ACTA
ORTHOPAEDICA
et
TRAUMATOLOGICA
TURCICA

Author s translation
Acta Orthop Traumatol Turc 2007;41 Suppl 1:37-46

Salter osteotomy: An overview

Salter osteotomisi

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Pelvik osteotomiler 18 aydan büyük, gelişimsel kalça displazili çocukların tedavisinin çok önemli bir parçasıdır. Bu makalede, 1961 yılında Robert Salter tarafından tanımlanan iliyak kemik osteotomisi ayrıntılı olarak tartışıldı. Salter osteotomisinde iliyak kemiğe tam bir kesi yapılıp, asetabulum simfizis pubisten itibaren anterolaterale doğru döndürülür. Asetabulumu bu pozisyonda tutmak için kemik grefti kullanılır ve greft kaynayana kadar kemikler Kirschner teli ile tutturulur. Kırk yılı aşkın süredir dünyanın dört bir yanında yaygın olarak kullanılan bu yöntemle ilgili, kısa ve uzun döneme ait çok sayıda mükemmel sonuç yayınlanmıştır. Yöntemin başarısı, uygun hasta seçimine ve cerrahi tekniğin titizliğine bağlıdır.

Pelvic osteotomies are an integral part of treatment in developmental dysplasia of the hip after 18 months. This article focuses on the innominate osteotomy which was introduced by Richard Salter in 1961. Salter innominate osteotomy is a complete pelvic osteotomy that hinges on the symphysis pubis and results in anterolateral displacement of the acetabulum. The derotated acetabulum is held in place with a bone graft and fixed with Kirschner wires. Salter osteotomy has been performed over four decades and excellent short- and long-term results have been reported from different centers all over the world. Its success is closely related to appropriate patient selection and meticulous surgical technique with strict adherence to prerequisites.

Developmental dysplasia of the hip is a significant cause of morbidity in the population. Despite increased awareness, a number of patients still present late. The goal of all treatment modalities are the same which is to get a reduced, stable hip joint. Pelvic osteotomies has become an important part of the standard care for these patients. This review focuses on the Salter osteotomy which was designed by a Canadian Orthopedic Surgeon, Robert B Salter, in 1957.

Common problems observed in patients presenting >18 months

As with all diseases, the earlier the diagnosis is made the better the outcomes. There are two reasons, first it is always easier to treat pathology before initial adaptive changes become permanent; and second, one can use remodeling capacity of the developing skeleton more effectively. Therefore, eighteen months is an important point in the course of the disease since the effects of certain treatment methods decrease significantly. In the first eighteen months, the treatment is based on achievement and maintenance of a reduced hip through closed or open reduction, so that the femoral head and the acetabulum can remodel. The remodeling capacities of these structures are very high at birth and decrease as the child becomes older. Also, as long as the hip remains dislocated and child becomes older, secondary changes become more pronounced and less flexible. Hence, it becomes more difficult to achieve and maintain reduction with either or closed or open reduction. Therefore, the patients over 18 months usually require additional procedures which will address these secondary changes in the proximal femur and acetabulum and current treatment approach consists of primary open reduction with capsulorrhaphy and simultaneous acetabuloplasty.

Pathoanatomy

One of the prerequisites for normal development of the femur and acetabulum is concentric reduction of the hip joint. As long as the hip remains dislocat-

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ed, secondary changes in the femur and acetabulum arise. Since the acetabulum is not stimulated by the femoral head, it does not acquire its normal shape but remain shallow. Besides, it assumes a flexed and abducted orientation when compared to the normal, which prevents maintenance of concentric reduction even if the proximal femoral anatomy is normal. On the other hand, the femur is dislocated to a postero-superior direction. In the dislocated position, the proximal femur is forced to external rotation which results in increased anteversion of the femoral neck.

Alternative treatments to Salter osteotomy for DDH in 1960s

When Salter first proposed the innominate osteotomy there were limited treatment options for the patients over 18 months. He grouped them in 3 headings in his original article as prolonged retention of reduction in a stable position, operations on the femur and acetabulum.[1] Prolonged immobilization in patients >18 moths is usually accompanied by significant joint stiffness, contracture, atrophy of muscles and osteoporosis. Besides, immobilization provides little stimulus for development of acetabulum.[1] Interventions directed to correct the deformity in the proximal femur can prove successful outcomes only if the acetabular dysplasia is mild. Otherwise, valgus deformity or increased anteversion would recur.[1] The procedures that are aimed to correct the acetabular deformity were limited. There were basically three options. First group of operations relied on development of fibrocartilage from the joint capsule. One was Shelf operation which was technically difficult and the results were not reliable.[2] Another was Chiari procedure which was raising concern about the decrease in pelvic volume.[3] Acetabuloplasty aimed to change the angle of the roof of the acetabulum by an incomplete osteotomy. However, there was a question about the long term result of this procedure since it was producing angulation of the articular surface.[4] Besides, this procedure was believed to result in a decrease in acetabular volume. Capsular arthroplasty provided stability by creation of a bony socket either at the original acetabulum or at a higher site and application of the redundant joint capsule as an interposition membrane.[5] Overall, although these treatment modalities might have produced excellent results, the percentage of excellent results was not high and there was a search for alternative treatment methods.

Rationale for Salter osteotomy

While searching for an alternative approach, Salter focused on the reasons of instability after reduction. He realized that the acetabulum has changed its direction rather than simply being shallow. It was directed more anterolaterally than normal, so that the femoral head is inadequately covered anteriorly when the femur is extended and laterally when the hip is abducted. This observation explained why the hip is stable in a position of abduction and flexion. In addition, it also explained why, in the presence of excessive anteversion of the femur, the combination of lateral rotation and extension results in anterior redislocation and resubluxation. He suggested that the major abnormality responsible for instability was the abnormal direction the entire acetabulum faced.[1] He proposed that if the entire acetabulum can be made to face normal direction, hip stability in the functional position can be attained. His studies in cadavers revealed that if a transverse ostetomy was performed just above the acetabulum, than the distal portion could be redirected by opening the osteotomy site anterolaterally.[1] The hinge point would be the symphysis pubis which is quite mobile in children. In summary, the principle of innominate osteotomy is simply redirection of the entire acetabulum in such a way that the reduced dislocation or subluxation, which previously was stable only in position of abduction and flexion, is made stable in the position of function. This would enable early weight bearing providing an ideal stimulus for remodeling. In addition, Salter osteotomy increases the blood flow around the hip joint which is believed to increase the remodeling capacity of the procedure.[6,7] Although, first it was suggested that Salter osteotomy lateralizes the hip joint resulting in an increase in joint reaction forces, later it has been shown that a correctly performed Salter osteotomy does not increase the moment forces across the hip, but instead decrease them by medialization of the hip joint.[8]

Prerequisites for Salter osteotomy

Salter designated several prerequisites in order to anticipate a satisfactory outcome.[9] These are as follows:

1. Ability to bring the head of the femur opposite the acetabulum: The muscles around the hip may contract as the hip remains dislocated. These muscles namely adductors and iliopsoas should be released since they diminish the stability of the reduced hip in the weight-bearing position and exert excessive pressure on the articular cartilage when the hip is reduced with resultant pressure necrosis of the articular cartilage.

2. Complete and concentric reduction of femoral head in the depth of the true acetabulum: Since the objective of the osteotomy is to stabilize a completely reduced hip joint, one can not achieve satisfactory results by performing a an innominate osteotomy above a hip that is either in false acetabulum or in a "wandered acetabulum" or above a hip that is still "standing out" and articulating with only the outer portion of the acetabulum. Ideally a concentric reduction of hip joint should be achieved with 25-30 degrees of abduction and neutral rotation.

3. Reasonable congruity of the hip joint surfaces: Significant incongruity between the reduced femoral head and the acetabulum prevents a full range of smooth gliding motion and leads to degenerative arthritis.

4. A good range of hip joint motion: Unless there is good range of motion of the hip joint, the redirection of the acetabulum by innominate osteotomy will only alter the arc of motion of the hip without increasing the range of motion. Indeed, if the hip is stiff, redirection of the acetabulum merely produces redirection of the lower limb without providing better coverage of the femoral head. Ideally, there should not be no more than 15 degrees loss of motion in any plane

5. The correct age of the patient: For children < 18 months innominate osteotomy is contraindicated because satisfactory outcomes can be achieved by other measures. Besides, the patients are usually too small raising technical difficulties as difficulties in harvesting and fixing bone graft. For children > 6 years, the prerequisites of complete reduction and reasonable congruity usually could not be met, hence it is contraindicated.

Surgical technique

The surgical approach is so designed that the combination of accurate open reduction and stabilization of the reduction by innominate osteotomy can be performed through the same incision at one operation. The patient lies supine on the operating table with a sandbag under the thorax of the affected side. The patient is draped so that the lower extremity is free to move during the procedure. Any residual contracture of the adductor muscles is dealt with by subcutaneous adductor tenotomy.[1] The skin incision begins below the middle of the iliac crest and passes obliquely forwards distal to the anterior superior iliac spine. The interval between the tensor fascia lata and sartorius has been developed and the rectus femoris is elevated off the anterior inferior iliac spine with its reflected head. An incision is made in the iliac apophysis down to the bone along the iliac crest from its midpoint to the anterior superior iliac spine and then distally to the anterior inferior iliac spine. The lateral part of the apophysis with the periosteum of the external surface of the ilium is then stripped in a continuous sheet inferiorly to the lateral edge of the acetabulum and posteriorly to the greater sciatic notch. If the fibrous capsule of the hip has been adherent to the lateral aspect of the ilium above the acetabulum by being stretched upward by the intracapsular dislocation, it should be freed. Blunt dissection in this plane provides excellent exposure of the anterior and lateral part of the capsule. The open reduction can be performed at this point. If open reduction is not performed, the cartilaginous iliac apophysis is displaced medially from the anterior half of the iliac crest with an elevator, and the periosteum of the inner surface of the ilium is stripped off in continuous sheet to expose the sciatic notch. Extreme care should be taken to remain in the subperiosteal plane, particularly during the exposure of the sciatic notch where sciatic nerve and superior gluteal artery are located. The tip of a curved forceps is passed subperiosteally behind the notch from the medial side in order to grasp one end of the Gigli saw. The osteotomy extends in a straight line from the sciatic notch to the anterior inferior spine and is at right angles to the vertical axis of the ilium, The soft tissues are retracted so that the iliac bone can be divided with a Gigli saw which is considered as safer than an osteotome. A full thickness bone graft is taken from the anterior part of the iliac crest with bone cutting forceps, and trimmed to the shape of a wedge, the base of which should correspond approximately to the distance between anterior superior and inferior spines. One stout towel forceps is used to steady the proximal segment of the innominate bone, and a second is used to grasp the distal segment of the inominate bone containing the entire acetabulum and shifted forwards, downwards and outwards so that the osteotomy site is opened anterolaterally. It is important to avoid any backward and inward displacement of this fragment.[1] The wedge-shaped bone graft is then inserted on its edge into the osteotomy site: when traction is released the graft is found to be held firmly by the two segments of the innominate bone. Then, a stout Kirschner wire is inserted across the osteotomy site, through the graft and into the distal segment posterior to the acetabulum in order to prevent any subsequent shift of the graft or of the distal segment. The two halves of the iliac apophysis are the sutured together over the iliac crest. The Kirschner wire is cut so that its end lies in the subcutaneous fat. The skin is closed with continuous intradermal suture.[1] A unilateral hip spica is applied with the hip still in the same position of slight abduction, slight flexion and slight medial rotation. The knee is maintained flexed to diminish the tension of the relatively short hamstring muscles and thereby prevent continuous compression of the articular cartilage of the hip joint during the period of immobilization. Following verification of bony union, the hip spica is removed at 6 weeks. Active movements are permitted, and as soon as muscle tone is satisfactory partial weight bearing with crutches is encouraged for a few weeks after which full weight bearing is permitted. The Kirschner wire(s) are removed under general or local anesthesia later on. [1]

Errors and technical pitfalls

Since the design and application of the innominate osteotomy, it has been performed in several centers throughout the world. Several surgeons communicated with Robert B Salter and shared the problems that they had experienced with the application of the principle of innominate osteotomy to developmental dysplasia of the hip. He, then reviewed these common errors and pitfalls to warn other surgeons to prevent practices that may lead to unsatisfactory outcomes.[9] These are grouped under the following headings:

Poor clinical judgement in the selection of patients:

1. Failure to adhere to the indications for innominate osteotomy.

2. Failure to observe the prerequisites for innominate osteotomy.

3. Failure to adhere to contraindications for innominate osteotomy.

Mistakes in preoperative managemen:t

1. Failure to use continuous traction until the femoral head is opposite the acetabulum.

2. The use of “well leg” traction with bilateral dislocation, particularly when used on the second hip after operation on the first hip .

Errors in operative technique of open reduction and capsulorrhaphy:

1. Failure to perform a subcutaneous adductor tenotomy for residual adduction contracture. A good range of motion, particularly abduction is one of the essential prerequisites.

2. Inadequate operative exposure of the anatomical structures. This is an important step to obtain a complete open reduction.

3. Failure to obtain a complete and concentric redirection of the femoral head in the true acetabulum.

4. Mistaking a well developed false acetabulum for the true acetabulum. This pitfall can be avoided by stripping down the periosteum of the lateral aspect of the ilium distally to the cartilage model of the acetabulum.

5. Failure to release the tendinous portion of the iliopsoas. This is probably the most common error in technique and is a significant cause of redislocation and resubluxation. An iliopsoas tenotomy at the pelvic brim not only decreases compression on the femoral head but also allow distal fragment mobility.

6. Failure to perform an adequate capsular repair (Capsulorrhaphy). This step is important to increase the stability of the reduction.

Errors in the operative technique of the osteotomy

1. Inadequate operative exposure of the sciatic notch. It is necessary in order to pass the gigli saw behind the notch with ease.

2. Failure to stay within the periosteum. This is particularly important at sciatic notch with potential risk for injuring neurovascular structures.

3. Use of an osteotome or power saw to divide the innominate bone. This practice may increase the iatrogenic injury to superior gluteal artery and sciatic nerve.

4. Opening the osteotomy site with a mechanical spreader. This maneuver moves the proximal fragment proximally and distal fragment distally without rotating the distal fragment through the symphysis pubis.

5. Leaving the osteotomy site open posteriorly. The hip joint would move distally without adequate redirection of the acetabulum and the ipsilateral limb is made longer.

6. Allowing the distal fragment to become displaced posteriorly and medially. This will result in loss of redirection of the acetabulum.

7. Failure to rotate the distal fragment. If the distal fragment is not rotated through the symphysis pubis, there will not be adequate correction. While the inferior fragment is pulled distally and anteriorly with a towel clamp, the mobility of the fragment can be enhanced by placing the ipsilateral leg into the figure-of-four position of hip flexion, abduction, and external rotation. However, one should be careful not to displace the proximal fragment, which will lead to opening of the osteotomy posteriorly at the sciatic notch, and result in ipsilateral leg lengthening.

8. Use of thin kirschner wires for fixation. Thin wires may bend or even break with consequent loss of ideal position of the osteotomy site.

9. Inadequate penetration of the kirschner wires into the distal fragment. This may result in loss of the ideal position of the osteotomy site.

10. Insertion of a Kirschner wire across the hip joint. If the wire protrudes into the joint space it may lacerate the cartilage with hip motion even in the hip spica. If it traverses the joint, it may disturb the normal relationship of the femoral head with the acetabulum

11. Insertion of Kirschner wires upward from below rather than downward from above. If the Kirschner wires medial to the proximal fragment, they could injure retroperitoneal and intraperitoneal structures.

12. Bilateral innominate osteotomy in one stage. If the pelvic ring is divided at two sites, there is little stability at either side making maintenance of correction difficult. There should be at least 2 weeks between the two osteotomies.

Inadequate postoperative management:

1. Immobilization of the reduced hip in other than the most stable position. The degree of rotation of the hip should be adjusted in parallel with the femoral anterversion.

2. Immobilisation of the hip in a forced or extreme position. When the hip is forced into an extreme position, there is excessive and continuous compression of the articular cartilage with resultant pressure necrosis.

3. Immobilisation of the hip in a hip spica cast for much shorter or much longer than 6 weeks which may result in loss of correction and stiffness, respectively.

4. Unsupervised walking during the first few weeks after weight-bearing is allowed. An unguided fall during the first weeks may result in tear of the capsule through the site of capsulorrhaphy or a supracondylar femur fracture that has been weakened by disuse osteoporosis.

Midterm results

Several authors reported excellent and good midterm results with Salter osteotomy. Salter and Dubos reported good or excellent results in 93.6% by Severin's classification after primary surgery in patients under four years of age, and 56.7% for those treated between the ages of four and ten years after an average of 5.5 years' follow-up.[1] Roth et al reported that 100% of 12 hips in patients 1.5 to 4 years of age with primary surgery for congenitally dislocated hip and 80% of 25 hips in patients 1.5 to 16 years of age with secondary treatment for residual dislocation or subluxation had excellent or good results after an average of 5.4 years' follow-up.[10] Paterson reported 84% clinical good outcomes in a series of 143 patients with an average of 4.7 years follow-up.[11] Barrett et al reported that 74% of 68 hips with congenitally dislocated hip, congenital subluxation, or residual subluxation showed excellent or good results after an average follow-up of 8.3 years.[12] Haidar et al reviewed 37 hips in 36 children at an average of 91 months after simultaneous open reduction and Salter innominate osteotomy for developmental hip dysplasia. At the latest review 97.3% were clinically and 83.8% radiologically good or excellent.[13] Macnicol and Bertol reviewed the radiographic outcome after 188 Salter osteotomies 5–25 years postoperatively using a comprehensive rating scale; and the best results occurred in children under the age of 30 months treated by combined open reduction and Salter osteotomy, when no further operation was required [14] Gulman et al reviewed 39 patients with 52 congenitally dislocated hips, all managed by open reduction and Salter's innominate osteotomy.[15] Mean follow-up period was 13 years (range, 8 to 25 years); 78.9% of the hips had a good or excellent clinical result, and 71.1% were good or excellent radiologically. The patients who underwent Salter's innominate osteotomy before the age of 4 had better clinical and radiological results (88.4 and 81.4%, respectively). Karakas et al reviewed the results of a primary one-stage combined operation in 47 patients (55 hips) who were > or = 4 years and had congenital dislocation of the hip.[16] At a mean follow-up of 7.5 years (2-16 years), 67% of the whole series had good or excellent clinical results, and 65% were good or excellent radiologically. Finally, Morin et al reviewed 180 osteotomies in 122 patients and concluded that patients who underwent innominate osteotomy before age 4 years were the most likely candidates to receive a very satisfactory result.[17] These studies demonstrated that the patients who are less than 4 years of old are the ideal candidates and usually have excellent or good outcomes with this procedure. There are several reasons, first the acetabular remodeling capacity is highest during the first 4 years of life and hinge point of Salter osteotomy which is symphysis pubis is more flexible and hence allows more correction in the younger patients.

There is still debate whether an open reduction should be performed before or simultaneously with the procedure. Haidar et al reviewed 37 hips in 36 children at an average of 91 months after simultaneous open reduction and Salter innominate osteotomy for developmental hip dysplasia.[13] At the latest review 97.3% were clinically and 83.8% radiologically good or excellent. Barrett et al reviewed 68 innominate osteotomies that were performed in 54 patients, showed that there was no noticeable difference between the results of innominate osteotomy combined with open reduction and those of innominate osteotomy performed after a previous open reduction.[12] On the other hand Bohm and Brzuske reviewed 61 patients with 73 Salter osteotomies after a mean follow-up of 31 years and concluded that when open reduction is necessary it is preferable to perform it prior to osteotomy.[18] Finally, Macnicol and Bertol reviewed 188 osteotomies with concurrent and staged open reduction, and concluded that in the child of 24–30 months the concurrent procedure can be carried out safely. However, after that age, the risks of redisplacement and avascular change increase, particularly in the type III dislocation; therefore, preliminary open reduction and proximal femoral shortening should then precede the Salter osteotomy.[14] Baki et al treated 15 hips (15 patients) with developmental dysplasia by a single-stage combination of open reduction through a medial approach and innominate osteotomy.[19] The mean age of the patients at the time of operation was 20 months with a mean follow-up period of 9.6 years. At the final follow-up, 14 hips were assessed clinically as excellent and one hip as good. Radiologically, ten hips were rated as class I, four as class II and one as class III according to the criteria of Severin. The average improvement in the acetabular index after osteotomy was reported to be 10 -24 degrees.[20,21] The results of these studies showed that innominate osteotomy achieved good radiographic results that were well maintained. McKay reported that good and excellent clinical results in 18 (69%) of 26 hips correlated well with good and excellent anatomic results in 19 (74%) of 26 hips.[22]

Long term results

Gulman et al reviewed 39 patients with 52 congenitally dislocated hips, all managed by open reduction and Salter's innominate osteotomy.[15] Mean follow-up period was 13 years (range, 8 to 25 years); 78.9% of the hips had a good or excellent clinical result, and 71.1% were good or excellent radiologically. Macnicol and Bertol reviewed the radiographic outcome after 188 Salter osteotomies 5–25 years postoperatively using a comprehensive rating scale.[14] When 132 patients were assessed clinically at maturity (between the ages of 16 and 35 years), clinical, functional and radiographic review revealed that 121 of 148 hips were graded in Severin groups I and II. Bohm and Brzuske reported 73 Salter osteotomies with an average follow-up of 31 years and concluded that good long term outcomes can be expected when the acetabulum can be restored to a normal configuration without development of avascular necrosis.[18] Rinonapoli reviewed 18 hips 10-19 years after the index procedure and reported 80% clinical and radiographic success rate.[23] Although long term follow-up studies demonstrated that the excellent results at the midterm follow-up is maintained, they also pointed out the inherent limitation of this procedure which is the overcorrection of the acetabulum. Dora et al reviewed 73 patients who reached maturity after having a Salter osteotomy and demonstrated that 27% of patients had retroversion of the acetabulum with an average of -15 degrees.[24] Anterior acetabular overcoverage of the femoral head was also present, when lateral coverage was insufficient.

It has been previously demonstrated in a biomechanical study that in Salter's osteotomy reorientation of the distal fragment allows extension to take place to a far greater extent than abduction.[25] This means that anterior coverage of the femoral head can be improved to a much greater extent than lateral coverage. In other words, if a patient with acetabular insufficiency anteriorly, Salter's osteotomy is ideal to achieve a well-balanced coverage of the femoral head. If, however, acetabular insufficiency is mainly superolateral or even in the posterior; then Salter's reorientation of the acetabulum will not fit the requirements for a well-balanced containment of the femoral head and will exaggerate anterior coverage and superoposterior insufficiency. This is an inherent disadvantage of Salter's pelvic osteotomy and may cause posterior subluxation or dislocation of a previously reduced hip. Dora et al examined 6 patients who had hips showing anterior overcoverage.[24] Five of six patients showed reduced range of flexion and internal rotation of their hips of a mean of 16° and 10°, respectively. This reduction in internal rotation and flexion is suggested to be due to retroversion of the acetabular dome and anterior overcoverage as the femoral neck impinges on the anterior acetabular lip with internal rotation and flexion respectively.

There is increasing evidence that the long-term effects of retroversion of the acetabular dome are harmful. Tönnis and Heinecke reviewed computerized tomographic scans and conventional radiographs of 356 hips in 181 patients, and concluded that decreased acetabular and femoral anteversion is a major cause of altered rotation, hip pain and osteoarthritis.[26] Reynolds et al. showed that in 28 of 43 hips showing acetabular retroversion, the origin of pain was in the groin, as reproduced by a positive impingement test.[27] They suggested that anterior impingement of the femoral head-neck junction against the border of the prominent anterior acetabular wall, may lead to fatiguing and destruction of the acetabular labrum and the adjacent cartilage and initiate groin pain and early osteoarthritis.

It is suggested that anterior overcoverage of the femoral head results from ignorance, when choosing the type and performing the pelvic osteotomy, In order to avoid retroversion of the acetabular dome efforts should be made to understand the location of acetabular deficiency in each individual case preoperatively and to better control the acetabular reorientation during surgery.

Complications

Unsurprisingly, complications may occur with Salter osteotomy. The best way to avoid them is to follow strictly the indications, prerequisites, surgical technique and the defined postoperative care. It is a specialized operation and should not be performed by the inexperienced surgeon who is not trained in pediatric hip surgery.

The complications can be studied as early and late postoperative ones. Immediate postoperative ones are superficial and deep wound infection, wound dehiscence and retroperitoneal hematoma. These can be overcome by paying attention to sterility of technique, gentle handling of tissues, and thorough hemostasis at the time of surgery. The incidences of superficial and deep infections range between 0-11% and 0-1.3%, respectively.[10-13,28-31] Rossillon et al demonstrated distinct hypoplasia of the ilium due to premature growth arrest in 16 of 21 patients who had unilateral pelvic osteotomy.[32] To prevent this complication the authors recommend avoiding the use of an electrocautery to incise the iliac apophysis and cutting the Kirschner wires so that their proximal ends lie within the subcutaneous fat, in order to avoid repeated splitting of the apophysis at the time of hardware removal. It has also been shown that the Salter osteotomy can decrease midpelvis and pelvic outlet diameter below the critical threshold of 9.5 cm; particularly when performed patients close to maturity. Sciatic nerve palsy can be caused by stretching or inadvertent division of the nerve during exposure of the sciatic notch. Special attention should be paid to stay within the periosteum during surgery.[34] Performing the osteotomy with a Gigli saw will eliminate the risk of splintage of the thick cortex at the osteotomy site which may injur sciatic nerve. Femoral nerve may be injured with stretching or division of the nerve instead of psoas tendon during surgery. A nerve stimulator may help to identify the nerve during surgery.[34] Migration of Kirschner wires can be prevented by utilization of threaded ones.[35] In addition special care should be paid to prevent penetration of the hip joint during fixation of the graft, and the pins should be directed posteriorly and medially. The complications related to pin placement may reach to 7.4%[10,12,14,18,28] The use of intraoperative radiographs will help to prevent problems of overlong wires penetrating the rectal mucosa or the hip joint. Loss of correction due to crushing of the bone graft is due to osteoporosis of disuse atrophy, operating on children <18 months of age or premature removal of kirschner wires. Graft displacement or dislocation can be secondary to poor surgical technique, inadequate fixation or migration of Kirschner wires and the incidence ranges between 0-19%.[12,18,28,29,31,36] Postoperative stiffness of the hip may result from increased intraarticular pressure because of failure to release the already contracted hip adductors and iliopsoas; prolonged immobilization or chondrolysis secondary to the penetration of the pins to the joint. Therefore full range of motion is essential prior to innominate osteotomy. Progressive lateral and upward subluxation and redislocation may be due to poorly executed osteotomy, excessive femoral antetorsion and laxity of the capsule. The reported incidence of redislocation ranges between 1-13%.[10,11,,13,14,18,22,2836,37,38] It can be prevented by ensuring that the reduction is complete and adequate prior to performing the innominate osteotomy, by performing a taut capsulorrhaphy at the time of open reduction, and by provision of adequate protection during healing of capsular repair.

Modifications

Salter osteotomy had several modifications throughout the years. These modifications designed primarily to address the limitations of the osteotomy which are namely inherent instability of the osteotomy necessitating internal fixation and later pin removal, and lengthening of the ipsilateral lower extremity. The first modifications are probably to use multiple or threaded kirschner wires to prevent pin migration and loss of correction.[22,35] Then Marafioti and Westin described a modified innominate osteotomy by combining some features of the Salter and Pemberton osteotomies.[39] The osteotomy begins immediately above the anterior inferior iliac spine and follows line parallel to the dome of the acetabulum. The osteotomy line, instead of being directed to the posterior limb of the triradiate cartilage, as in the Pemberton procedure, is directed to the inner pelvic brim, as in the Salter osteotomy. Then, instead performing a complete osteotomy at the sciatic notch, the osteotomy curves into the body of ischium and a greenstick fracture is produced in the remaining part of the ischium. A triangular wedge of bone is used to maintain the new position of the osteotomy. Internal fixation is not necessary. The proposed advantages include decreased risk of inadvertent damage to the sciatic nerve or superior gluteal vessels at the sciatic notch because the line of osteotomy does not go into sciatic notch. In addition, the greenstick fracture provides stability, hence eliminating the need for internal fixation. Kalamchi et al described removal of a wedge shaped bone from the proximal edge of osteotomy and lodging of the distal fragment to this notch, hence preventing posterior and medial displacement of the osteotomy.[40] The removal of this wedge limited distal displacement of the distal osteotomy fragment and as a result decreased the ipsilateral leg lengthening as well as the pressure on the articular cartilage. Synder reported 97% excellent radiologic and 93 % excellent or good clinical results with these modifications, however, it is technically more difficult than the conventional osteotomy.[34]

Kremli suggested use of bioabsorbable pins to eliminate secondary pin removal.[29] Recently, Eren et al developed a new modification so that the line of the osteotomy is more oblique when compared to the original osteotomy.[42] Following the redirection of the osteotomy, the distal part of the ilium becomes horizontalized, which produces a more stable setting where the bone wedge may stay in place. The change in the direction of the osteotomy does not compromise the redirection potential. The radiological evaluation demonstrated that the pinless Salter osteotomy produced similar results to the original osteotomy. The acetabular index was restored to within normal limits in the immediate postoperative period and further improved until the final follow-up.

Another target of the modifications is the elimination of iliac crest bone graft harvesting in order to decrease blood loss, operation time and procedure related morbidity. Kamegaya et al compared hydroxyapetite bone blocks with autologous bone graft.[43] The radiological outcomes were similar in both groups and the surgical time and blood loss was lower in the hydroxyapetite block group. Zerrog et al used the resected femoral segment as a wedge to open the osteotomy site.[44]

Comparison with alternative osteotomies

Currently there are three pelvic osteotomies that are commonly performed to treat developmental dysplasia of the hip in this age group. These are Salter osteotomy, Pemberton osteotomy[45] and Dega osteotomy.[46] The advantage of Salter osteotomy is that it is well understood procedure and easy to perform once the principles are learned. Salter osteotomy is referred as a complete osteotomy because it disturbs the integrity of the posterior column of the pelvis.[47] On the other hand, Pemberton and Dega osteotomies preserve posterior column and hence referred as incomplete osteotomies.[47] The integrity of the posterior column is important because first it determines whether internal fixation is necessary and second whether the osteotomy may result in a change in the length of the extremity. Salter osteotomy may result in lengthening of the ipsilateral limb and requires internal fixation for maintenance of the correction ; whereas the latter two do not[47] Removal of the internal fixation requires another operation and considered as an important disadvantage of the procedure. There are attempts to eliminate this disadvantage through use bioabsorbable pins and changing the direction of the osteotomy[29,42] Besides, Salter osteotomy can provide a limited correction (15-20 degrees) which can be considered as a disadvantage in patients with severe dysplasia.[20,21] Although Pemberton or Dega osteotomies can be a better option in patients with high acetabular indexes, one should also note that sometimes cartilage index is lower than the bony index and a technically sufficient osteotomy can provide enough correction that would result in stimulation of secondary ossification centers in the labrum with normal acetabular development.

Another difference among these osteotomies is the mechanism of correction. Salter osteotomy hinges on the symphysis pubis and does not change either the shape or capacity of the acetabulum, therefore it is referred as a redirectional osteotomy.[47] Although it provides reliable anterior and to a lesser extent lateral coverage, it does not provide posterior coverage where Pemberton and Dega osteotomies are more effective. Pemberton osteotomy hinges on the posterior limb of the triradiate cartilage.[45,48,49] Although, it has been initially accepted as a reshaping osteotomy, a recent animal model demonstrated that it actually redirects the acetabulum.[49] It has also been demonstrated that pemberton osteotomy either preserves or increases the acetabular volume.[49,50] It is technically difficult and there is a higher risk of premature closure of triradiate cartilage since osteotomy hinges on the posterior limb of the triradiate cartilage.[51] This complication was also observed after Salter's osteotomy [52], but it was related to extensive deperiostation of the fragment distal to the osteotomy, not to the osteotomy itself. The results of the Pemberton osteotomy are similar to that of Salter osteotomy and can be preferred since it does not require a second procedure to remove pins. The main disadvantage is the learning curve for this procedure is steep. Dega osteotomy is also a reshaping, incomplete osteotomy. The theoretical location of the hinge in the Dega osteotomy can involve, to varying degrees, the sciatic notch, the posterior portion of the inner pelvic cortex, the horizontal limb of the triradiate cartilage, and the symphysis pubis.[46] Since the hinge point is variable and not confined solely to the triradiate cartilage, it is believed that the risk of damage to this structure is lower. In addition the amount of coverage at the deficient area can be more specifically addressed by adjusting the place of the graft, particularly in cases where the deficiency is superior or posterior as in patients with neuromuscular diseases and Down syndrome.[53] Similar to Pemberton osteotomy it also increases acetabular volume.[54] Therefore these osteotomies may be the procedure of choice in patients who are at risk or already developed coxa magna.

Conclusion

In summary, Salter osteotomy is a reasonable alternative in treatment of developmental dysplasia of the hip and it is one of the most well-known procedures pediatric orthopedics. It has been performed with similar successful short and long term outcomes in multiple centers throughout the world for the past 40 years. There are several options to correct acetabular dysplasia in patients with developmental dysplasia of the hip. Each osteotomy has unique advantages and none of them is absolutely superior to another. Therefore, it is a logical option for the orthopedic surgeons to prefer the osteotomy that they are familiar and have the most experience.

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