abduction contracture or windblown deformity. If the varus osteotomy is not done to treat the hip with fixed abduction contracture, the reconstructed hip will very quickly be driven into adduction, and a recurrent adduction contracture will develop.

Other Pelvic Osteotomies

Many other pelvic osteotomies have been used for doing reconstruction. The Pemberton osteotomy is an osteotomy that extends into the ilium to the triradiate cartilage as well, but it hinges the
osteotomy on the transverse arm of the triradiate cartilage rather than the anteroposterior arm of the triradiate cartilage (Fig. 1). This osteotomy therefore opens the pelvic cut at exactly 90° anterior to the peri-ilial osteotomy described here. The Pemberton osteotomy is the primary procedure for use in anterior acetabular dysplasia, usually seen with an anterior hip dislocation. The Pemberton pelvic osteotomy is the most appropriate. This osteotomy is hinged on the transverse or medial lateral limb of the triradiate cartilage. This osteotomy provides excellent anterior coverage but poor posterosuperior coverage (b). Other osteotomies have all been described for use in spastic hips; however, the published experience is minimal or poor for all other types (c).

Fig. 1 The pelvic osteotomy that most directly provides the correction of the acetabular deficiency present in the typical posterosuperior hip dislocation is the peri-ilial osteotomy, which hinges on the anteroposterior limb of the triradiate cartilage. The cut extends to the posterior border of the triradiate cartilage (a). For a rare anterior-deficient acetabulum, usually seen with an anterior hip dislocation, the Pemberton pelvic osteotomy is the most appropriate. This osteotomy is hinged on the transverse or medial lateral limb of the triradiate cartilage. This osteotomy provides excellent anterior coverage but poor posterosuperior coverage (b). Other osteotomies have all been described for use in spastic hips; however, the published experience is minimal or poor for all other types (c).

The Pemberton osteotomy is one of only a small angle degree; therefore, the small angulation differences in many individuals may not be that important. Likewise, it has been somewhat difficult to determine whether Dega extended the osteotomy into the sciatic notch or the triradiate cartilage. In a fairly detailed report by Dega near the end of his career and is the form of the osteotomy used by his descendants in Poland (Dega 1974), he gives a good description of the osteotomy, which extends into the sciatic notch as was detailed by Mubarak et al. (1992). The peri-ilial osteotomy has been developed by extending the posterior cut away from the sciatic notch and into the posterior limb of the triradiate cartilage, which provides a more posterior and inferior opening of the osteotomy. Although the difference between the peri-ilial osteotomy and the Pemberton osteotomy is one of only a small angle degree; therefore, the small angulation differences in many individuals may not be that important. Likewise, it has been somewhat difficult to determine whether Dega extended the osteotomy into the sciatic notch or the triradiate cartilage. In a fairly detailed report by Dega near the end of his career and is the form of the osteotomy used by his descendants in Poland (Dega 1974), he gives a good description of the osteotomy, which extends into the sciatic notch as was detailed by Mubarak et al. (1992). The peri-ilial osteotomy has been developed by extending the posterior cut away from the sciatic notch and into the posterior limb of the triradiate cartilage, which provides a more posterior and inferior opening of the osteotomy. Although the difference between the peri-ilial osteotomy, the Dega
osteotomy, and the Pemberton osteotomy is primarily one of direction, trying to focus the best coverage onto the area where there is the greatest dysplasia is important. Based on this review of the peri-iliac, Dega, and Pemberton osteotomies, the classic Pemberton osteotomy in which there is only an anterior opening will result in more posterior dislocations if pushed to the limit for children with severe posterosuperior dysplasia.

Shelf acetabular arthroplasty has also been reported specifically for children with CP (Lyne and Katcherian 1988; Zuckerman et al. 1984), but again these reports provide very poor information as to exactly what were the indication criteria and their failure criteria. Range of motion and pain are mainly used in these reports for defining failure, but in spite of this, there is a high variability of failure with successes reported at 69%, 90%, and 80%, all of which are higher than all the peri-iliac or Dega osteotomy reports. The problem with the shelf acetabular arthroplasty is dislocation posterior to the shelf arthroplasty, which therefore removes the capability for the acetabulum to allow itself to remodel and to continue to grow. Shelf acetabular arthroplasty clearly should not be done in children who have not reached adolescence. This procedure may have an occasional place as an augmentation to a peri-iliac osteotomy, but it is important to be careful to avoid too much dissection or adding too large a graft, as there have been two case reports of autofusion after shelf arthroplasty in spastic children (Alonso et al. 1986; McHale 1991). Also, an excellent shelf may be present on a radiograph, but the hip is dislocated out posterior and superior to the anterior shelf (Case 6).

Several reports promote Chiari pelvic osteotomy (Nishioka et al. 2000; Osterkamp et al. 1988; Dietz and Knutson 1995); however, these same authors report failures from either pain or redislocation in approximately 20% of patients. This failure rate is clearly much higher than the peri-iliac osteotomy reports (Case 7). The Chiari pelvic osteotomy may have a limited role in adults with painful hip subluxation and severe degenerative arthritis in whom the goal is to avoid total hip replacement, at least temporarily (Nishioka et al. 2000).

The Salter redirectional osteotomy is specifically not recommended by Salter himself for children with CP. Other authors have reported using the Salter osteotomy for children with CP (Brunner 1998; Cesari et al. 1995; Pope et al. 1994); however, none of these reports allow any actual assessment of the role of this procedure and the outcomes. This procedure is contraindicated in children with spasticity because it not only provides coverage in the wrong location, but it provides that coverage by taking it from the area where these children have the most deficient acetabulum.

Steel (1977) reports that his triple pelvic osteotomy has many failures in children with CP. Good results were reported in a small series (Cesari et al. 1995; Jerosch et al. 1995); however, these papers provide few data to support the optimistic view. This procedure is not recommended in children or adults with CP because the prime deformity is a mostly posterior, opened-up acetabulum, which is difficult to address with this procedure. Furthermore, it is difficult to provide rigid fixation allowing immediate motion without the use of Spica cast immobilization with this procedure. The periacetabular pelvic osteotomy has become popular for adult hip dysplasia, and there has been some interest in its application to mature dislocated hips in CP. This procedure seems to have all the same problems as the triple innominate osteotomy in that it does not affect the shape of the acetabulum. At this time there are no case series of adults with CP who have been treated with periacetabular pelvic osteotomy.

Indication for Doing Bilateral Femoral Varus Osteotomy

The question of needing to do bilateral hip surgery is one that is often of concern to families and question that still has some debate among orthopedists. The advantage for the child is that there is only one anesthesia, one acute recovery, one rehabilitation, and one disruption of the family and school environments. The disadvantages to the child are that there might be a need to do a blood transfusion with bilateral surgery and there might
be slight increased stress with a little additional operative time. The disadvantages to the surgeon are that the longer surgical time may cause fatigue especially for the inexperienced surgeon or one working without assistants, there is often an impact on billing since most reimbursements for doing a second side are poor, and there is the concern for more complications especially if it is perceived to not be a required part of the procedure.

There are a number of clear indications for doing bilateral surgery, the first being the presence of bilateral subluxation and the second a fixed abduction contracture on the contralateral side. The indication for a reconstruction is the same regardless if it is unilateral or bilateral. The question then only becomes to do the surgery on the same day, separated by a week, or after initial side has recovered. It is my strong opinion that separation for more than a week if this is required because of the surgeon skill or level of assistance really puts the child and family through increased pain and suffering and, with exception of clear medical problems, longer waiting should be avoided. Another clear indication is that the child with a fixed abduction contracture on the contralateral side requires this hip to be shortening and varus or, when the child is seated, the abducted leg will require the pelvis to rotate forward on that side which then puts the repaired hip into adduction and is set up to cause recurrent dislocation. Since this is only a varus osteotomy, it should be able to be done in almost all cases on the same day as the reconstruction for the displaced hip.

The area that is more controversial is how to address the radiographically normal hip that has no abduction contracture. The rationale for doing a varus shortening osteotomy is to obtain symmetric leg lengths for seating and standing in a stander. This should also avoid the hip later developing a dislocation or abduction contracture. One study reported an increase risk of subluxation but suggested managing the risk with close clinical monitoring and then reconstruction when subluxation occurs (Canavese et al. 2010). A previous report noted a very high rate of progression to subluxation or development of hip abduction contracture (Carr and Gage 1987). It is my practice to most commonly recommend bilateral varus osteotomy when reconstructing a dysplastic hip. Usually the limb length discrepancy is hard to deal with in sitting even for children who do not stand, and the risk is small.

Complications of Reconstruction

The primary and most frequent complication after reconstructive procedures is the development of a wound infection at the site of the varus osteotomy (Case 8) (chapter “Complications of Hip Treatment in Children with Cerebral Palsy, Hyporonic and Special Hip Problems in Cerebral Palsy”). If a deep wound infection occurs, the wound needs to be opened, packed with antibiotic dressings, and treated with oral antibiotics if children are not febrile. Dressing changes are performed twice daily, and as soon as there is no cellulitis present, oral antibiotic treatment can be discontinued 10–14 days after initiation. Local wound care is continued, allowing the wound to remain open or granulate closed until the osteotomy is healed. Adductor wound infections are treated as previously noted, and the pelvic osteotomy site has an extremely low infection rate, as we have never seen a deep wound infection in the pelvic osteotomy site. Infections in the pelvic osteotomy site, however, should be treated with open irrigation and packing, followed by possible secondary closure.

Loss of Fixation

Loss of fixation of the plate or fracture of the proximal bone may occur, and this usually needs to be corrected with repeat open reduction and the addition of more screws or a wire. The use of the locking screw construct may be an alternative if the plate blade failed; however, if the locking screw and side plate failed, often due to screws being too short in the femoral head, a blade plate might be considered if the fit is better. If it is difficult to gain solid fixation, cast immobilization may be needed on rare occasions.
Repeat Early Dislocation

Repeat early dislocation occurs primarily in individuals who are being treated for hypotonic hip disease or who have overlying paralysis with spasticity. There are children in whom the limit of reconstruction has been stretched because of a severe femoral head deformity and also acetabular deformity. The surgeon will decide to do a repeat open reduction if there is a sense that increased stabilization can be achieved, or it is better in some situations to leave the hip alone, gaining range of motion hopefully without pain. If the hips are symptomatic, the surgeon will proceed to salvage treatment (Case 9).

Heterotopic Ossification

The development of heterotopic ossification is usually noted when there is a persistently high level of pain. This ossification may occur with exuberant callus formation and sometimes occurs as pericapsular ossification (Case 10). There may also be severe heterotopic ossification that limits motion and requires resection. In this case treatment to prevent recurring ossification is recommended; we usually use a single dose of 600 Rads on postoperative day one to the hip region.

Sleep Problems

The postoperative pain sometimes causes children to develop very poor sleep patterns, become depressed, and lose their appetite. This pain should be treated using a standard postoperative protocol that depends primarily on antidepressants, such as amitriptyline hydrochloride (Elavil).

Prolonged Hip Pain

Prolonged pain in the hip joint may occur because of degenerative arthritis, which can be treated using a steroid injection protocol. If the pain is persistent after three steroid injections, additional palliative treatment should be considered (Case 11).

Avascular Necrosis

Avascular necrosis (AVN) following reconstruction has been reported (McNerney et al. 2000; Khalife et al. 2010; Kim et al. 2012; Koch et al. 2015; Root et al. 1995). The incidence of avascular necrosis after CP hip surgery was found to vary from 0 to 46% on a systematic review (Hesketh et al. 2016). No specific risk factors could be ascertained in the review. Avascular necrosis may be due to either the anterior approach to the hip capsule or more likely, to immobilization in casts, which puts increased pressure on the hip joint. Although in our experience AVN is very rare event, in most cases it is not possible to identify the etiology. Treatment of the avascular necrosis should be with gentle range of motion, and then after its resolution, it will need to be addressed with the residual remaining deformity. In some cases it may require a palliative salvage procedure (Case 12).

Intraarticular Extension of Pelvic Osteotomy

Osteotomy extending into the acetabulum is sometimes done intentionally, especially in a child with a closed triradiate cartilage, because it is not possible otherwise to open the wedge. If this extension should occur inadvertently, it usually does not cause any long-term problems, and it is important to start and continue to work on the range of motion immediately postoperatively.

Other

Premature closure of the triradiate cartilage has not been reported with either the peri-ilial osteotomy or the Pemberton osteotomy in children with CP.

Prominent hardware, especially the blade plate on the lateral side, may become tender. This plate
should be removed if it continues to be tender after the osteotomy has healed or if it continues to create wound breakdown.

Fractures during rehabilitation are most common at the distal femur and proximal tibia and have a much higher incidence in those children treated with casts. These fractures need to be treated appropriately, without trying to immobilize them for too long.

Case 1 Shamika
Shamika, a 9-year-old GMFCS V girl with severe spastic quadriplegia and severe mental retardation, was brought to the clinic from a residential home where the caretakers felt she was having severe pain. They reported that if she did not move, she would be quiet; however, any movement would cause her to cry out. She also cried when she sat. She was fed by gastrostomy tube, took medication to control seizures, and had chronic constipation. She had never had pneumonia. On physical examination, she had good head control but could not prop-sit, and she did not weight bear and had mild scoliosis. The left hip lacked 20° to come to neutral abduction. The right hip abducted 70° but could not be brought to the neutral adduction. The popliteal angle on the left was 90° and on the right it was 60°. The feet were in severe planovalgus. On physical examination, she cried with attempted left hip abduction and all attempts to sit, stand, or change her position. Radiographs were obtained that demonstrated a dislocated left hip with moderate degenerative changes in the femoral head but a well-formed acetabulum. The hip clearly appeared to be the source of the pain, and the radiograph was consistent (Fig. C1.1). A reconstruction was performed with an adductor lengthening on the left and bilateral femoral varus derotation shortening osteotomy with a peri-iliac pelvic osteotomy (Fig. C1.2). She was mobilized immediately, and by 3 months all the preoperative pain had resolved. She was sitting all day and not crying with dressing and other position changes. At final follow-up at age 20 years, 11 years after reconstruction, the hips had symmetric range of motion with full extension and flexion, abduction to 20°, but rotation limited to 20° internally and 30° externally (Fig. C1.3). No hip pain was present, and the hip appeared to have a nearly normal configuration.

Case 2 Andrea
Andrea, a 15-year-old GMFCS IV girl with a severe spastic diplegic pattern, presented with a complaint of severe pain in the right hip. She used to walk with a walker GMFCS III level; however, her walking decreased related to both her increased size and the development of intermittent hip pain 3 years prior. One year prior she had undergone a dorsal rhizotomy because of increased hip pain. Following the rhizotomy, she had never been able to stand. She had mild mental retardation, fed herself, and was very clear that her hip hurt with almost any motion. On physical examination, she was noted to be somewhat overweight at 70 kg and was extremely hesitant about all aspects of the examination. Because of this hesitation, good range-of-motion data could not be obtained; however, the left lower extremity had no spasticity and no apparent contractures. The right hip caused pain with motion but also had no spasticity. A radiograph showed the right hip to be dislocated with moderate to severe arthritis; the left hip appeared to be normal (Fig. C2.1). The growth plates were just closing. She had been sent as a second opinion from a physician who had recommended a proximal femoral resection. Her parents wanted to

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try to get her back to ambulating with a walker again and were very hesitant to have a resection. After an extensive discussion in which her parents stated that they were willing to risk a second operation if reconstruction failed, a reconstruction was performed. After the reconstruction, the hip subluxated inferiorly due to no muscle tone (Fig. C2.2). However, immediate motion was pursued, and within 6 months, all the pain had resolved. By a 6-year follow-up at age 21 years, she had painless free motion of the hip except for very limited rotation (Fig. C2.3). She still could not stand because of extreme weakness that persisted from the very aggressive dorsal rhizotomy.

Case 3 Alyona
Alyona is a 5-year-old girl (GMFCS IV) with spasticity who is interested in standing and making some steps but has pain in her

(continued)
right hip. She has not had previous hip x-rays. The femoral head is in a high dislocated position with flattening of the medial side of the femoral head (Fig. C3.1). The acetabulum appears to be shallow with dysplasia and a wide medial wall at the triradiate cartilage; the shape of the acetabulum is formed better than expect from a fixed dislocation secondary to DDH from birth. Based on this, it is presumed to be a CP hip dislocation likely occurring since age 2 or 3 years old. The difficulty for a reduction is the wide medial wall making the acetabular depth very shallow, which is even worse than what the x-ray shows because there is substantial cartilage buildup as well. The options for this are to hope for remodeling with pressure from the femoral head after reduction or to directly remove some of the cartilage and bone from the medial aspect of the acetabulum or to thin the triradiate cartilage and impact the medial wall. In this case, the pelvic osteotomy was performed, and through the

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pelvic osteotomy, the triradiate cartilage was partially removed with a curette. The medial wall was then impacted with a 22 mm femoral head impactor used to impact the acetabulum during a total hip replacement. Significant femoral shortening and capsulotomy was also performed. The immediate postoperative x-ray shows the hip as well reduced and bilateral, although the right hip is not as deeply seated (Fig. C3.2). At 4 weeks postoperative x-ray, the right hip is now seated lateral of the acetabulum (Fig. C3.3). She continued with physical therapy using a stander and gait trainer with well-developed hips 2 years after surgery (Fig. C3.4). Nine years postoperative, at age 14 years, she has a well-formed acetabulum and reduced hips (Fig. C3.5).

**Case 4 Jose**

Jose, a 5-year-old GMFCS IV boy with severe spastic diplegia, could do some walking with a walker. His mother was most concerned about the slow progress with his walking ability and his feet crossing over. On physical examination, he had hip abduction of 20° on each side, 90° of internal rotation, and no external rotation of the hips. Popliteal angles were 60° bilaterally. A radiograph demonstrated bilateral hip subluxation of 90% on the right and 80% on the left (Fig. C4.1). It was decided that he should have a femoral varus derotation osteotomy, adductor lengthening, and distal hamstring lengthening (Fig. C4.2). Following surgery, he was slow to regain his walking ability, and by 1 year after surgery, his left leg was again becoming adducted and internally rotated. The radiograph showed subluxation (Fig. C4.3). This subluxation was monitored for 2 more years, with more severe subluxation present (Fig. C4.4), and then was reconstructed. However, not enough acetabular coverage could be obtained because of a widened triradiate cartilage (Fig. C4.5), and he

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again subluxated and developed hip pain at age 13 years (Fig. C4.6). He developed a severe windblown deformity. In retrospect, this very poor outcome started with the poor decision to avoid reconstruction of the acetabulum at age 5 years and was secondarily followed by an inadequate reconstruction of the acetabulum.

Case 5 Brittany
Brittany, a 6-year-old GMFCS V girl with a moderate quadriplegia, could feed herself, had some speech, and had moderate mental retardation but no ambulatory ability. Her mother was concerned about her crossing-over legs. Physical examination demonstrated hip abduction limited to 15° (continued)
bilateral and a 45° popliteal angle. Radiographs of the hip demonstrated severe hip subluxation (Fig. C5.1). She had lengthening of the hip adductors and femoral derotation osteotomies. Initially, at 1 year after surgery (Fig. C5.2), and by the 5-year follow-up, the hips looked very good (Fig. C5.3). However, by 8 years of follow-up, she had developed a severe adduction and hip flexion contracture with intermittent pain in the left hip (Figs. C5.4 and C5.5). An aggressive adductor lengthening was then performed; however, during anesthesia the hip could be felt to be subluxating posterolaterally. Although the positioning improved (Fig. C5.6), the pain did not, and she required a reconstruction that stabilized her hip (Fig. C5.7), and all pain was resolved. By 3 years after the reconstruction, she is pain-free with an excellent range of motion (Fig. C5.8). The addition of the pelvic osteotomy at the time of the initial varus osteotomy at age 7 years most likely would have avoided the need for adolescent surgery.

Case 6 Alyssa
Alyssa, an 8-year-old GMFCS V girl with spastic quadriplegia, was initially seen in the CP clinic as a second opinion because her parents felt her left hip was causing her pain. She was noncommunicative and a dependent sitter, was actively being treated for renal failure due to a familial kidney condition not related to the CP, and had seizures that were controlled with Dilantin. She was fed orally but could not feed independently. She had undergone a hip reconstruction 2 years previously but had never been very comfortable since the cast was removed. Further specifics concerning the procedure were not available. On physical examination, her left hip was fixed in 20° of adduction and the hip motion caused her to cry. Flexion to 90° was present, but extension was limited to −40°. The right hip had

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an abduction contracture of 30° and had not had previous surgery. The radiograph showed a posterolateral hip dislocation with a proximal femur, which had a varus osteotomy, and a very prolonged lesser trochanter (Fig. C6.1). This was felt to represent the residual effects of a shelf acetabuloplasty, with a hip that dislocated behind the shelf. The femoral head had a moderate degree of degenerative changes, but she still had wide-open growth plates.

The hip was reconstructed using the standard pelvic osteotomy and adductor lengthening on the left with a bilateral femoral shortening osteotomy (Fig. C6.2). The hip has done well over a 6-year follow-up period until she was at skeletal maturity (Fig. C6.3). This case shows how difficult it is to get the shelf posterior to avoid the hip dislocating out the back of the joint. This is also a poor plan because the abducted right hip was not addressed and the adductors were not lengthened.

Case 7 Antwain
Antwain, a 15-year-old GMFCS II boy with spastic diplegia, was an independent ambulator who presented to the CP clinic with the complaint of pain in the right hip. Over the past 3 years, he had gradually noticed the onset of this pain, and now it was limiting him so that he had a hard time getting through the school day, and he did not want to go out with friends. He was in the tenth grade in a regular high school and was totally independent in all activities of daily living. His right hip had full flexion,
extension to $-20^\circ$, and abduction only to neutral and had pain with forced abduction. Popliteal angles were $60^\circ$. Radiographs demonstrated marginally open growth plates, a normal left hip, and a right hip with dislocation and severe acetabular dysplasia (Fig. C7.1). He had a Chiari osteotomy and slowly was able to return to walking, so at age 20 years he again walked independently but complained of problems when he sat and pain when he walked long distances. Physical examination showed only $20^\circ$ of flexion from $-10^\circ$ of extension. There was no motion in rotation or abduction or adduction. Radiographs showed a severely degenerative hip (Fig. C7.2). This case shows the relatively poor outcome of Chiari osteotomy in an adolescent with spasticity. Antwain would have been better off with a fusion because he functioned like a hip fusion but still had the pain of an arthritic hip.
Case 8 Derek

Derek, a 12-year-old boy with spastic quadriplegia, had a reconstruction of the right hip with an adductor lengthening, peri-iliac pelvic osteotomy, and femoral osteotomy. Postoperatively, he did well and was discharged home with his mother on postoperative day 6. On postoperative day 18, his mother called to say that he had a temperature of 39.8 °C, was refusing to eat, and seemed to have pain in the hip. He was brought in for a clinical examination, which showed a femoral osteotomy wound with erythema and seropurulent drainage. The other wounds were dry and without erythema. Radiographs demonstrated no change and the white blood cell count was 15,300. The wound was gently palpated and noted to open easily down to the plate. A culture swab was sent for culture, the wound was packed with betadine-soaked gauze, and he was admitted and started on cephalothin. In 24 h, the culture showed a growth of *Staphylococcus aureus* sensitive to the cephalosporin. After 2 days in the hospital, he was afebrile; his mother was taught to do wound packing dressing changes twice a day, and he was discharged home to continue with oral antibiotics and dressing changes. At an outpatient visit in 1 week, the wound was clear of purulent drainage, and the dressing was changed to a betadine wet-to-dry dressing. The antibiotics were continued for 1 more week. Four weeks after discharge, the wound was showing signs of closing with granulation tissue that bled with each dressing change (Fig. C8.1). The dressing was now switched to being changed once a day. By 2 months following discharge, only a small 1-cm opening persisted, which drained fluid that looked like synovial fluid, with the plate being completely covered. Dressing changes were changed to dry dressings and changed as needed. The drainage varied from day to day, but by 4 months after the initial infection, he still had a persistent

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Case 9 Samantha
Samantha, a 10-year-old GMFCS V girl with severe quadriplegia, presented with a complaint of severe hip adduction that made perineal care difficult. With forced abduction, the hips were also painful. She had severe mental retardation and was completely dependent in all her care needs. Physical examination confirmed the history. A radiograph demonstrated bilateral hip dislocation with severe acetabular dysplasia and widening of the triradiate cartilage (Fig. C9.1). Bilateral reconstruction was performed with adductor lengthening, femoral shortening varus osteotomy, and peritrochanteric pelvic osteotomy. It was very difficult to obtain intraoperative stability of the hip joint, especially on the left side. In the immediate postoperative period, both hips remained in good position (Fig. C9.2). At the follow-up visit at 4 weeks after surgery, her mother noted the left hip seemed shorter and did not abduct as much as the right side. A radiograph showed the left side to have dislocated again (Fig. C9.3). Considering the difficulty in gaining stability during the reconstruction, it was believed that a repeat attempt would not be any more successful. Therefore, after discussion with the family, it was elected to leave the hip dislocated. Over a 6-year follow-up, the hip remained pain-free and with adequate range of motion to allow easy sitting, lying, and perineal care. In spite of the repeat dislocation, her mother still felt the surgery was successful.

Case 10 Henri
Henri, an 18-year-old boy, GMFCS IV, had a reconstruction for a dislocated hip. A good, stable hip was obtained; however, he continued with significant pain with range of motion even at the 6-month follow-up. Radiographs at this time demonstrated peri-acetabular ossification (Fig. C10.1). He was injected with depo-steroid several times over the next 6 months and gradually had a decrease in his pain, although at the 18-month follow-up he was still uncomfortable with full hip extension and hip rotation. The heterotopic ossification had matured (Fig. C10.2). Often, this ossification slowly resolves over the 6- to 18-month period following surgery, although this has not happened in this boy.
Aaron, an 11-year-old GMFCS V boy with a severe spastic quadriplegia, had increased problems with sitting. His parents did not feel that he had much pain; however, dressing and bathing were getting more difficult as he had severe adduction deformities. He was orally fed and had seizures that were well controlled by medication. He had severe mental retardation. On physical examination, he was noted to have severe upper extremity spasticity, and the hips could not be brought to neutral abduction on either side. Hip flexion was to 100° and popliteal angles were 70°. Radiographs of both hips showed completely dislocated hips with a more dysplastic acetabulum on the right (Fig. C11.1). He underwent bilateral adductor lengthening, varus derotation osteotomy, and peri-iliac pelvic osteotomy. His recovery went well for the first month, but his parents noted that he slept and ate very poorly due to continued hip pain. He was then started on amitriptyline hydrochloride, 25 mg in the evening. After 4 weeks, he slept and ate a little better so the amitriptyline was increased to 50 mg per night. After 3 months, he ate and slept well; however, he had not tolerated therapy. Specifically, he tolerated hip range of motion very poorly. After a 3-week rest from

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therapy, another attempt at therapy caused severe pain. At 4 months after surgery, a radiograph showed a well-healed osteotomy, but there was erosion on the medial side of the joint on the right side where the growth plate had caused a ridge to form in the acetabulum (Fig. C11.2). The pain was believed to be caused by degenerative arthritis from the incongruent hip joint. The hip joint was then injected with depo-steroid and gentle range of motion was again started. After 2 weeks, he tolerated hip motion somewhat better. A second injection was given 1 month after the first, and the pain continued to improve; finally, by 1 year after surgery, the hip plate was also removed to make sure it was not causing pain. The erosions were still there, although the pain was greatly decreased (Fig. C11.3). Over the next year, he became completely pain-free, and by the 5-year follow-up, the hip remodeled almost completely so he had excellent flexion motion, 30° of abduction, and 20° of adduction, but he still continued to have only 20° of total rotation (Fig. C11.4). The excellent remodeling is typical of hips in children with open growth plates, and the steroid injections seem to decrease the inflammation and allow this remodeling to continue.

Case 12 Honey
Honey is a 10-year-old GMFCS V girl with progressive hip subluxation who is recommended for reconstruction (Fig. C12.1). The reconstruction was performed with an inferior medial capsulotomy on the right (Fig. C12.2). The hip plate was removed 1 year postoperative because of increasing hip discomfort. After the hip plate removal, the hip pain became progressively worse over the next year as she had progressive collapse of her femoral head (Fig. C12.3). Due to the increasing
Fig. C12.1

Fig. C12.2

Fig. C12.3
pain and progressive adduction contracture, a resection arthroplasty was performed with a shoulder prosthesis interposition at 2.5 years postoperative (Fig. C12.4).

References