Outcome of severe fixed-flexion deformity of the knee managed by ring fixator

Ahmed I. Zayda

Department of Orthopedic Surgery, Faculty of Medicine, Menoufia University, Menoufia, Egypt

Correspondence to Ahmed I. Zayda, MD, Department of Orthopedic Surgery, Faculty of Medicine, Menoufia University, Menoufia, Egypt. Tel: +20 100 699 3055; e-mail: dr.ahmedzayda2018@gmail.com

Received: 24 April 2018
Revised: 10 May 2018
Accepted: 13 May 2018
Published: 17 November 2021

The Egyptian Orthopaedic Journal 2021, 56:140–147

Objective
The aim was to assess the effectiveness of gradual correction of severe flexion deformity of the knee by Ilizarov fixator.
Background
Acute correction of severe knee-flexion contractures (KFC) with soft-tissue release, osteotomy, or both may lead to serious complications. In contrast, gradual correction of KFC, a circular frame, and a constrained hinge, avoids acute stretch injury to soft tissues, with a low recurrence rate.
Patients and methods
Between March 2011 and February 2017, 16 patients with 21 affected knees included 12 male and four female patients, the age ranged from 4 to 58 years, and mean (20.81 years), unilateral in 11 patients, and bilateral in five patients. The etiology was maltreated deep burns in two patients, four patients with arthrogryposis multiplex congenita, one had systemic lupus erythematosis, two had poliomyelitis, two complicated femoral lengthening, two had fibular hemimelia, complicated trauma in one case, and septic arthritis in two patients. Only gradual correction by Ilizarov fixator was used, except in one case where additional corrective osteotomy was done for hyperextended distal femur.
Results
The mean duration of the fixator was 3.9 months (range: 3–8 months). The follow-up period ranged from 4 to 48 months after frame removal with a mean of 10.8 months. Extension range significantly increases from the mean of –83°, to a mean of –4.7° at late follow-up ($P<0.05$). Mean flexion range was 35.9° that improved at late follow-up to a mean of 63.3°. The arc of motion postoperative was nearly the same of the preoperative with a mild increase. Two cases had recurrence of the KFC (15°) and knee subluxation, four cases had reversible excessive arthodiastasis of the knee joint, and two cases had epiphyseal injury in proximal tibia during the early stages of correction of the deformity.
Conclusion
Gradual distraction of the contracted tissues around the knee joint by Ilizarov fixator is a highly efficient and safe method that can address all components of intractable severe flexion contracture of the knee joint whatever the etiology of the deformity. There is a significant increase in the extension range and low recurrence rate compared with any other treatment method converting a nonambulant patient to an active ambulant one with a low complication rate.

Keywords:
deformity, flexion, Ilizarov fixator, knee

Egypt Orthop J 56:140–147

1110-1148

Introduction

Knee-flexion contracture (KFC) is a debilitating condition that may affect patients with congenital deformities, cerebral palsy, hemophilia, post-traumatic deformities, and septic arthritis of the knee, after femoral lengthening and after total knee replacement [1].

The mechanical axis of the limb falls posterior to the knee in its flexion contracture, thus placing increasing demand on the quadriceps muscle to resist the progressive crouch, crouch gait, and excessive energy consumption during walking, making daily activities difficult such as standing, reaching for objects, and even walking [1]. In severe cases, walking becomes impossible and if the deformity is bilateral only, crawling becomes their only mean for transfer from one place to another [1].

Several nonoperative treatments, including serial casting, reverse dynamic sling, and extension de-subluxation hinges, have been indicated to correct mild-to-moderate contractures. However, in severe contractures (>30°), these measures may not suffice

and corrective surgical procedures have to be performed [2,3].

Several operative approaches, including hamstring tendon lengthening with posterior knee capsulotomy, distal femoral extension osteotomy, and guided growth with anterior distal femoral hemiepiphysiodesis in skeletally immature patients, have all been indicated to correct the flexion deformity. However, the recurrence rate of these nonoperative and operative procedures can be very high [1,4,5].

Acute correction of severe KFC with soft-tissue release, osteotomy, or both may lead to serious complications such as skin breakdown, peroneal nerve damage, arteriovenous stretching with distal ischemia, and possible gangrene and amputation. In contrast, gradual correction of KFC, a circular frame, and a constrained hinge, avoids acute stretch injury to soft tissues and prevents compression of the anterior joint. Furthermore, gradual correction with histiogensis leads to soft-tissue lengthening that should make the contracture less likely to recur [6–8].

Gradual correction of the deformity has been reported previously using various external fixators. Several authors have used an Ilizarov circular fixator, a monolateral fixator, or hinged distraction apparatus [9,10]. Many authors reported the associated procedures, including hamstring release or supracondylar osteotomy and tenotomy of the medial and lateral hamstrings [11], although Volkov and Oganesyan [12] and Hosny and Fadel [13] used only distraction without operative procedures.

In this study, only gradual correction of contracture without any soft-tissue dissection was used, except in one case where additional corrective osteotomy was done for hyperextended distal femur.

Patients and methods

In this prospective study, 16 patients with 21 knees suffered disabling fixed-flexion knee deformities ranging from 45 to 110°. The study was approved by the institutional ethics committee in the Orthopedic Department of Orthopaedic Surgery, Menoufia University, Cairo, Egypt. The study was done between March 2011 and February 2017.

All patients with fixed-flexion deformity more than 30° were included in this study, except those with malignant tumors around the knee joint in whom limb-salvage protocol for tumors was applied.

The study included 12 male and four female patients, the age ranged from 4- to 58-year mean (20.81 years). Ten patients had unilateral affection and six patients had bilateral flexion contracture. Flexion contracture of the knee was due to maltreated deep burns around the knee in two patients, one of them has bilateral affection of his both knees and the other has extension of contracture to the ipsilateral ankle with equinus deformity. The last four bilateral patients had arthrogryposis multiplex congenita.

Among unilateral cases, paralytic poliomyelitis was the cause in two patients, congenital short femur and post-lengthening KFC and subluxation in two patients, fibular hemimelia in two cases, postburn contracture in one case, complicated trauma in one case, and postseptic arthritis in two patients. The last patient had systemic lupus erythematosis with fixed deformity of 70° in the left knee, also she had 35° in the right knee that unfortunately was managed with hamstring lengthening and soft-tissue release by another surgeon and suffered peroneal nerve damage. So, only her left knee was included in this study (Table 1).

Equinus ankle was present in six cases. Lower-limb shortening in five patients ranged from 1.5 to 8 cm with a mean of 3.2 cm. Only one case needs lengthening of 8-cm shortening, the other two cases had poliomyelitis with 2-cm shortening that was beneficial in their gait. The last two cases with 1.5- and 2.5-cm shortenings did not need lengthening.

No previous surgical trials for correction were done for nine patients, only manipulation under anesthesia was done in three cases, and soft-tissue release and hamstring muscle lengthening in two cases with fibular hemimelia and two cases with poliomyelitis.

The degree of knee-flexion deformity was measured clinically using a goniometer. In the supine position, the patient was asked to extend the knee maximally, with full extension of the knee as 0°. Mean preoperative range of motion (ROM) was −83° extension (range: −45° to −110°), 63.5° flexion (range: 13°–95°) (Table 1). The degree of equinus contracture of the ankle was measured clinically along the middle plane of the lateral aspect of the leg and plantar surface of the foot, with neutral position of the foot as 0°. Mean preoperative ROM was −29° ankle dorsiflexion (range: −10° to −50°).

All patients with unilateral deformity were ambulatory before surgery with crutches or walking aids, all patients with bilateral deformity were nonambulatory and were just crawling.

Table 1 Etiology, epidemiology, preoperative, and postoperative range of motion and late complication of cases

Patient	Knee affected	Age	Sex	Etiology	Preoperative flexion	Preoperative extension lag	Postoperative extension lag	Postoperative arc of motion	Serious complications and case progress at late follow-up
1	1 R	4	M	Arthrogryposis	30	110	5	30	
	2 L				30	110	5	30	Epiphyseal slipping of proximal tibi-
2	3 R	6	M	Arthrogryposis	45	90	0	45	–
	4 L				45	90	5	45	Excess arthrodiastasis-
3	5 rt	10	M	Postburn	25	90	10	100	Excess arthrodiastasis-
	6 lt				20	95	5	95	
4	7 rt	5	M	Arthrogryposis	45	90	10	50	Epiphyseal slipping of proximal tibia
	8 lt				40	100	5	40	
5	9 rt	4	M	Arthrogryposis	35	100	0	35	–
	10 lt				35	100	**0**	35	–
6	11 lt	14	F	Systemic lupus (bilateral but only left side included)	60	70	5	120	Excess arthrodiastasis–limbing due to contralateral foot drop
7	12 lt	55	M	Poliomyelitis	60	50	10	90	–
8	13 lt	11	M	Fibular hemimelia	20	115 subluxation+	15	20	Progressive shortening at 4 years of follow-up with 15° flexion, posterior subluxed tibia
9	14 rt	58	F	Poliomyelitis	50	45	**15**	65	15° flexion
10	15 rt	8	M	Postfemoral lengthening	30	55 subluxation+	0	130	8-cm shortening at 4 years of follow-up
11	16 rt	43	M	Septic arthritis knee	30	45	0	50	Advanced OA knee
12	17 lt	9	F	Postfemoral lengthening	30	70 subluxation+	0	100	Excess arthrodiastasis-
13	18 rt	14	M	Postburn	25	80	5	90	–
14	19 lt	38	M	Post-traumatic	40	45	0	40	OA knee
15	20 lt	7	M	Fibular hemimelia	30	80	5	30	-Recurrent subluxation
16	21 rt	47	F	Septic arthritis knee	30	45	0	90	–
Total 16 patients	21 knees								

F, female; lt, left; M, male; rt, right.

Technique

Under spinal or general anesthesia and on the radiolucent table and C-arm control, all patients with flexion deformity were operated. In all of them, neither soft-tissue release nor hamstring muscle lengthening was done. Both knees in three of the bilateral cases were operated in the same sitting, and in two of the arthrogrypotic patients with a small-size lower-limb and severe deformity, it was impossible to operate on both limbs simultaneously. So one limb was operated first and the other one was done 2 months later after near-total correction of the other side to create a space for the frame on the contralateral side.

The construct of the frame was composed of femoral and tibial components, the femoral one was a ring or 5/8 ring with two or three 1.8-mm wires and a proximal arch with a wire and Schanz pin, 4, 5, or 6 mm. In six cases with a small-size limb, only one ring and two wires with a third drop wire were applied.

On application of Schanz screws, it was a strict role not to introduce the Schanz screw directly on the power drill to avoid future loosening and possible fracture of the femur. First, the drill pit was used (2.5-, 3.2-, and 4-mm drill pit for 4-, 5-, and 6-mm Schanz pins, respectively) and the Schanz screw was later introduced with the T handle.

The tibial component was either two rings or one ring distal and proximal 5/8 ring in most cases. In six cases with a small-size limb or bilateral severe deformities, only one tibial ring was used with two wires and one drop wire (1.5- or 1, 8-mm wires).

After application of the two components, connection between them was done by two distraction rods posteriorly and two rods with hinges anteriorly (the hinges used were universal joints). The anterior hinges were put opposite the center of rotation of the knee joint. The hinge point of the knee was at the intersection of the posterior cortex and Blumensaat's line. Although knee center of rotation is not a constant fixed point but is J-shaped, roughly we considered it 2 cm proximal to the knee joint. Distraction rods were fixed to the rings with an unlimited number of configuration via plates, twisted plates, posts, and conical washers to create a strong and stable smooth distraction till the end.

In one patient with fibular hemimelia, he had shortening of 8 cm and tibial corticotomy and lengthening was done to correct leg-length discrepancy as well. Also, this patient had hyperextension deformity in his femur, so correction osteotomy was done, which aggravates his flexion deformity, then in the same sitting, the frame was applied for correction (Fig. 1).

In another patient with ipsilateral equinus and knee-flexion deformity, the frame was extended to the ankle for correction of both postburn contractures simultaneously (Fig. 2). Three cases with equinus were treated with posterior capsulotomy and tendoachilis lengthening and the last two cases were corrected with manipulation and physiotherapy.

In two patients with arthrogryposis, proximal tibial epiphyseal slippage occurred gradually during correction of the left knee, so open reduction was done with wire fixation and prophylactic wires were inserted into the contralateral side during frame application on the right side.

Statistical analysis

Comparisons between the preoperative and postoperative ROM were performed with use of paired-sample *t*-tests. Significance level was set as *P* value less than 0.05.

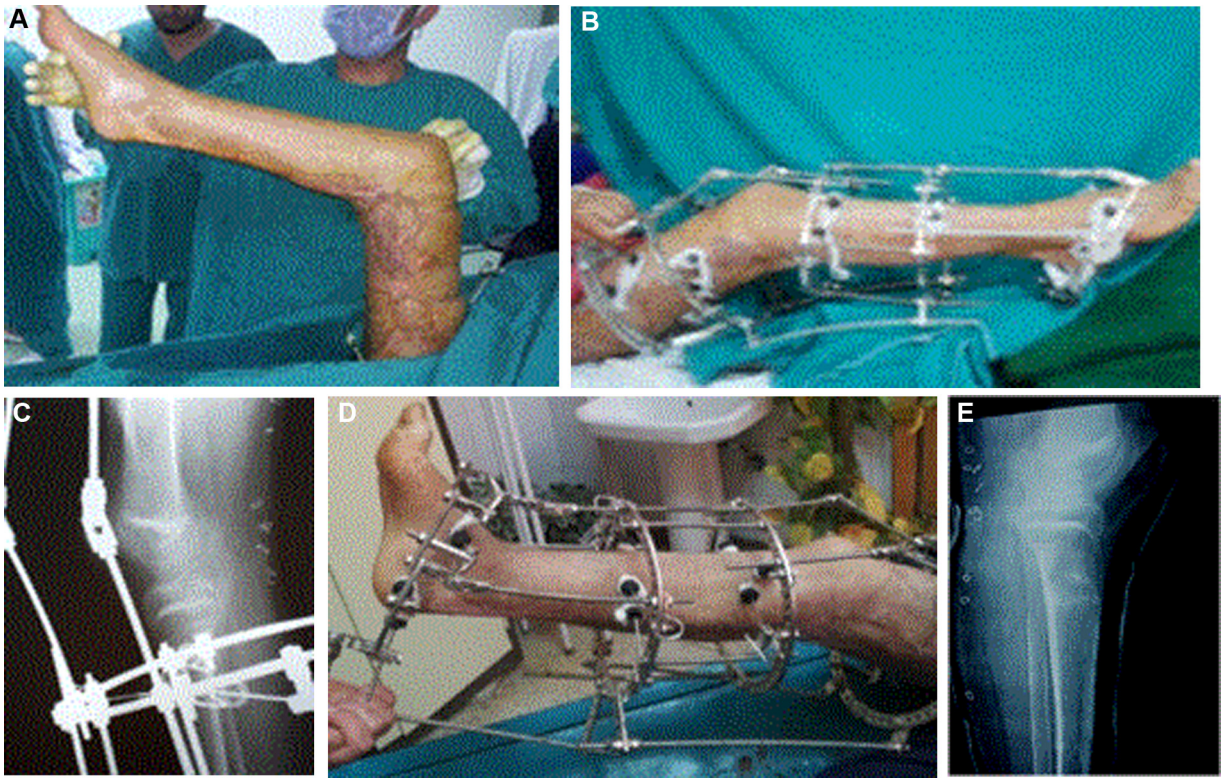
Postoperative care and follow-up

Postoperative antibiotics (third-generation cephalosporins) for 3 days, followed by oral antibiotics according to the case. Care for pin site was done regularly. Correction of deformity started the first postoperative day. The rule of similar triangles or the rule of concentric circles was used to determine

Figure 1

(a) Preoperative radiography of a 10-year-old boy with fibula hemimelia shows severe flexion deformity and deformed distal femur with subluxed tibia. (b) Preoperative clinical picture. (c) Postoperative radiography shows correction of the extended femur and beginning of correction of knee flexion. (d) Clinical picture with frame mounted. (e) Four-year follow-up clinical photo with mild recurrence of flexion. (f) Four-year follow-up radiography shows recurrent subluxation.

Figure 2



(a) Preoperative picture of postburn knee flexion and ankle equines. (b) Frame applied for simultaneous correction of both deformities. (c) Radiography of knee shows the anterior position of the hinges in relation to knee center of rotation. (d) After full correction of knee and ankle deformities. (e) One-year postremoval knee radiography shows complete correction.

the rate of distraction. The aim was to hypercorrect the knee to 5–10° of hyperextension, and the ankle to 10–15° of dorsiflexion, to prevent recurrence of the contracture.

Postoperative radiography was done and every 2 weeks later until full correction was achieved to rule out joint subluxation and monitor progress. At the end of the correction, the external fixator was maintained in full extension of the knee for 4–10 weeks and then removed (at least the time for full correction of deformity) [14]. Weight bearing was allowed when the knee is nearly extended till the end of treatment in walking patients. The mean duration of the fixator was 3.9 months (ranged from 3 to 8 months).

After frame removal, above-knee cast was done for one month and then physiotherapy was started to regain knee motion. Patients were followed up monthly for assessment of knee motion, radiological evidence of subluxation, or recurrence. The follow-up period ranged from 4 to 48 months after frame removal with a mean of 10.8 months.

In two patients with flexion subluxation of the knee due to inaccurate femoral lengthening procedures, flexion deformity was corrected first, but subluxation was still evident. So gradual anterior translation of posteriorly translated tibial relative to the femur was done by means of long connecting plates and anteroposterior rods. With full correction of subluxation, locking the frame in extension was done and follow-up is completed as usual.

In one patient with short tibia and fibular hemimelia, lengthening of tibia 8 cm was done and the frame was removed after correction of both flexion deformity and leg-length discrepancy.

Results and complications

The mean duration of the fixator was 3.9 months (range: 3–8 months). The follow-up period ranged from 4 to 48 months after frame removal with a mean of 10.8 months.

With full extension of the knee as 0°, mean preoperative ROM was −83° extension (range: −45° to −110°) that significantly decreases to a mean of −4.7° (range: 0–15°) at late follow-up ($P<0.05$). Mean flexion range was 35.9° (range: 20°–60°) that improved at late follow-up to a mean of 63.3°

(range: 20–130°). The arc of motion postoperative was nearly the same of the preoperative, especially in patients with arthrogryposis and fibular hemimelia and poliomyelitis (preoperative mean was 38.75° and postoperative was 42.9°), while markedly improved in patients with burns and in those with complicated femoral lengthening (preoperative mean was 26° and postoperative was 103°) (Table 1). Ankle equinus in six patients had a mean preoperative value of −29° (range: −10° to −50°). Equinus deformity was corrected in all patients with a mean of −4° at late follow-up.

Among five nonambulant patients preoperative, three become ambulant at late follow-up, one of them was due to postburn contracture four years earlier that was successfully treated with no recurrence. Two of the four cases with arthrogryposis become able to walk with support and walking aids, while the remaining two cases still nonambulant but with great improvement in the shape of their lower limbs and their hygiene and great satisfaction of their parents.

All patients developed a superficial pin infection that was successfully treated with oral antibiotics. No patient required pin removal or exchange. Two knees (8.6%) in two patients with arthrogryposis had slipping of proximal tibial epiphysis that was managed with open reduction and k-wire fixation and prophylactic wires in the contralateral knee. Two unilateral cases (8.6%) had recurrence of the KFC (15°) and knee subluxation that did not need correction at the final follow-up. One of them had progressive shortening up to 10 cm after 48 months postremoval that will need further lengthening (Fig. 2). Four cases (17.2%) had excessive arthodiastasis of the knee joint during the early stages of correction of the deformity that was successfully treated with gradual closure of the diastasis after full correction, while the frame was still applied and locking the knee extended in the frame till ligamentous contracture occurred. One unilateral patient (4.3%) with complicated femoral lengthening had 8-cm shortening after 48 months of follow up and is prepared for another lengthening.

No patient had fracture femur or tibia related to the frame and no one had frame impingement on the skin of the lower limb.

Discussion

Knee-flexion deformity places more force on the quadriceps, leading to overstretching of the muscle fibers and the patellar tendon, resulting in chondromalacia, patella alta, patellar fragmentation, joint instability, and muscle weakness in terminal extension and pain. This increases the loading on several joints, especially on the patellofemoral joint, and may result in stress fractures of the patella and tibial tubercle [1,15]. In severe bilateral cases, even walking becomes impossible. Several nonoperative treatments, including serial casting, reverse dynamic sling, and extension de-subluxation hinges, have been indicated to correct mild-to-moderate contractures. However, in severe contractures (>30°), these measures may not suffice and corrective surgical procedures have to be performed [2,3].

Several operative approaches, including hamstring tendon lengthening with posterior knee capsulotomy, distal femoral extension osteotomy, and guided growth with anterior distal femoral hemiepiphysiodesis in skeletally immature patients, have all been indicated to correct the flexion deformity [1]. All these surgical techniques have significant complications and limitations including infection, neurovascular injuries, wound problems, inability to correct large angles without shortening, and inability to manage limb deformity and shortening simultaneously.

One 14-year female patient had systemic lupus erythematosis with fixed deformity of 70° in the left knee and 35° in the right knee. Unfortunately, the right knee was managed with hamstring lengthening and soft-tissue release by another surgeon and suffered peroneal nerve damage. It was disappointing to get the knee with severe deformity to have an excellent result, while the moderate deformity is complicated with permanent peroneal nerve damage.

The results of this study show significant increase in the extension range compared with preoperative range. It was −83° extension (range: −45° to −110°), that significantly decreases to a mean of −4.7° (range: 0–15°) at late follow-up ($P<0.05$). This is comparable to the results of Hosny and Fadel who treated 50 patients (71 knees) who had a preoperative average of 68° (range: 25°–140°) that declines to an average of 3.5° (range: 0–20°) after fixator removal. At the last follow-up, the average angle was 13.5° (range: 0–70°) [13]. Also, go with the result of Vulcano *et al.* [1] where the mean ROM at the final follow-up was − 10° extension (range: 0 to −50°), 64° flexion (range: 20–100°) in 21 patients. The arc of motion postoperative was nearly the same of the preoperative, especially in patients with arthrogryposis and fibular hemimelia and poliomyelitis (preoperative mean was 38.75° and postoperative was 42.9°), while markedly improved in patients with burns and in those with

complicated femoral lengthening (preoperative mean was 26° and postoperative was 103°). Hosny and Fadel had similar results for the first 42 patients who had an average total arc of motion that remained almost unchanged when comparing the preoperative (mean 48°, range: 0–66°) with the follow-up results (mean 52°; range: 0–90°). For the last eight patients, there was a marked improvement from preoperative (mean 40°, range: 10–70°) to postoperative (mean 67°; range: 35–110°) average [13]. Vulcano *et al*. [1] found that the preoperative arc of motion of 52° was similar to the postoperative arc of motion of 54°. Vishnu *et al*. [16] had different results where the preoperative arc of motion ranged from 10 to 140° with an average of 67°. Following the correction of the deformity, the terminal arc of motion at the latest follow-up ranged from 10 to 120° with an average of 53.7°. There were no patients with an increase in terminal arc of motion. Thirteen patients had a terminal arc of motion equal to the preoperative values [16].There was no fracture related to the frame, while Vulcano *et al*. [1] had one patient (4.8%) who developed a femoral neck fracture secondary to pin loosening. Hosny and Fadel [13] describe that fracture related to treatment occurred in seven patients (14%). This may be due to the smaller number of cases in this study compared with the large number in their study.

Two knees (8.6%) in two patients with arthrogryposis had slipping of proximal tibial epiphysis that was managed with open reduction and k-wire fixation and prophylactic wires in the contralateral knee. In these two cases, the limb was small-sized with bilateral deformity and a very crowded field, and only femoral ring and one very distal tibial ring were applied. It may be due to the force conducted by the long distal lever arm on the weak tibial epiphysis. Hosny and Fadel [13] also explained that one (2%) epiphyseal injury led to Salter–Harris II. They reversed the deformity and fixed the physis by two crossed wires.

Recurrence of deformity up to 15° flexion and subluxation occurred in two cases (8.6%) with fibula hemimelia and poliomyelitis with severe quadriceps wasting and treated with knee brace; also, progressive shortening (not related to treatment) occurred in two cases that require future lengthening. Hosny and Fadel had five patients (7%) who had recurrence of the deformity. The etiology was arthrogryposis multiplex congenita in four patients and sacral agenesis in the other [13], while Vulcano and colleagues had two patients (9.5%) who had recurrence (40 and 45°, respectively) without any benefit compared with preoperative deformity. Both patients had neurogenic etiologies [1].

Limitations of the study

The small number of cases and different etiologies of each deformity, like burn, congenital deformity, and paralytic cases, make standardization difficult. Also, the unequal follow-up period for all cases may obscure the actual final result of cases with short follow-up periods compared with cases with long periods.

Conclusion

Gradual distraction of the contracted short tissues around the knee joint by Ilizarov fixator is a highly efficient and safe method that can address all components of intractable severe flexion contracture of the knee joint, whatever the etiology of the deformity. It can overcome flexion, subluxation, shortening, varus or valgus deformities, and leg-length discrepancy and safely treat bad skin with even ugly scars of deep burns not suitable or risky for any surgical dissection. There is significant increase in the extension range and low recurrence rate compared with any other treatment method. It can convert a nonambulant patient who cannot even stand erect on his legs to an active ambulant one. The functional range of movement of patients greatly improved, despite of a very mild increase in their actual arc of motion. Patients with postburn contracture and those with complicated femoral lengthening procedures did better than those with neurogenic and paralytic etiologies.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Vulcano E, Markowitz JS, Fragomen AT, S Robert R. Gradual correction of knee flexion contracture using external fixation. J Limb Length Reconstr 2016; 2:102–107.

2 Westberry DE, Davids JR, Jacobs JM, Pugh LI, Tanner SL. Effectiveness of serial stretch casting for resistant or recurrent knee flexion contractures following hamstring lengthening in children with cerebral palsy. J Pediatr Orthop 2006; 26:109–114.

3 Mortazavi SM, Heidari P, Esfandiari H, Motamedi M. Trapezoid supracondylar femoral extension osteotomy for knee flexion contractures in patients with haemophilia. Haemophilia 2008; 14: 85–90.

4 Temelli Y, Akalan NE. Treatment approaches to flexion contractures of the knee. Acta Orthop Traumatol Turc 2009; 43:113–120.

5 Karam MD, Pugely A, Callaghan JJ, Shurr D. Hinged cast brace for persistent flexion contracture following total knee replacement. Lowa Orthop J 2011; 31:69–72.

6 Wallny T, Eickhoff H, Raderschadt G, Brackmann H. Hamstring release and posterior capsulotomy for fixed knee flexion contracture in haemophiliacs. Haemophilia 1999; 5(suppl 1):25–27.

7 Heydarian K, Akbarnia BA, Jabalameli M, Tabador K. Posterior capsulotomy for the treatment of severe flexion contractures of the knee. J Pediatr Orthop 1984; 4:700–704.

8 Balci HI, Kocaoglu M, Eralp L, Bilen FE. Knee flexion contracture in haemophilia: Treatment with circular external fixator. Haemophilia 2014; 20:879–883.

9 Herzenberg JE, Davis JR, Paley D, Bhave A. Mechanical distraction for treatment of severe knee flexion contractures. Clin Orthop Relat Res 1994; 301:80–88.

10 Ilizarov GA. Clinical application of the tension-stress effect for limb lengthening. Clin Orthop Relat Res 1990; 250:8–26.

11 Damsin JP, Ghanem I. Treatment of severe flexion deformity of the knee in children and adolescent using the Ilizarov technique. J Bone Joint Surg Br 1996; 78:140–144.

12 Volkov MV, Oganesyan OV. Restoration of function in the knee and elbow with a hinge-distractor apparatus. J Bone Joint Surg Am 1975; 57:591–600.

13 Hosny GA, Fadel M. Managing flexion knee deformity using a circular frame. Clin Orthop Related Res 2008; 466:2995–3002.

14 Herzenberg JE, Waanders NA. Calculating rate and duration of distraction for deformity correction with the Ilizarov technique. Clin Orthop North Am 1991; 22:601–611.

15 Sutherland DH, Davids JR. Common gait abnormalities of the knee in cerebral palsy. Clin Orthop Relat Res 1993; 288: 139–147.

16 Vishnu K, Reddy YH. Effectiveness of the ilizarov method in the management of fixed flexion deformities of the knee joint. Int J Contemp Med Res 2017; 4:7–13