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ORIGINAL ARTICLE

Development of modified Ilizarov hip reconstruction surgery for hip dysfunction treatment in adolescent and young adults

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ABSTRACT

Background/objective: Hip dysfunction in young population caused by developmental dysplasia of the hip, congenital hip deformity or femur head necrosis severely affect the quality of life of young patients, and total hip replacement is the current widely accepted standard therapy for hip function reconstruction in adults, but not for young patients. Alternative safe and effective surgical method for hip function preservation/reconstruction for young patients is lacking. Ilizarov hip reconstruction osteotomy was an alternative method for preserving hip function but the surgical procedures were rather complicated using discomforting ring fixation at the hip region that prevents its wider acceptance and application. Here we reported a modified Ilizarov hip reconstruction surgery for hip dysfunction/deformity correction in adolescent and young adults using femoral shaft osteotomy and simplified unilateral external fixation configuration at the hip region with satisfactory clinical outcomes.

Methods: This is a retrospective study with five male and twelve female patients aged from 10 to 34 years old (mean 20.6 years) including 11 developmental dislocations of the hip and 6 femoral head necrosis. Modified Ilizarov hip reconstruction surgery was performed using single-arm triangular configuration, threaded half pins on the femur and multiple drill hole guide for osteotomy. The mechanical axis and limb length were corrected spontaneously during the subsequent limb lengthening process in all patients. Preoperative and postoperative gross appearance, radiography of the hip and hip function assessment scores were recorded and compared during the follow-up period.

Results: The mean follow-up period was 64.3 months (12–87 months). Satisfactory hip appearance, hip and knee functions were achieved in all patients, none resulted in hip replacement surgery at the follow-up period. The mean preoperative and postoperative Harris hip scores were 45.92 ± 19.41 and 87.16 ± 5.31 , respectively ($p < 0.01$). Pin-track infections occurred in four patients, treated successfully with wound dressing care and oral antibiotics. Restricted range of motion of the knee was observed in eight patients, all gradually overcome by active functional exercises. Osteotomy site fracture of the middle femurs after removing external devices occurred in two patients due to unexpected fall, and complete healing was achieved after plaster fixation. Complications such as fixation device failure, knee dislocation, vessel or nerve impairments did not occur.

Conclusions: Modified Ilizarov hip reconstruction surgery significantly reduced the surgery time and discomforts to patients, avoided the disturbance of blood supply at the osteotomy sites. This modified method is a useful alternative for correction of hip deformities and reconstruction hip function in adolescent and young adults who are not suitable for conventional pelvis support surgery or hip replacement surgery.

Translational potential statement: The modified Ilizarov hip reconstruction surgery provides an alternative for hip replacement surgery with satisfactory clinical outcomes. This procedure is minimally invasive, safe and simple, with few complications compared to conventional pelvis support surgery, and it may be the first choice of surgery for the management of hip dysfunction in adolescent and young adults.

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Introduction

As one of the most important joints, the hip joint involves in various daily activities such as climbing, walking, running, jumping, sitting, squatting, etc. A lesion in the hip joint may lead to serious impairment of daily life of the patients. Hip dysfunction in a young population is a challenging condition, which could lead to serious consequences affecting their life quality if not treated timely and correctly. A number of diseases such as congenital hip deformity, developmental dislocation of the hip, traumatic injury or drug induced femoral head necrosis could lead to hip dysfunction. These disorders are characterized by pain, limping gait, limb length discrepancy, restricted range of hip joint motion, unstable hip joint and positive Trendelenburg sign, which seriously affect the quality of life of the patients [1].

The aims for the treatment of hip dysfunction are to relieve pain, correct limping gait and improve range of motion of hip. Hip replacement surgery can quickly rebuild the hip joint anatomical structure, eliminate pain and restore hip functions. It has become the standard treatment for hip diseases in the elderly. However, due to the limited “lifetime” of joint implants, young patients may have to face two or more joint revision surgeries in their life time, therefore, hip replacement surgery is not the primary choice for adolescent and young adults [2].

Various hip reconstruction osteotomies, especially proximal femoral valgus osteotomy have been reported with success for the management of hip dysfunction in younger patients. The osteotomy techniques achieved stable hip joints and improved hip functions [3,4]. Ilizarov had modified the proximal femoral valgus osteotomy, avoided several disadvantages such as lower limbs length discrepancy and mechanical axis disturbance, known as “Ilizarov hip reconstruction osteotomy” [5,6]. However, the original Ilizarov hip reconstructive osteotomy surgery employed complicated external fixation with full ring and k-wires fixation configuration at the hip region and challenging surgical procedures which hampered its wider acceptance and application. Hence to simplify the external device configuration and surgery protocol are needed [5,6].

We hereby described a modified technique based on Ilizarov hip reconstruction osteotomy surgery to treat adolescent and young adults with hip dysfunction. Preoperative and postoperative hip function were assessed and compared over a medium-term follow-up period, the data indicated that our modified Ilizarov hip reconstruction osteotomy is a simple and effective procedure with satisfactory clinical outcome.

Methods

Patients

During July 2012 to August 2018, totally 17 adolescent or young adult patients (5 males and 12 females) with hip dysfunction were enrolled in this study, 11 cases of whom suffered from developmental dislocation of the hip and 6 had femoral head necrosis (left, right or bilateral hips were involved). Patient age ranged from 10 to 34 years (mean 20.6 years) at the time of surgery. The patients' details are shown in Table 1. The inclusion criteria are: remarkable hip pain, limping gait and positive Trendelenburg sign; partially or totally dependent on care for daily life activities; and patients don't want hip replacement surgery. Exclusion criteria: patients who have mental illness and cannot cooperate with surgery, post-surgery managements. Written informed consent was obtained from patients before surgery to undertake the modified Ilizarov hip reconstruction osteotomy surgery. Preoperative and postoperative clinical presentations, radiological and hip function (Harris hip score) examinations [7] of all patients were recorded and compared.

Preoperative preparation

Before surgery, x-ray of full length of the lower limbs including hip was taken. According to the conditions of each affected hip joint such as the degree of joint motion, an individualized surgical plan is prepared.

Table 1

Patients details.

Patient	Sex	Age	Diagnosis	Hip (L/R)	Shortening (cm)	Harris Hip Score
1	F	16	Developmental hip dysplasia	R	5.0	59
2	F	20	Developmental hip dysplasia	R	3.5	59
3	M	32	Avascular necrosis of femoral head	L	0.5	28
4	F	20	Avascular necrosis of femoral head	R	5.0	30
5	M	26	Developmental hip dysplasia	L	3.2	58
6	F	23	Developmental hip dysplasia	R	3.3	65
7	F	34	Avascular necrosis of femoral head	L	0.6	28
8	F	32	Developmental hip dysplasia	L	4.2	46
9	M	16	Avascular necrosis of femoral head	R	2.0	56
10	M	19	Avascular necrosis of femoral head	L	0.7	56
11	F	21	Hip tuberculosis/ femoral head necrosis	L	1.0	27
12	F	14	Developmental hip dysplasia	R	6.5	65
13	F	10	Developmental hip dysplasia	L	5.0	65
14	F	15	Developmental hip dysplasia	R	3.2	65
15	M	11	Developmental hip dysplasia	R	2.8	65
16	F	20	Developmental hip dysplasia	L+R	0.5	65
17	F	19	Developmental hip dysplasia	R	5.6	65

According to the length and circumference of the affected thigh, suitable external fixator components are selected and assembled into a ring-shaped triangular configuration before the surgery, and tried on the patients. The size of the selected ring should be that the inside ring edge is 2–3 cm from the skin. It is important to explain to the patients and their family members about the treatment planning, their understanding and cooperation are very important for the success of the treatment.

Surgical procedure

The patients were operated on in a supine position under general or epidural anesthesia. The hip of the affected side was properly elevated to allow easy operation. The first osteotomy point was marked under the C-arm X-ray, when the hip presented a maximum adduction position, the cross point of the femur and ischial tuberosity was marked under fluoroscopy as the proximal osteotomy point. Two 4.0-mm threaded half-pins were inserted percutaneously proximal to the proximal osteotomy point under fluoroscopy (Fig. 1A). The pre-assembled ring-shaped triangular external fixator was then fit into the affected thigh. A 1.5 cm incision was made on the anterolateral side of the marked proximal osteotomy point, and the femur was cut transversely using multiple drill hole osteotomy guide using 3 mm diameter drill bits. The proximal segment was maintained in maximum adduction position, while the distal segment was abducted and shifted 1/2 of the bone diameter inward (Fig. 1A and B). Then the inserted half-pins were fixed on the proximal triangular external fixator (Fig. 1B). The 2nd osteotomy point at the distal femur was marked under the C-arm fluoroscopy as following: the cross point of the straight

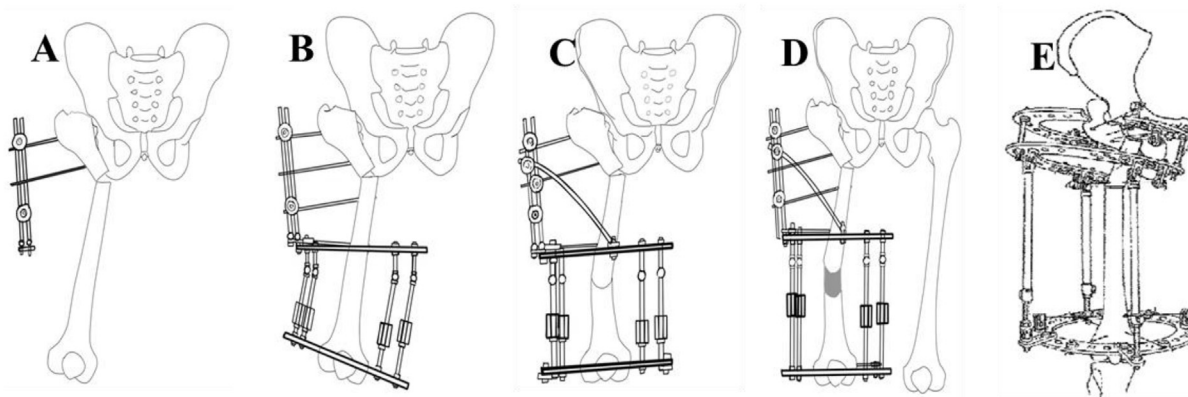


Figure 1. Schematic diagram shows the stepwise surgical procedure of the modified Ilizarov hip reconstruction surgery. **A.** The position of the first (proximal) osteotomy site and the insertion of the half-pins. **B.** The assembly of the triangular external fixation device at the distal femur. **C.** The site of 2nd osteotomy site at the distal femur and configuration of the external device. **D.** Diagram shows the complete configuration during the lengthening and the alignment of the mechanical axis of the femur. **E.** Diagram shows the classical Ilizarov hip reconstruction surgery with two half-rings fixation configuration at the proximal femur site and one ring fixation at the distal femur site, which may cause great discomfort to the patient.

line perpendicular to the horizontal line of the pelvis and the proximal axial extension line of the tibial axis (Fig. 1C). A 2.0–2.5 mm Kirschner wire was then inserted from the outside to the inside of the femoral condyle far from the marked 2nd osteotomy point and fixed to the distal ring after the k-wires were being tensioned (Fig. 1C). A 4.0–5.0 mm threaded half pin was inserted on each of the plane of the ring from outside to inside direction. A small incision was made on the anterolateral side of the second osteotomy point to cut off the femur using multiple drill hole guide. Then all the half-pins and wires were tightened to firmly fixed on the ring-shaped triangular external fixator, the skin was sutured in layers (Fig. 1C).

For patients with stiff hip joints, an osteotomy at the middle of the femoral neck and the base of the femoral neck was carried out to remove a piece of bone, to create a small gap for releasing the restriction of hip joint movement. Briefly, a 5 cm anterolateral incision was made on the affected hip, dissecting the femoral arteries, veins and nerves and pulling them inward and protect them. Using osteotomy guide, the femoral head was cut off at the middle of the femoral neck, the excessive cortical or trabecular bone at the femoral neck base were removed to release the hip stiffness. The femoral head was kept in the acetabulum; cares were taken not to destroy the hip joint structures.

Postoperative management

Postoperative managements include anti-inflammatory and analgesic medication; pin-holes care; postoperative physiotherapy or voluntary exercises. The operated limb was elevated and maintained at 30° knee flexion. The patients were encouraged to perform isometric contraction exercises of the operated limb muscles from day 1 after surgery. Once the pain was controlled, the patient may start hip and knee flexion, extension and partial weight-bearing exercises with walking aid/crutches. One week after the surgery, the femoral lengthening started at a rate of 0.25mm/12 h. 1 week after lengthening, radiography was taken to monitor the separation of the bones and adjust the lengthening speed, in that the speed for the lateral side was slightly faster than the medial side, at 0.5–0.7mm/12 h. Radiographs were taken biweekly during the lengthening phase to monitor the callus formation, length and mechanical axis of both limbs, and the lengthening speed was adjusted accordingly. The lengthening stopped once the limb lengthen were equal and mechanical axis was corrected aligned (Fig. 1D).

After completion of lengthening phase, patients shall intensify the functional exercises of the hip and knee joints, slowly increase the weight-bearing on the operated limb, gradually practice independent walking with crutches (Fig. 2). Radiographs were then taken every 2

months till the 1st osteotomy site was united. Then gradually reduce the rigidity of the external fixation frame by removing the half-pins one by one, till completely remove the external fixation. After removing the external fixation, it is necessary to protect the limb with braces for 2–3 months, and the patients shall walk with crutches to prevent fall and re-fracture. During the regular follow-up checks, the patients' limb gross appearance, radiographs and Harris hip scores were recorded.

Statistical analysis

Data analysis was performed using SPSS 24.0 software (IBM Corp., Armonk, NY, USA). Comparison between preoperative and postoperative data was conducted using paired t test, and a difference with a two tailed *p*-value less than 0.05 was considered statistically significant.

Results

All patients tolerated the surgery well, with a mean blood loss of 120 ml (40–200 ml). Patients were followed up for an average of 64.3 months (range: 12–87 months). At the time of last follow-up, bone union at the proximal osteotomy site and the femoral lengthening site was all achieved with satisfactory lower limb appearance and function in all patients. There was no hip pain and no restricted range of hip motion in all patients. Limping gait was dramatically improved to normal gait, and the Trendelenburg sign was negative in all patients. We have used Harris hip score system [7] to access hip function in terms of pain, function, degree of joint motion and joint deformity, with a total score of 100 points. In the current study, we had 7 cases graded as “Excellent” (90–100 points); 8 cases graded as “Good” (80–89 points); 2 cases graded as “Fair” (70–79 points); and no one was graded as “Poor” (less than 70 points). The mean preoperative and postoperative Harris hip scores were 45.92 ± 19.41 and 87.16 ± 5.31 , respectively ($p < 0.01$). All patients and their family members were happy and satisfactory for the treatment outcome. Representative cases illustrating the treatment procedures and functional exercise were shown in Figs. 2 and 3.

For complications, four patients developed pin-track infections, which were successfully dealt with pin track care and oral antibiotics. Restricted range of motion of the knee was observed in eight patients during the follow-up, which was treated by active knee functional exercise with the help of physiotherapists, except two patients underwent manual knee release under local anesthesia. Fracture at the middle of femur near the newly formed lengthening regenerate site occurred in two patients after removing the external fixation due to accidental fall. They were treated with herringbone plaster fixation and all healed within 3

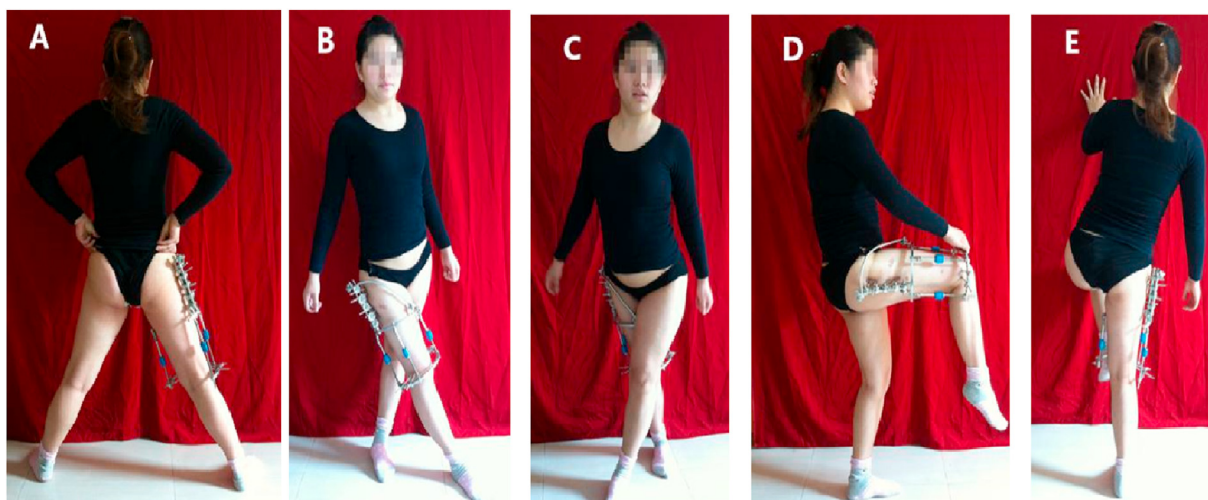


Figure 2. A young patient with developmental hip dysplasia treated with modified Ilizarov hip reconstruction surgery and femoral lengthening. A-E. During the treatment the patient had daily weight-bearing exercises; flexion and extension exercises for the affected hip and knee joint. Please note that the proximal thigh was in a single-arm triangle configuration and the distal half ring structure allows hip and knee joint flexion and extension activities, bringing comforts to the patient. Patient tolerate the modified frame very well.

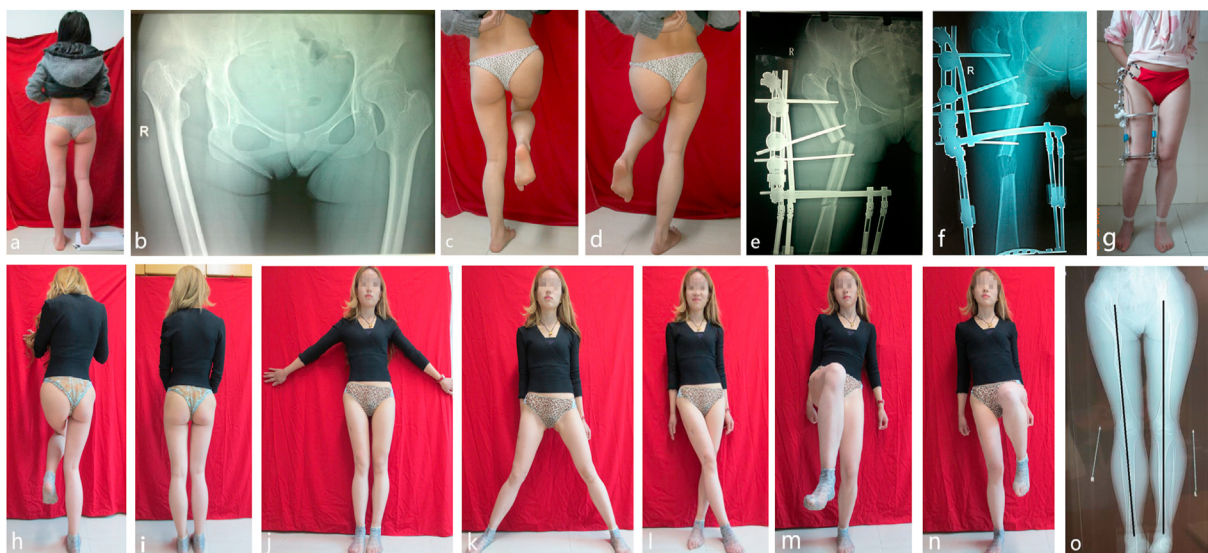


Figure 3. A female patient, 22 years old, had right hip dysplasia. She had aggravated right hip pain and limping gait for 20 years. A. Appearance of standing position before surgery. B. Preoperative hip x-ray. C-D. Positive Trendelenburg sign on the right side before surgery. E. X-ray of the right hip after modified Ilizarov hip reconstruction surgery. F. X-ray of the right hip 3 months after the surgery with femur lengthening. G. Appearance just before removal of the external fixation 7 months after surgery. H-N. Photographs showing the various functional assessments of the hip joints 3 years after the external fixation removal, showing normal range of motion of the hip and knee. O. X-ray of the hip and limbs showing the normal mechanical axis of both lower limbs, 3 years after the surgery.

months. Complications such as fixation device failure, knee dislocation, nerve paralysis and vessels impairment were not observed in any of the patients.

Discussion

Hip joint is one of the most important load-bearing joints. While hip lesions will seriously affect patients' daily lives and functions. Hip joint replacement is the most common and effective treatment method for reconstructing hip function. Shortcomings of joint replacement began to appear over time, such as potential implant infection, loosening especially the limited "lifetime" of joint prosthesis, hence the joint replacement surgery in young patients is not the first treatment choice [1,2].

Traditional femoral tuberosity abduction osteotomy can effectively provide pelvic support and alleviate joint pain, but the procedure causes

severe knee valgus and limb shortening deformities, which affects the appearance and function of the limb, causing great physical and psychological distress to the patients [4–6]. This contradicts with modern medicine's concept that all treatments shall fulfil the purpose of pursuit improvements in "physical, psychological and aesthetic" aspects of patients and distraction histogenesis techniques provide an alternative for tissue regeneration through gradual biomechanical stimuli [8]. In the 1970s, Dr. Ilizarov modified the tuberosity abduction osteotomy, in that the femoral trochanter abduction osteotomy was used in conjunction with mid-femoral shaft osteotomy for femoral lengthening. The Ilizarov hip procedure corrects knee valgus deformity, restores the lower limb mechanical axis and limb length through gradual limb lengthening at the same time. The use of minimally invasive osteotomy technique during surgery further reduces surgical trauma, reduces the risk of delayed or non-union of the osteotomy sites [5]. People also refer the Ilizarov's

modified hip osteotomy surgery as pelvic support osteotomy (PSO) [9–12].

Ilizarov hip reconstruction surgery is to use the extreme adduction of the hip joint to move the pelvic support point inward. When the proximal femur is adducted, the greater trochanter will move to the distal and lateral sides, thereby increasing the tension of the abductor muscle and forming a new balance of the leverage force to maintain dynamic balance of the hip [5,6]. The basic principle of the proximal femoral abduction osteotomy is to eliminate the Trendelenburg gait through extreme valgus osteotomy and use all the existing hip joint adduction to eliminate the Trendelenburg gait. It is well known that the Trendelenburg gait is when standing on one leg, the contralateral pelvis is prolapsed. If the hip joint cannot be adducted, the pelvis cannot be prolapsed. Therefore, an abduction osteotomy is performed at the basis of extreme adduction of the hip joint. This osteotomy maximizes the abduction of the proximal segment of the femur, moves the greater tuberosity to the distal end and the outside, forms a dynamic structure of the lever force system, and increases the tension of the abductor muscles, thereby maintaining good dynamic balance. The ideal proximal femoral osteotomy point should be such that the proximal femoral supports pelvis at the acetabulum or at the lower edge of the transverse pubis. The closer the osteotomy point is to the middle section, the closer the proximal femoral support point to the pelvis line of gravity, further enhancing the leverage force effects. At the same time, to correct limb shortening caused by proximal abduction osteotomy of the femur, secondary osteotomy at the middle femur is applied for limb lengthening to restore the mechanical axis and femur length [5]. By slow adjusting the external fixation frame, the procedure could serve the purposes of “natural rehabilitation, optimized and patient-centered reconstruction” [8]. The patients are encouraged to carry out weight-bearing exercise early after the surgery and during limb lengthening to prevent joint stiffness and muscle wastage.

In conventional Ilizarov hip reconstruction surgery, the proximal femoral osteotomy was fixed to half-ring using full length K-wires, which requires skillful operation to avoid potential damage to the sciatic nerve and blood vessels [Fig. 1E]. In addition, the proximal half-ring configuration at the thigh was unfriendly to patient causing discomfort and difficulties in care after surgery [Fig. 1D]. The semi-circular ring configuration of the proximal thigh causes great inconvenience to the daily activities of the patient (sitting, lying, hip joint activities, etc). The full circle ring of the distal thigh restricts the flexion of the knee joint, and the prolonged treatment time discomforts to the patients. Some doctors called it “a surgical technique with a high tendency to complications” [13]. Our modified Ilizarov hip reconstruction surgery replaced the classic half-ring with a double-rod single-arm and distal ring-shaped frame [Fig. 1C and D]. At the same time, the proximal single-arm frame and the distal ring-shaped frame are connected by a connecting rod with an arc to form a ‘triangular’ configuration [Fig. 1]. This configuration is simplified, ensures the stability of the external frame, increases the patient’s comfort and facilitates the postoperative functional exercises [Fig. 2]. The proximal and middle femurs are fixed with two thick-diameter threaded half pins, and the direction of pin insertion is from the outside to inside, thereby avoiding injuries to blood vessels and nerves, which greatly simplifies the surgical procedure and the increases postoperative comfort for the patients. The modified Ilizarov hip reconstruction surgery is different from traditional surgical methods, it is closely related to the post-operative management and patient’s cooperation. Active functional exercises can promote blood circulation of bones and soft tissues, increase synovial fluid to provide nutrition to cartilage and prevent joint stiffness [14–16]. Ilizarov hip reconstruction surgery changed the anatomical shape of the proximal femur significantly, which is difficult to accept or understand for some orthopaedic surgeons and the patients, especially the joint surgeons may have doubts. This technique is not yet well applied due to its requirements for the surgeons to have limb lengthening skills. However, increasing successful clinical cases have proven that this novel procedure can effectively relieve joint pain, correct hip deformity and regain hip function [5,6,9–12]. Detailed surgical

protocols and care are given in the current report, which will provide a reference guide for others who may use the modified Ilizarov hip reconstruction surgery for the young patients.

In our early experiences, we tried to immediately correct the lower limb mechanical axis line during the surgery; the bone lengthening was performed afterwards only to restore the limb length, but this approach was not easy and had drawbacks. First, it increased the surgery time substantially and the intraoperative use of C-arm fluoroscopy. Second, when correcting the mechanical axis at the 2nd osteotomy site, it may cause misalignment of the bones, improper or excessive correction of the mechanical axis angles, and interference of the blood supply at the osteotomy site hence affecting bone formation later on. Therefore, we believe that immediate correction of the mechanical axis during the surgery may do more harm than good to the patients. In our later experience, we corrected the mechanical axis and limb length spontaneously during the subsequent limb lengthening process, in that the speed of lengthening for the lateral side was slightly faster than that in the medial side, at 0.5–0.7mm/12 h, and the mechanical axis and limb length was checked periodically by X-ray and readjusted accordingly. This strategy significantly reduced the surgery time and avoided the disturbance of blood supply at the osteotomy sites. Our modified procedures did not increase the time for healing nor difficulty in post-surgery adjustment.

The present study was a retrospective study with no control group to other surgical procedures, the hip dysfunction cases in young adults are not too common as most of the developmental hip dysplasia cases were treated earlier in children. It is difficult to carry “controlled” study with limited patients, and to have a clinical trial to compare the modified technique with the classical one was not feasible either from the ethical point of view. Because the purpose of modifying the classical Ilizarov hip reconstruction surgery was to reduce the complications and suffers of the patients, and hence it is not possible nor necessary to have a “control group” using the classical surgical procedure as such. However, all the 17 cases (with mean follow-up period 64.3 months) had gained normal hip function, eliminated limb discrepancy and were satisfactory with the outcome.

Lastly, because the Ilizarov hip reconstruction surgery involves pelvis support surgery, external fixation and limb lengthening procedure, the surgical procedure shall be carried out by an experienced surgeon who is specialized in external fixation or Ilizarov method to avoid unnecessary complication and ensure desirable clinical outcomes.

Conclusions

In summary, for managing hip dysfunction of adolescent and young adults who are not suitable candidates for hip replacement surgery, the modified Ilizarov hip reconstruction surgery provides a useful and safe alternative with satisfactory clinical outcomes. All patients in the present study were satisfied with the hip appearance and function during the follow-up period. This procedure is minimally invasive, safe and simple, with few complications compared to conventional pelvis support surgery, and it may be the first choice of surgery for the management of hip dysfunction in adolescent and young adults.

Conflict of Interest

The authors have no conflicts of interest to disclose in relation to this article.

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