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Hybrid External Fixation (Ilizarov) for the Management of High Energy Tibial Plateau Fractures

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ABSTRACT

Objective: The current study aimed to assess the treatment results of high energy tibial plateau fractures with hybrid external fixation.

Methodology: It included 20 adult patients (17 males and 13 females). At emergency rooms, patients were clinically and radiologically evaluated according to standard protocols, then the assessment was completed and treatment was started in the inpatient department. Preoperative preparation was completed according to standard protocols. Then, the surgical fixation was performed and the patient scheduled for postoperative evaluation. Radiological evaluation had been achieved by anteroposterior and lateral X-ray of the knee and leg. Computed tomography and Doppler ultrasound were requested for specific patients when indicated. Routine laboratory investigations were carried out. All operations carried out under spinal anesthesia. The 1st follow up visit was at the 2nd week postoperative, and follow up was done every 2 weeks. In each visit, patient was assessed clinically and by radiological investigations.

Results: Five patients (25 %) had excellent, 8 patients (40%) had good, 2 patients (10 %) had fair, 5 patients (25%) had poor final result. In addition, 13 patients (65%) had no varus or valgus angulation, 18 patients (90 %) had 0-5mm limb shortening, 14 patients (70 %) had normal knee range of motion, 12 patients (60 %) had no pain and 14 patients (70 %) had normal gait. Two patients had non-union treated by removal of Ilizarov, proximal tibial locked plate, autologous iliac bone graft. 6 patients had multiple degrees of stiffness treated by physiotherapy and had fair, good outcomes, 3 patient had Pin track infection treated by surgical debridement with good outcome, 1 patient had deep vein thrombosis DVT treated by anticoagulant medication.

Conclusion: Hybrid external fixation is a safe and effective treatment modality for tibial plateau fractures.

Keywords: **Tibial; Fractures; Severe; External Fixation; Hybrid**.

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INTRODUCTION

Tibial plateau fractures incidence is about 9.2% of all tibial fractures, and it is one of the challenges to Orthopaedic surgeons. The bicondylar type represented 20-40% of all tibial plateau fractures and is the most challenging subtype [1].

Complex tibial plateau fractures are usually defined as Schatzker Type V and VI or as 41- C type injury on AO classification. Recently, three column fixation method (according to the axial cut in the CT to detect the affected column that need to be fixated) is being used to treat the multiplanner complex tibial plateau fractures [2,3].

Complex tibial plateau fractures are characterized by marked articular depression; severe comminution and displacement of the fracture. The target of management is anatomic reconstruction of the joint surface, reinstatement of axial alignment, preservation of the soft tissue envelope, enclosing the proximal tibia and rigid fixation. Previously, the standard accepted management method of these fractures was open reduction and internal fixation through an extensive-incision. Several alternative techniques, including percutaneous reduction and circular frame stabilization, minimally invasive surgical interventions with implants, and transient external fixation followed by postponed ultimate surgery, have been promoted the advantages of circular frame fixation [3].

The aim of this study was to assess the treatment results of high energy tibial plateau fractures with hybrid external fixation clinically and radiologically**.**

PATIENTS AND METHODS

The current study is a prospective study to evaluate the efficacy of hybrid external fixation (Ilizarov) for the treatment of high energy tibial plateau fractures in 20 patients (17 men and 3 women) aged 19 to 55 years old, recruited from Al-Azhar university hospital from August 2018 to May 2019, and followed up for average 6 months. Patients were included if they are adults older than 18 years of age, any gender, had tibial plateau fracture types IV, V and VI according to Schatzker classification, with compartment syndrome or open fractures. If the patient had associated vascular and/or nerve injury, skin loss, and pathological fractures or was in pediatrics age group, he/she had been excluded from the study.

Pre-operative and Emergency Room (ER) evaluation: This includes patient assessment, counseling, clinical assessment (history, general and local examination), radiological studies and the data of preoperative preparation. The assessment was completed according to the Advanced Trauma Life Support (ATLS) protocol and all for all patients, there was a complete assessment of patients' head, neck, chest, pelvis, abdomen, and any suspected other injuries of the limb [4].

Clinical assessment had been carried out systematically (inspection, palpation and neurovascular examination). Inspection for soft tissue (skin integrity, swelling, abrasions, skin bullae, contusions, ecchymosis and any open wound should be addressed according to its extent and size. Palpation had been applied for site of tenderness. Neurovascular examination included assessment of the posterior tibial and dorsalis pedis pulsation, ankle movements and sensation around the foot.

Radiological evaluation had been achieved by anteroposterior and lateral X-ray of the knee and leg and for other suspected injuries. The fractures were classified using AO classification. The intra-articular extension of the fracture, the degree of intra-articular depression and plan for reduction of the fracture according to the axial view of the articular surface were assessed by computed tomography. In suspected vascular injuries, Doppler ultrasound was requested (3 cases in the present work).

In emergency room, primary management included resuscitation, suture of lacerated skin, the limb was rapidly splinted with a well-padded above knee slab. Then, patient had been admitted with an elevated limb and received medical treatment (low molecular weight heparin, pain killer and antibiotic).

All about the condition and proposed treatment was discussed with each patient and his relatives, and an informed consent was signed by each patient. Preoperative preparation included lab study (CBC, PT, PTT, INR, blood sugar, liver function tests and kidney function tests). All laboratory investigations were done.

Timing of surgery: All patients underwent the surgical procedure as soon as possible for every case according to general and local condition, time of operation was from 3 to 15 days after injury. All operations carried out under spinal anesthesia.

Operative technique: The frame was preassembled in the OR and it is formed of 3 or 4 rings of the same size dictated by the limb circumference, each ring connected primarily by only 2 threaded rods anterolateral and posteromedial position to avoid interfering with wire application and to give a clear X ray intraoperatively to the fracture. Then the patient was positioned supine, with well-padded sand bag under the ipsilateral hip to push the patella to face dead anterior position (facing the AP plane). Tourniquet was applied high on the thigh and kept deflated, only inflated if minimal incisions are needed to decrease blood loss. Then the limb was sterilized and draped and the C-arm was covered with a sterile draping. Our strategy was to get indirect reduction the fracture to an orthogonal frame aiming to get a well reduced joint line with a fracture well aligned and restored length of the limb. The frame was stiff and orthogonally applied to give the chance of compression distraction in the post-operative period if needed.

1- Fixation of intra articular fracture:

The goals were to anatomically reconstruct the proximal tibial articular surface, fix metaphyseo-diaphyseal comminution, and restore limb alignment in all planes.

- After the fracture was distracted and aligned, the joint surface was assessed; if not well reduced; reduction was done percutaneous or through limited incision. The tibial articular cartilage was compared in width in relation to that of the femoral side to avoid broadening of the tibial articular surface.

- Usually the medial tibial condyle was reduced with ligamentotaxis and the lateral one is reduced in relation to it. If the medial condyle was still depressed, it was elevated with percutaneous elevators or half pin through small access incisions. The lateral plateau may need percutaneous or open reduction (through a minimal sharp small incision) in comminuted depressed fractures (Figure 1). A big pointed bone clamp was used to compress the tibial condyles from side to side. Image intensifier was then used to evaluate the reduction of the articular surface; an AP and lateral view were taken to confirm adequate reduction. In bicondylar reconstructable intraarticular fractures were fixed by one or two partially threaded 6.5 screws from lateral to medial directly under the articular cartilage (Figure 2).

2-Ilizarov frame application:

The 1st wire (the reference wire) was applied parallel to the knee joint line and perpendicular to the longitudinal axis of the tibia at the level of the fibular head and at least 1.5 cm below the joint line to avoid the knee capsule to prevent septic arthritis to occur (while the screws were applied immediately below the joint line). An olive wire was used aiming to compress the lateral condyle to the medial one. This wire was essentially important for centralization of the frame and it was parallel to the articular surface in AP view and in the center of the tibia in the lateral view (Figure 3).

Precision in placing the horizontal reference wires facilitated subsequent reduction of the fracture. Safe zones were followed during application of this wire to avoid injury of the common peroneal nerve (never put it at the neck of the fibula).

The frame was opened from one side and passed to the leg and the bolts were connected again around the leg. The bolts and nuts used to assemble the rings were in the anterior-posterior (AP) plane centered on the shin of tibia. The frame was then applied with the most proximal ring at the level of fibular head, 2nd ring is 2 cm to 3 cm just below the lower extension of the fracture and the 3rd ring is 4 cm to 5 cm above the ankle region. Then, it was centralized around the tibia leaving around 2-3 cm as a clear space from the skin especially posteriorly to avoid skin irritation by postoperative swelling (Figure 4).

3-Reduction of the fracture:

While traction was placed on the leg, the foot is rotated to align with the patella. The rotational alignment was adjusted by aligning the distal shin of the tibia to the tibial tubercle. (The 2nd toe should be in line with the tibial tubercle, but the foot may not be clearly identified as it is covered in the operation). The fracture was viewed under the C-arm to assess the translation and angulation of the fracture. A hybrid frame (wires and pins) was applied, first half pin was applied into the mid ring of the frame on the anteromedial surface of the tibia using 3 holes Rancho cube and the shanz screw was well tightened to it. Pre drilling of the half pin reduced the heat necrosis that might be developed during application reducing the incidence of pin tract infection. The principle used was the proximal side of the fracture was aligned orthogonally, the, the distal segment of the fracture. The tibial plateau metaphyseal block was rotated on the horizontal reference wire into an orthogonal position and fixed with an additional two to three opposed divergent wires from lateral to medial on the 1st ring. A minimum of three divergent wires were placed, directing the wires in pathways that will stabilize and secure the key fracture fragments in the plateau. Distraction was then applied on the working threaded rods between the 1st and 2nd rings; the reduction of the metaphyseal part of the fracture was improved in this step. Without distraction, the reduction of the over-riding fragments of the bone, the alignment and translation correction were impossible. With the fracture distracted, we corrected the residual posterior angulation of the fracture. Manual pressure under the calf muscles was applied to reduce the metaphysis, towels were placed between the ring and fracture site, a towel was draped under the calf and over the AP rods and the towel was then pulled up and clamped. An arch wire was used instead of this step or by manipulating the half pin attached to the 2nd ring up by a Rancho cube, the shanz pin should be released till the angulation adjusted then retightened again after adjustment of the angulation. The posterior angulation was usually reduced first, allowing the metaphysis to be fixed in an orthogonal position. The fracture was viewed on the AP image and the shaft manipulated medially or laterally. This was done using a medial half pin to push or pull the shaft fragment. Another big pointed bone clamp was used in oblique extension of the fracture. Once the fracture was reduced, additional tensioned wires and half pins were added to the fixator in divergent planes to increase stiffness of the frame. Care was taken to adjust the posterior slope of the tibia by closing the 2 posterior rods more than the anterior; this can be facilitated by using a male hinge or using conical washers. Wounds were closed by simple sutures and the wounds and the pin sites were dressed with betadine-soaked gauze.

Figure (1): Reduction of lateral tibial plateau.

Figure (2): fixation of articular surface by cannulated screws

Figure (3): Reduction of articular surface by olive wires

Figure (4): application of Ilizarov.

(4) Postoperatively, in the recovery room, the patient was observed, neurovascular assessment was done to the affected limb and any abnormal bleeding was excluded for 2 hours. Then, Patients sent back to the ward with the strapping in dorsiflexion of the foot to the last ring of the frame, and the limb was elevated on 2 pillows. All patients received parenteral antibiotic (3rd generation Cephalosporin) till the third day and continued for 1weeks more on oral antibiotic after discharge. All patients received Low molecular weight anticoagulant for one week till start mobilization. AP and Lateral X rays were taken in the 2nd postoperative day to assess the integrity of the articular surface, the condylar widening and the alignment of the proximal tibia. Wounds were dressed after 2 days of the surgery. Pin tract care was started immediately on the first day of surgery. Mobilization from bed started on the 2nd postoperative day non weight bearing using walker or crutches.

Motion of the knee: (In cases without femoral extension), it was started as much as tolerated by the patients on the 2nd postoperative day by immediate passive range of motion of the knee, and isometric quadriceps exercises and hip raising exercises. Ankle equinus deformity was prevented by active joint mobilization and keeping the ankle in dorsiflexed position by the strapping. Most of patients were discharged on the 5th day of surgery.

The 1st follow up visit was at the 2nd week postoperative, and follow up was done every 2 weeks. In each visit, patient was assessed clinically for wound condition and pins were assessed for pin tract infections and any discharge from it was assessed. Pin tract care was reinstructed to the patient and to the relatives, after removal of the sutures, patient was allowed to be showered by tape water but very adequate dryness to the pin site should be done after the shower. The limb was reassessed for the vascularity, swelling and any painful site. The degrees of knee and ankle motions were reassessed again and confirm that the patient was exercises. The frame was assessed for any loose nuts and any loose one was retightened.

Follow up radiology: X ray AP and lateral were done with reassessment of articular depression, widening of the condyle, alignment of the articular cartilage and signs of healing. The alignment of the fracture could be corrected in the outpatient clinic depending on mobilization of the threaded rods between the 1st and 2nd rings. Follow up was done every week for the 1st month then every 2-3 weeks till union was achieved. Weight bearing was started on the 6th week for patients with intra-articular extension started by partial weight bearing toe touch bearing and increased gradually.

Frame removal: in femoral extension ring, was removed on the 6th week of surgery and the knee motion was started immediately. The frame was removed when healing callus was noticed on 3 columns around the

metaphyseodyapheseal part of the fracture in AP and Lateral view X-rays. When healing was noticed dynamization between the 1st and 2nd ring was done; if patient could move with no pain the frame could be removed. The frame was removed under sedation and above knee cast was applied for 2 weeks after removal. Physiotherapy continued immediately after removal to gain the best range could be achieved.

Methods of statistical analysis: Data were stored in excel files on a personal computer and analyzed using IBM SPSS software package version 22.0. Qualitative data were expressed as number and percent. Quantitative data were described using mean and standard deviation. Significant difference was declared at the p value of (0.05) level or lower. Qualitative data compared by Chi square test.

RESULTS

In this study, the youngest patient was 19 years and the oldest was 55 years old; the mean age was 39 years. There were 17 males and 3 females. Eight patients (40%) are manual workers, 6 patients (30%) are employees, 3 patients (15%) are housewives, 2 patients (10%) are students and 1 patient (5%) did not have a job. Smokers represented 40.0% of studied patients (8 patients). 30% had chronic illnesses (e.g.; Diabetes Mellitus and Hypertension), and 14 patients (70%) didn't have medical history (Table 1).

In this study, 12 patients (60%) had right and 8 patients (40%) had left side Tibial plateau fracture. Eighteen patients (90%) had closed fracture, 2 patients (10%) had open fracture. Nine patients (45%) were 41-C1, 8 patients (40%) were 41-C2 and 3 patients (15%) 41-C3. Fifteen patients (75%) injured due to road traffic accident, 5 patients (25%) due to falling from height. Twelve patients (60%) were operated upon in the first 5 days after trauma, 4 patients (20%) were operated upon 6-10 days after trauma, 4 patients (20%) were operated upon 11-15 days after trauma (Table 2).

In the studied group, 5 patients (25 %) had excellent final result according to Johner-Wruhs' criteria, 8 patients (40%) had good final result, 2 patients (10 %) had fair final result, 5 patients (25%) had poor final result. In addition, 13 patients (65%) had no varus or valgus angulation, 4 patients (20%) had between 2-5° angulation, 2 patients (10%) had between 6-10° angulation and 1 patient (5%) had >10° angulation. Also, 15 patients (75%) had 0-5° anteroposterior angulation, 3 patients (15 %) had between 6-10° angulation, 2 patients (10%) had between 11-20°angulations. Furthermore, 18 patients (90 %) had 0-5mm limb shortening, 2 patients (10 %) had between 6-10mm shortening and no patients had >10mm shortening (Table 3). In the studied group, 14 patients (70 %) had normal knee ROM (0°-150°), 2 patients (10%) had > 80% (120°) of normal knee ROM , 2 patient (10%) had > 75% (75°) of normal knee ROM, 2 patients (10%) had <75% (75°) of normal knee ROM (Table 3).

In the studied group, 12 patients (60 %) had no pain, 5 patients (25 %) had occasional pain. 2 patients (10%) had moderate pain and 1patient (5%) had severe pain. 14 patients (70 %) had Normal gait, 2 patients (10 %) had insignificant limp. 4 patients (20%) had significant limp. 12 patients (60 %) were able to do strenuous activities. 4 patients (20%) had limited ability to do strenuous activities**.** 2 patients (10%) had severely limited ability to do strenuous activities, 2 patients (10%) were not able to do strenuous activities. In the studied group, 18 patients (90%) had closed fracture, mean time to union was 18 weeks, while 2 patients (10%) had open fracture and mean time to union was 21 weeks which was about 3 weeks longer than that of closed fractures. According to AO classification, 9 patients (45%) had 41-C1 type, mean time to union was 17 weeks, 8 patients (40%) had 41-C2 type, and Mean time to union was 19 weeks. 3 patients (15%) had 41-C3 type, mean time to union was 21 weeks. In the studied group, 8 patients (40%) were operated upon in the first 5 days after trauma, of which 3 had excellent result, 5 had good result , 7 patients (35%) were operated upon 6-10 days after trauma, of which 2 had excellent result, 2 had good result, 1had fair result, and 2 had poor result; 5 patients (25%) were operated upon 11-15 days, of which 1 had good result, and 1 had fair result,3 had poor result. There was significant increase of fair and poor outcomes with increased time elapsed before surgery (table 4).

In the studied group, 2 patients had non-union treated by removal of Ilizarov, proximal tibial locked plate, autologous iliac bone graft. 6 patients had multiple degrees of stiffness treated by physiotherapy and had fair, good outcomes. 1 patient had varus>10^{o} but he lost follow up after 6months with fair outcome, 3 patient had Pin track infection treated by surgical debridement with good outcome, 1 patient had DVT treated by anticoagulant medication.

Table (1): Patient characteristics

Variables		N=20	%
Age	19-<31	5	25.0%
	31-<43	5	25.0%
	43-55	10	50.0%
	Mean ± SD (Min-Max)	39.25 ± 12.67 (19.0-55.0)	
Sex	Male	17	85.0%
	Female	3	15.0%
Smoking	Positive	8	40.0%
Occupation	Not working	1	5.0%
	Student	2	10.0%
	Housewife	3	15.0%
	Employee	6	30.0%
	Manual worker	8	40.0%
Positive medical history		6	30.0%

Table (2): Distribution of patients according to fracture characters

		N=20	%
Side	Right	12	60.0
	Left	8	40.0
Fracture type	Open	2	10.0
	Closed	18	90.0
AO classification	41-C1	9	45.0
	41-C2	8	40.0
	41-C3	3	15.0
Cause of trauma	Falling from height	5	25.0
	RTA	15	75.0
Associated injuries	-ve	13	65.0
	+ve	7	35.0
Time before surgery (days)	1-5	12	60
	6-10	4	20
	11-15	4	20

Table (3): Distribution of the studied cases according to outcome

		n=20	%
Final results	Poor	5	25.0
	Fair	2	10.0
	Good	8	40.0
	Excellent	5	25.0
Varus valgus deformity	None	13	65.0
	2-5°	4	20.0
	6-10 °	2	10.0
	>10°	1	5.0
Recurvatum / Procurvatum	0-5°	15	75.0
	6-10°	3	15.0
	11-20°	2	10.0
Shortening	0-5 mm	18	90.0
	6-10 mm	2	10.0
Mobility (range of motion) % Knee	Normal (0°-150°)	14	70.0
	>80(120°)	2	10.0
	>75(75°)	2	10.0
	<75(75°)	2	10.0

Table (4): Relation between times elapsed before surgery and final result.

		Total	Final outcome				P value
			Excellent	Good	Fair	Poor	
Time elapsed before surgery/days	1-5	8(40%)	3(60%)	5(62.5%)	0	0	0.05*
	6-10	7(35%)	2(40%)	2(25%)	1(50%)	2(40%)	
	11-15	5(25%)	0	1(12.5%)	1(50%)	3(60%)	

Case presentation:

A 55- years old male, manual worker, presented to the emergency room after falling from height with closed Right tibial plateau fracture. AO classification: 41-C1; with no other associated injuries. Oestern and Tscherne classification for soft tissue injury: Grade II; He was operated 10 days until soft tissue condition improved then closed reduction, fixation with Ilizarov, cannulated screws. Fracture united at 16 weeks with an excellent outcome (Figures 5 to 11).

Figure (5):AP and lateral radiographs of the right knee showing tibial plateau fracture type 41-C1.

Figure (6):Intra operative x ray showing fixation by Illizrove and cannulated screws

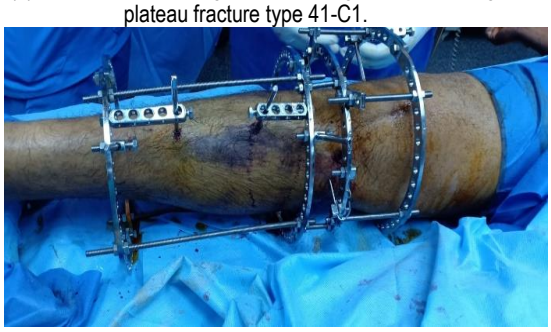

Figure (7): Intra operative photo showing Illizrove frame with femoral extension.

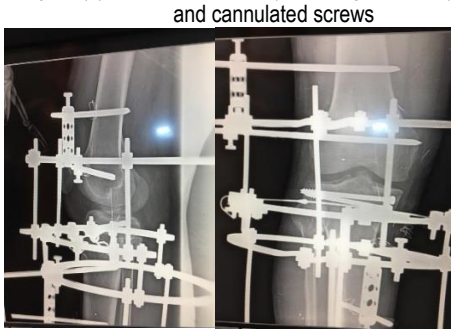

Figure (8):Immediate post operative x rays.

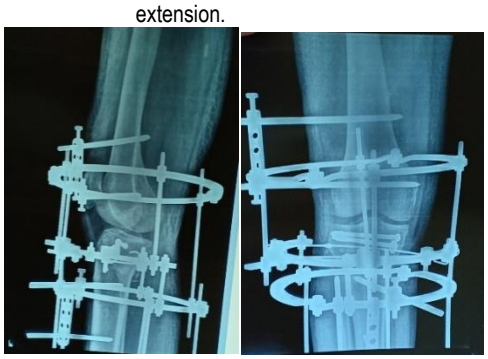

Fig ure(9): 1 month post operative

Figure (10): 3 months post operative (A) patient photo (B) Xray leg AP and lateral viwes

Figure (11): 4months post op. showing fair ROM

DISCUSSION

The management of complex tibial plateau fractures remains problematic and considered to be one of the most challenges in orthopedics. High energy-type fractures are characterized by increased comminution and distinctive fracture patterns compared to the low energy trauma. They are also frequently associated with marked soft tissue damage that requires specific consideration and

that may affect treatment modalities and the outcome [5].

The development of residual morbidity is a common finding after treatment of these injuries. The final outcome affected by many issues that include: the amount of soft tissues injury and damage of the articular cartilage, the precision of reduction, the stability of the knee joint and fixation, and the overall limb alignment. Many treatment methods are available. Conventionally, dual plating was considered to be the best mechanical stabilization method for these fractures, as it reflected the reduction achievement and stability of the medial and lateral columns. Recently, multidirectional screws, less invasive system of fixation and external fixators have been added. However, all of these methods have shown serious complications [6]

Other authors advocated the indirect reduction and external fixation to improve the outcome and to minimize complications resulting from the internal fixation methods. In the past 20 years, the development of devices and surgical procedures of external fixation had led to application of the principles of biologic osteosynthesis and minimally invasive management methods of comminuted proximal tibial fractures, including both intra and extra articular fractures. The surgical methods proposed by Ilizarov is unique by its variable indications and advantages with safe placement of proximal transfixing wires with respect to anatomic neurovascular structures. The development of Ilizarov frame increased the capability of axial compression with dynamization around the fracture site with respect to the associated soft tissue injuries. The development of olive wires has offered new likelihoods to the external fixators for the management of complex fractures [7]

In agreement with the present work, Jahan *et al*. [8] performed a study on 20 patients, 13 Schatzker VI, 5 Schatzker V and 2 Schatzker IV fractures. In addition, there were 4 patients with open fractures and one patient had compartment syndrome. Open fractures were treated in emergency department (ED). Patients who had severe swelling and blisters were postponed for few days and primary fixation by an external hybrid fixator was completed. Early mobilization was permitted for all patients and a minimum duration of one year follow up was completed and documented. Union was achieved for all patients within 4 months, and 95% of patients had range of motion of ≥ 90 degrees. Varus malunion of 10 degrees was seen in 2 patients (10.0%) and 17 patients (85%) had a condylar widening of < 5mm. The ROM at one year after operation was 0 to beyond 90 degrees or more in 19 patients (95%), and 10 patients had a range of 120° or more. Superficial wound infection was reported by two patients, while the infection of pin sites was reported in 3 patients (15%). They were treated by vigorous care of the pin site and did not need change of pins. Deep infection was reported by one patient that need surgical debridement, and antibiotic cement beads. However, there was no modification of the fixator. Septic arthritis, nerve or vessel injuries did not reported. Final outcome was good or excellent (score 80 or more) in 15 patients, while 4 patients had fair outcome and one patient had a poor outcome [6]. n addition, Babis *et al*. [9] performed a study on 33 patients (33 bicondylar tibial plateau fractures admitted and treated by fixation using a hybrid external fixator (Ilizarov and percutaneous screws). Results were excellent (55%), good (30%), fair (12%), and poor (3%). There were no systemic complications. All associated ligamentous and meniscal lesions were repaired at a second setting after fracture healing. All fractures healed within 3.4 months after intervention. The external fixator was completely withstood for the whole treatment duration by all patients. Two fractures (6.0%) need 6 months or more to complete healing. Five patients (15.1%) had at least 1 minor complication such as infection of the pin site, stiffness, mal-union and 1 patient (3.0%) came up with at least one major complication (septic-nonunion and osteomyelitis). A total of 78.8% of patients regained original function of the knee joint, good axis, with no instability or pain. Knee ROM was progressively increased at consecutive clinical assessment visits. Patients were discharged from the hybrid fixator after a mean time of 3.4 months (range 3 - 7 months). At the end of follow-up, the mean ROM was 115° for flexion and 5° lack for extension. Through the radiological follow-up evaluation, early osteoarthritic changes at the knee joint were reported in one patient (3.0%).

Furthermore, Jana *et al.* [10] performed a study on 15 patients were evaluated in a prospective study between 2011 and 2014. There were 13 males and 2 females. The injury was due to motor car accident in all patients. Open fractures were reported by 9 cases, and were categorized as Gustilo-Anderson type-I (2 patients), Type-II (5 patients) and Type-III (2 patients). Six patients had closed fractures (mostly Type I and II Tscherne and Gotzen). All patients with high-energy tibial plateau fractures (either closed or open) were included and treated by hybrid Ilizarov external fixation. All fractures healed with a mean time of treatment of 14.6 weeks. All but two fractures were united within 4 months. However, 11 patients needed additional casting and four patients did not need any other form of supports. In one patient, fracture took > 6 months to heal and 2 patients had infection of the pin track. All infections of pin track healed by regular dressing without need to remove wires. Two patients had united in varus (10°) but was asymptomatic, and one patient required muscle flap and two needed split thickness skin graft for coverage of the soft tissue injury. A total of 14 patients recovered the functional use of the knee joint, without pain or instability with improved quality of daily living. Mean flexion of 110° (range 70-130°) was achieved in all patients at a mean follow-up of 19.4 months. Thigh atrophy of more than 1 cm was reported by only one

patient. On AP X-rays, the varus tilt of 10° was observed in one patient. On lateral x-rays, the plateau tilt of <6° was observed in two patients. Only one patient had a step of <4 mm on the articular surface. Comparing injured with the uninjured knee, the tibial varus tilt was noted in two patients. Condylar widening was observed in 7 patients. The final radiological outcome was excellent (6), good (4), fair (4) and poor (1). Gross *et al*. [11] conducted a study on 40 patients, the rate of deep infection was observed in 2.5%. The union rate was reported for 80%, and the satisfactory reduction was reported in 70% of patients; however, malunion was reported in 52%.

Subramanyam *et al*. [12] reported on 30 cases; the mini-open reduction was achieved in 7, bone graft in 4, minimal internal fixation in 10 and knee temporary immobilization in 11 patients. The mean duration of external fixation was 3 months. All fractures were united. The infection of the pin tract was observed in 7 and common peroneal neuropathy in 2 patients. All were self-limited. Axial malalignment < 10^{o} was reported in two patients. At the end of the follow up period, the mean knee ROM was 114.7. The final outcome being not affected by classification of the fracture, use of minimal internal fixation and knee-spanning. They concluded that, Ilizarov external fixator offers acceptable outcome for complex tibial plateau fractures.

The Canadian Orthopedic Trauma Society [13] demonstrated a trend toward a superior knee ROM in a number of parameters after two years of follow, when compared with open reduction and internal fixation, but the differences were not statistically significant. Finally, Fenglin [14] did a study on 759 case with tibial plateau fractures. That was divided in two groups and found that, the average time to union in the external fixation group was 17.73 ± 4.87 weeks versus 15.64 ± 4.36 weeks with plating group. There were no significant differences between the groups regarding the mean time to union.

In short, the presented study show that hybrid external fixation is a safe and effective method for the treatment of tibial plateau fractures. Reduction of the articular surface, elevation of depression and fixation by percutaneous screws with or without bone graft then fix metaphyseodyapheseal comminution, and restore limb alignment in all planes. Another advantage of hybrid external fixation that it is done totally closed except in some cases when small incision is needed to elevate the articular surface.

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