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Comprehensive Evaluation of Clinical and Radiographic Outcomes in The Correction of Complex Knee Deformities Using The Ilizarov External Fixator: A Multi-Parameter Outcome Study

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ABSTRACT

Background: The natural history of lower limb alignment changes from varus to valgus during development. Therefore, complex knee deformities need adequate clinical examination and radiological assessment to exclude physiological from pathological causes. Management varies from conservative methods to surgical intervention, which include growth modulation or corrective osteotomies. **Objective:** This study aimed to assess functional and radiological outcomes of using distraction histogenesis in managing complex lower limb deformities around the knee.

Patients and methods: A prospective study held between February 2023 and January 2025, presented with coronal plane deviation among associated other plane deformities. Management was done using gradual distraction histogenesis using ilizarov external fixator. Patients were evaluated post-operatively using satisfaction criteria of achieving a mechanical axis through the center of the knee or within Zone 1 as well as the malalignment test.

Results: Our study showed satisfactory results in achieving the previously described correction goals in all cases except for two cases (94.4%) that had residual deformity post-frame removal.

Conclusion: Gradual correction using distraction histogenesis is a safe, accurate tool for achieving precise deformity correction and limb length equalization with the advantage of early weight-bearing, and shorter hospital stays.

Keywords: Complex knee deformities, PC corticotomy, Ilizarov fixator.

INTRODUCTION

Deformity can be defined as any deviation from normal bone or joint anatomy with a variable clinical significance from patient to another. Normal development leads to alteration of lower limb axis from varus to valgus during the early period of growth [(1)]. Limb deformities can be classified according to cause into congenital like tibial hemimelia, developmental like bone dysplasias localized to epiphyseal, physeal, metaphyseal, diaphyseal, idiopathic like tibia vara, metabolic disorders like Rickets or renal osteodystrophy, acquired like post-traumatic, post-infectious and physiologic bowing. Unlike adults, the deformities in skeletal immature children usually progressive due to remaining growth potential [(2, 3)].

When evaluating a deformity patient in order to develop a management plan, many important factors take into considerations not only the radiographs but a detailed history taking, a careful physical examination, adequate laboratory studies and imaging [(4)]. Deformity analysis was done based on the malalignment test and the malorientation test described by Paley and Tetsworth [(5)]. The following steps were discussed in details: Mechanical Axis Deviation MAD, measuring mLDFA MPTA, JLCA angle, ruling out a medial or lateral subluxation, ruling out any intraarticular source of the malalignment [(5)].

Many authors stress that these measurements are only reliable if the X-ray projection is anteroposterior with the knee in the true frontal plane, which is defined as the position where the patella is centered over the femoral condyles irrespective to feet position [(6)].

Several management modalities for treating complex knee deformities from unloading braces to minimally invasive procedure like growth modulation to corrective osteotomy [(7)]. Thus, this study aimed to assess the functional and radiological outcome of using distraction histogenesis in managing complex lower limb deformity around the knee.

PATIENTS AND METHODS

A prospective clinical trial conducted during the period from February 2023 to January 2025.

Sample size: 36 patients with complex coronal plane deformities were admitted to Pediatric Unit, Zagazig University Hospitals. Their ages ranged from 8 to 15, with a mean of 11.9 ± 2.23 years.

Inclusion criteria: Skeletally immature patients of either sex with less than 2 years remaining growth. Severe coronal plane deformity more than 20 degree not amenable for acute correction. Coronal plane deformity associated with other planes deformity either sagittal or axial necessitating gradual correction like LLD. Conditions where internal fixation is limited like, poor skin condition or history of infection.

Exclusion criteria: Cases with mild degree deformity that can be corrected acutely. Skeletally mature patients. Any surgical contraindication like unfit for surgery.

Methods: The clinical data of the patients fulfilling the inclusion criteria were evaluated as follows:

a) Clinical evaluation:

History taking was obtained from the patients or the parents including the date of onset of the deformity, course of the disease and if any previous surgical interventions was done.

- **General examination** was done to detect general features of metabolic, congenital or developmental causes of coronal plane deformities.
- **Local examination** included knee range of motion, knee stability using varus- valgus stress test, drawer test, lateral thrust assessment during walking and leg-length discrepancy using blocks and staheli rotational profile.

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A B C

Figure (1): showing (A) Clinical photo from back (B) Clinical photo from front and (C) prone position with normal tibial torsion.

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b) Radiological evaluation :

The patients had the following radiological examination:

- Long film standing antero-posterior and lateral views of both lower limbs.
- CT scan: If there is associated physeal bar formation.
- MRI: If suspected physeal injury.

C) Laboratory evaluation:

Pre-operative routine investigations:

- Complete blood count.
- Bleeding profile.
- Liver and kidney function tests.
- ESR-CRP: If suspected cases.
- Metabolic profile: Serum levels of calcium, phosphorus, alkaline phosphatase, parathyroid hormone and vitamin D.

d) Surgical technique:

Deformity analysis was done based on the malalignment test and the malorientation test described by Paley and Tetsworth [5], including MAD, mLDFA, MPTA and JLCA[2].

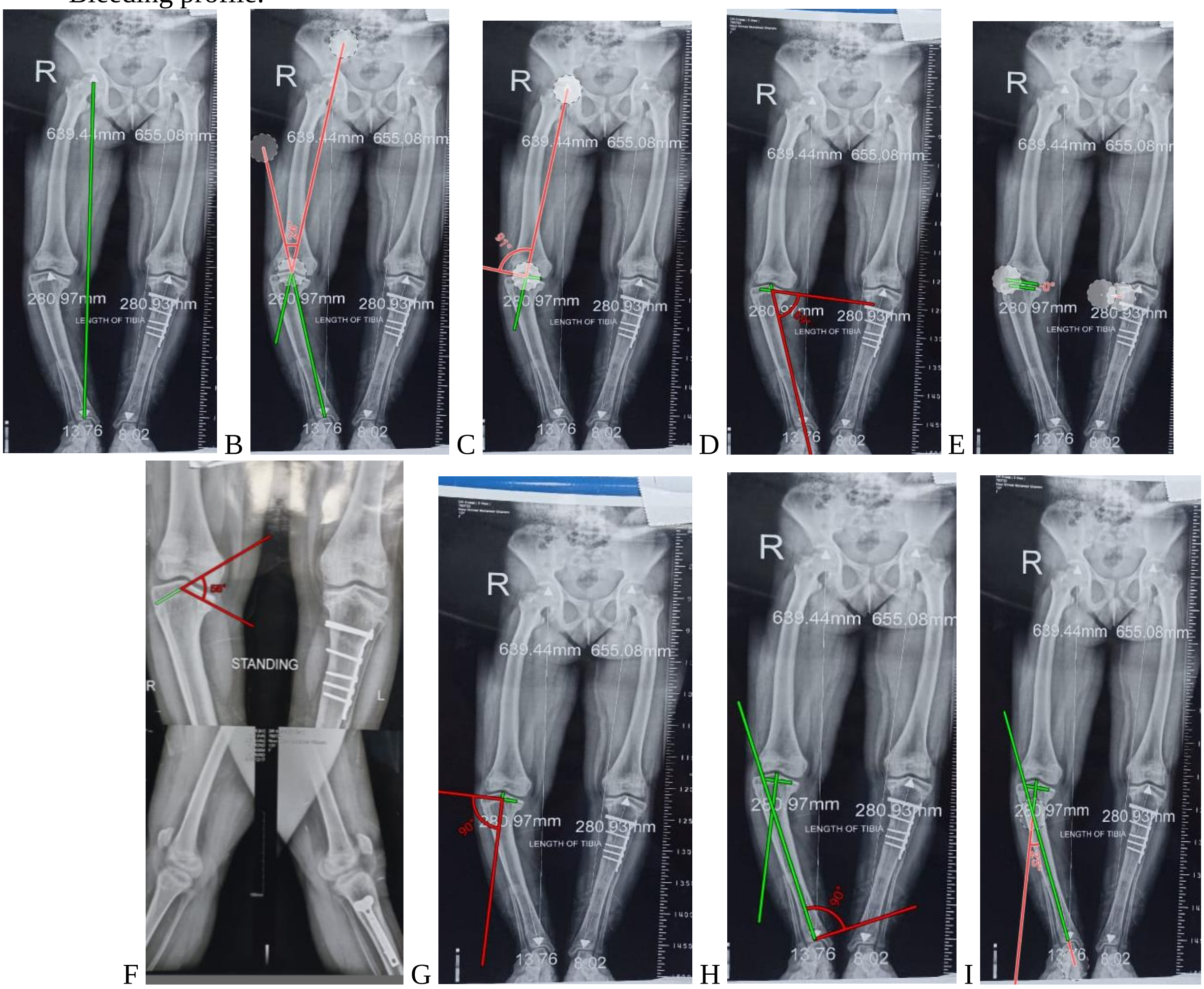

Figure (2): Showing (a) Medial MAD (b) mFTA 26 (c) mLDFA 91 (d) MPTA 69 (e), JLCA 0 (f) medial physeal slope 58 (g)PMA (h)CORA (i) CORA of 25 degree.

Operative procedure:

Double level osteotomy is planned due to significant medial physeal slope angle, therefore long segment fibulectomy is done and used as strut graft to support the elevated medial plateau and distal corticotomy is done for correction of the residual metaphyseal varus. Frame assembly composed of proximal one 5/8 ring and 1 full ring and distal component 2 full rings.

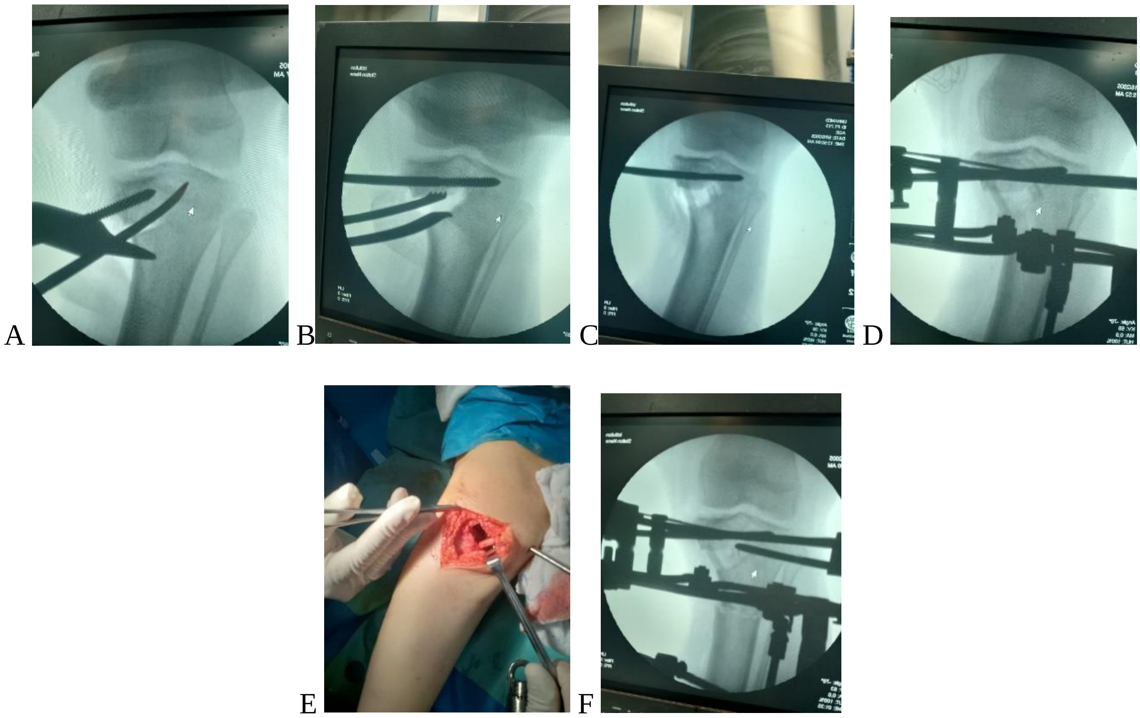

Figure (3): Showing: (a-d) c-arm images of sequential steps of elevating plateau technique (e) intra op image after graft placement (f) c-arm image after metaphyseal corticotomy.

Follow up and final result:

Correction started 10 days post-corticotomy, by lengthening of medial rod only as there is mild leg length discrepancy, restoration of the MA reached early as medial plateau elevation correct most of varus deformity, when apparent correction is achieved long film is ordered demonstrating correction of varus deformity.

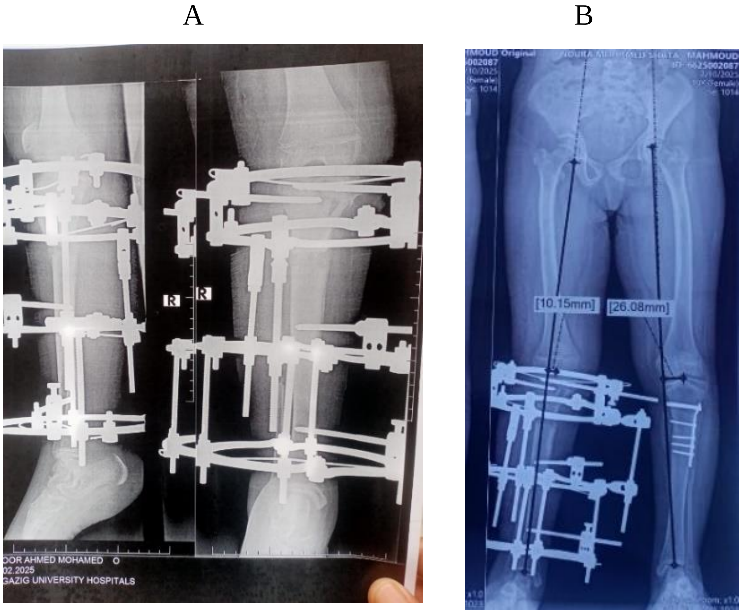

Figure (4): Showing: (a) X-ray image with adequate consolidation and graft incorporation (b) final scanogram.

Ethical approval: Zagazig University Faculty of Medicine's Ethics Committee authorized the study procedure, and the chosen participants provided their prior agreement to take part in the research. The study adhered to the Helsinki Declaration throughout its execution.

Statistical analysis

Data was collected, revised, coded, and entered into the Statistical Package for Social Science (IBM SPSS Statistics for Windows, Version 23.0, IBM Corp., Armonk, NY, USA).

Qualitative data: (n) Number of each observation at each category or order and (%) percentage of the observation to all category or order.

Quantitative data: Mean: sum of the observed values divided by the number of observations, median, which is used for summarization of skewed data because it is insensitive to extreme values. It is the middle observation in a set of observations arranged in ascending or descending order and magnitude. Standard deviation (SD), which is a measure of dispersion and square root of the variance. Inter-quartile range (IQR), which is the range of values that resides in the middle of the scores. Range: the difference between the largest and smallest values. A P value ≤ 0.05 in a two-tailed test signifies a statistically significant result.

RESULTS

This study included 36 skeletally immature patients presented with coronal plane deformities. Their ages ranged from 8 to 15 with a mean of 11.9 ± 2.23 years. 75% were males and 25% were females. 44.4% of the patients had a unilateral deformity and 55.6% had a bilateral deformity.

As regards etiology, the most frequently detected etiology was LOTV, which was detected among 47.2% of the patients, followed by post-traumatic physeal arrest among 13.9% of the patients, hypophosphatemic rickets among 11.1% of the patients, dysplasia and congenital LLD among 8.3% of the patients, while the least frequently detected etiology was ITV and iatrogenic neglected plate which were detected among 5.6% of the patients. **As regards the source of deformity**, the most frequently detected source was the tibia mainly with minor femoral contribution, which was detected among 52.8% of the patients, followed by femur mainly tibia minor which was detected among (27.7%) of the patients. femoral only source detected in (13.9 %) of the patients, while the least frequently detected source was only tibial source detected in (5.6%) of cases. **As regards components of deformity**, the most frequently detected component was multiplanar varus procurvatum ITT, which was detected among 47.2% of the patients, followed by multiplanar varus shortening among 25% of the patients, then multiplanar valgus shortening (22.2), while the least frequently detected component was multiplanar varus ITT among 5.6% of the patients. Also, the duration of deformity before intervention ranged from 2 to 8 with a mean of 3.28 ± 1.85 years.

Pre operative mFTA ranged from 20 to 38 with a mean of 28.86 ± 6.37 degrees, as the varus group had a mean of 31 ± 5.7 and the valgus group had a mean of 23.4 ± 4.62 degrees. 72.2% of the patients had medial MAD and 27.8% had lateral MAD. MPTA ranged from 59 to 93 with a mean of 72.19 ± 12.24, as the varus group had a mean of 72.19 ± 12.24 and the valgus group had a mean of 65.5 ± 6.46. mLDFA ranged from 63 to 112 with a mean of 85.53 ± 12.21, as the varus group had a mean of 92.5 ± 4.82 and the valgus group had a mean of 87.4 ± 3.06. JLCA ranged from 2 to 11 with a mean of 6.69 ± 3.11, as the varus group had a mean of 8.23 ± 2.14 and the valgus group had a mean of 2.7 ± 0.48 (Table 1 and figures 5 & 6).

Table (1): Analysis of components of deformities.

Variables		**All patients (n=36)**
Laterality *(n. %)*	Unilateral	16 (44.4%)
	Bilateral	20 (55.6%)
Etiology *(n. %)*	Post-traumatic physeal arrest*	5 (13.9%)
	Late-onset Tibia Vara	17 (47.2%)
	Infantile tibia Vara*	2 (5.6%)
	Hypophosphatemic rickets	4 (11.1%)
	Dysplasia	3 (8.3%)
	Iatrogenic neglected plate	2 (5.6%)
	Congenital LLD	3 (8.3%)
Source *(n. %)*	Tibia mainly femur minor	19 (52.8%)
	Tibia*	2 (5.6%)
	Femur*	5 (13.9%)
	Femur mainly tibia minor	10 (27.7%)
Components of deformity *(n. %)*	Multiplanar valgus shortening	8 (22.2%)
	Multiplanar varus procurvatum ITT	17 (47.2%)
	Multiplanar varus ITT	2 (5.6%)
	Multiplanar varus shortening	9 (25%)
Deformity duration before intervention	*Mean ± SD*	3.28 ± 1.85
	Range	(2 – 8)

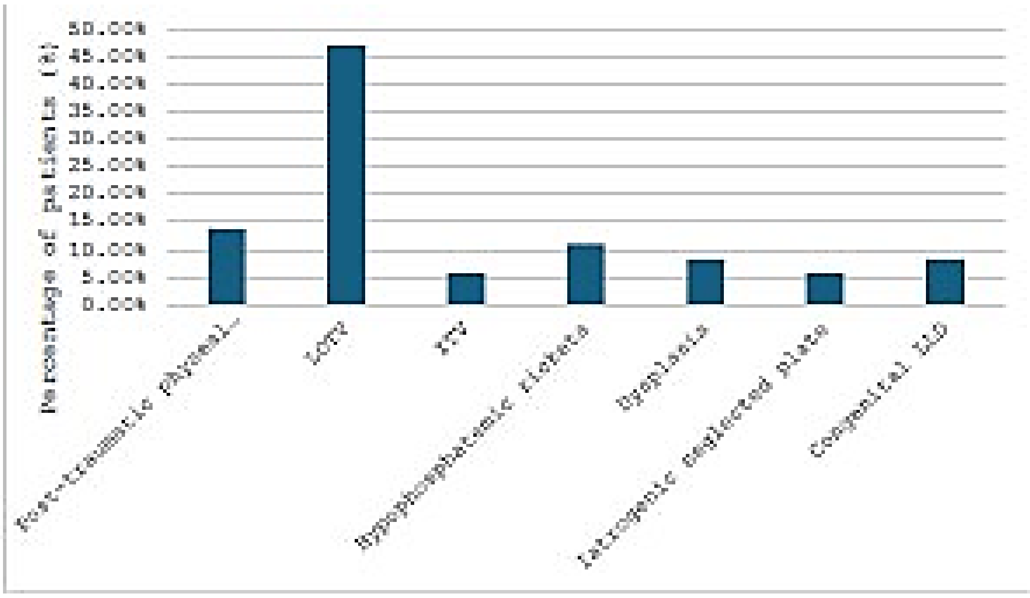

Figure (5): Different etiologies among studied cases.

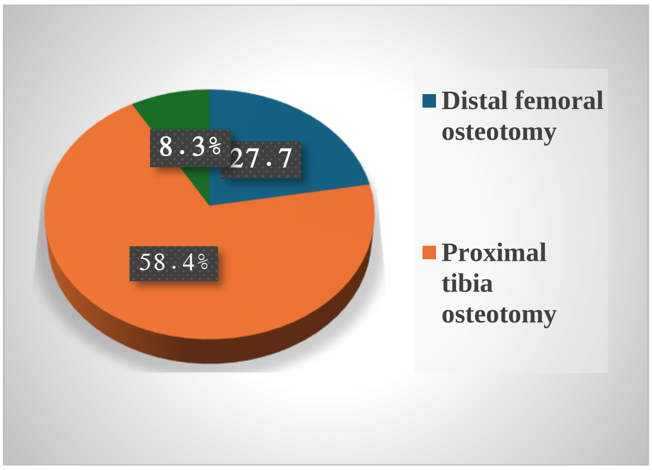

Figure (6): Distribution of osteotomy sites of studied cases.

As regards postoperative mFTA, 30.6% of the patients had zero-degree overcorrection, 25% had 2-degree overcorrection, 33.3% had 3-degree overcorrection and 14.3% had 5-degree overcorrection. ranged from 20 to 38 with a mean of 28.86 ± 6.37 degrees. As 28.6% of the varus group had zero-degree mFTA, 32.1% had 2-degree overcorrection, 25% had 3-degree overcorrection and 14.3% had 5-degree overcorrection. While, 37.5% of the valgus group had zero-degree mFTA and 62.5% had 3-degree overcorrection.

As regards postoperative MAD, 13.8% of the patients had mechanical axis deviation just medial to center, 55.6% had mechanical axis deviation just lateral to center, and 30.6% had central mechanical axis deviation. As 71.4% of the varus group had just lateral to center MAD, and 28.6% had central MAD. While, 62.5% of the valgus group had just medial to center MAD, and 37.5% had central MAD.

Also, **postoperative MPTA** ranged from 88 to 95 with a mean of 92.67 ± 2.74, as the varus group had a mean of 93.9 ± 1.68 and the valgus group had a mean of 89.5 ± 2.42. mLDFA ranged from 85 to 95 with a mean of 91.75 ± 2.47, as the varus group had a mean of 91.6 ± 2.77 and the valgus group had a mean of 92.1 ± 1.45. JLCA ranged from 2 to 3 with a mean of 2.69 ± 0.47, as the varus group had a mean of 2.69 ± 0.47 and the valgus group had a mean of 2.7 ± 0.48.

The most frequently detected complication was pin tract infection, which was detected among all the patients (100%), followed by premature consolidation, joint stiffness and residual deformity among 5.6% of the patients, then fracture regenerate, deep infection and temporary EHL paresis (2.8%), while none of the patients had wire loosening or breakage.

DISCUSSION

This study aimed to evaluate the outcomes of managing patients with coronal plane deformities through distraction osteogenesis using the Ilizarov external fixator, and to assess the accuracy of deformity correction. The criteria for satisfaction included achieving a mechanical axis through the center of the knee or within Zone 1 as well as the malalignment test described by **Paley *et al.*** **[2]**.

This study included 36 skeletally immature patients with severe coronal plane deformities. Their ages ranged from 8 to 15 with a mean of 11.9 ± 2.23 years. 75% of the patients were males, and 25% were females. Of the patients, 44.4% had a unilateral deformity, while 55.6% had a bilateral deformity. Regarding etiology, the most common cause was late onset tibia vara (LOTV), which was identified in 47.2% of the patients, followed by post-traumatic physeal arrest in 13.9%, hypophosphatemic rickets in 11.1%, then dysplasia and congenital leg length discrepancy (LLD) in 8.3%. The least frequent etiologies were infantile tibia vara (ITV) and iatrogenic neglected plate where both were detected in 5.6% of the patients. The data from our study are consistent with those reported by **Manner*et al.*** **[8]** who described deformity correction and limb lengthening using distraction osteogenesis, either with the Ilizarov frame or the Taylor Spatial Frame (TSF). Their study included patients with a range of etiologies, including congenital, developmental, and acquired deformities, and they reported successful correction in both simple and complex cases, from single-plane deformities to multiplanar deformities. **Horn *et al.*** [(9)] also reported comparable demographic data in terms of age and sex, including patients with diverse etiologies. Their study, however, involved a significantly larger sample size of 192 cases, all treated based on the same principle of distraction osteogenesis.

Our study involved 28 procedures aimed at correcting varus deformities, with angular deviations ranging from 22° to 38°, along with axial deviations and limb lengthening. Additionally, 8 procedures were performed to correct valgus deformities, with angular deviations ranging from 20° to 30°, also incorporating lengthening. These severe parameters are similar to those reported by **Horn *et al.*** [(9)]**,** who utilized external fixators to address coronal deformities of varying degrees, including mild, moderate, and severe cases. In their study, the deformity parameters included valgus of 11° (ranging from 5° to 35°) and varus of 16° (ranging from 5° to 35°). Similarly, **Eidelman *et al.*** [(10)]**.**

Our study involved 36 cases with complex multiplanar deformities. The analysis focused on the coronal plane component for deformity planning and results. Of the 36 patients, 28 (77.8%) had varus deformity (medial MAD), with mFTA ranging from 22° to 38° (mean: 31 ± 5.7), MPTA ranging from 59° to 89° (mean: 65.5 ± 6.46), mLDFA ranging from 85° to 112° (mean: 92.5 ± 4.82) and JLCA ranging from 3° to 11° (mean: 6.69 ± 3.11). Additionally, 8 cases of valgus deformity (lateral MAD) were observed, with mFTA ranging from 20° to 30°, mLDFA ranging from 63° to 70° (mean: 67.4 ± 3.06) and mPTA ranging from 88° to 93° (mean: 89.5 ± 2.42). Neutral MAD was achieved in 11 (30.6%) cases, while the remaining 25 cases (69.4%) were re-aligned within a 5° overcorrection. In the varus group, realignment improved MPTA from a mean of 65.5 ± 6.46 (range 59° to 89°) to 93.9 ± 1.68 (range 90° to 95°), mLDFA improved from 92.5 ± 4.82 (range 85° to 112°), and JLCA improved from 6.69 ± 3.11 (range 3° to 11°) to 2.69 ± 0.47 (range 2° to 3°). In the valgus group, re-alignment of mLDFA improved from a mean of 67.4° to 92.1°, with no significant change in MPTA or JLCA, as all cases of valgus deformity were of femoral origin. The findings of our study are consistent with **Eidelman *et al.*** [(10)] where the mean preoperative MPTA was 71.4° (range 67° to 77°), which was corrected to a mean of 87.1° (range 85° to 89°) (100). Similarly, **Manner *et al.*** [(8)] reported correction of 43 cases of coronal plane deformity, with a mean of 14.5° (range 2° to 53°), to neutral or within 5° overcorrection using the Ilizarov frame. Similarly, **Solomin *et al.*** [(11)] used the Ilizarov frame to correct femoral deformities with a mean frontal angulation of 18° and an mLDFA of 79.9 ± 2.95 (range 71° to 84°), which improved postoperatively to a mean of 87.6° (range 84° to 92°). Similarly, **McCarthy *et al.*** [(12)] reported correction of coronal plane deformities of tibial origin, with a preoperative mean MPTA of 59.98°, which improved to a postoperative mean of 87.88°. The preoperative TFA was 25.28° of varus, which improved to 4.88° of valgus postoperatively, representing a 5° overcorrection. **Donnan *et al.*** [(13)] achieved correction of valgus deformity with a mean of 14° (range 7° to 25°) and varus deformity with a mean of 21° (range 10° to 45°) using a monolateral external fixator. Similarly, **Lim *et al.*** [(14)] reported comparable results in managing coronal plane deformities of tibial origin using an external fixator. In their study, MPTA improved from a preoperative mean of 73° (range 66° to 78°) to a mean of 90° in the varus tibiae group, and from 104° (range 103° to 105°) to 89° (range 88° to 89°) in the valgus tibiae group.

Regarding the final outcome, the criteria for satisfaction included the restoration of the mechanical axis through the middle of the knee within Zone 1as **Stevens *et al.*** [(15)] in the review of the literature revealed that significant regenerate subsidence with recurrent deformity can occur after distraction osteogenesis. Therefore, the goal of deformity correction was to achieve either a normal MAD or an intended overcorrection of up to 5° in selected cases, particularly in those requiring deformity correction plus lengthening procedures. As a result, 5° of intended overcorrection is considered a satisfactory result [(8, 9)].

Our study reports satisfactory results in achieving the previously described correction goals in all cases, except for two cases (94.4%) that had residual deformity post-frame removal, manifested as leg length discrepancy. The lengthening had to be stopped due to intolerable pain, however the coronal deviation was corrected. These findings are consistent with those reported by **Manner *et al.*** [(8)] who used distraction osteogenesis for gradual deformity correction with the TSF external fixator. Similarly, **Horn *et al.*** [(9)] also reported satisfactory outcomes in nearly all cases, except for three patients who had residual deformity post-frame removal. Lengthening procedures were performed in 17 cases, involving either tibial or femoral shortening. The bone healing index ranged from 40 to 45.7 days/cm, with a mean of 41.8 ± 2.73. **McCarthy *et al.*** [(12)] reported a mean healing index of 42 days/cm. While, **Tsuchiya *et al.*** [(16)] reported a similar bone healing index of 42.6 ± 4.6 days/cm.

We reported a complication rate of 19.5% occurred in 7 cases, excluding pin tract infections, which occurred in 100% of cases. This is similar to **McCarthy *et al.*** [(12)] who reported a complication rate of 20%. All cases improved with daily pin care, including the use of normal saline, cotton swabs, and local antibiotics. Local antibiotics, however, caused skin reactions in many cases, prompting us to discontinue their use. Only one case developed a deep surgical site infection at the corticotomy site, which resolved with IV antibiotics. This infection was likely related to the underlying etiology, as the case involved a neglected 8-plate with bone overgrowth, which required time-consuming and aggressive maneuvers during plate removal. Additionally, this patient had poor compliance with follow-up visits and frame hygiene. **Horn *et al.*** [9] reported that nearly all cases, whether of congenital or acquired origin, developed superficial pin tract infections that resolved with daily dressing and oral antibiotics. Only one case required drainage and IV antibiotics for a deep infection. Despite the high incidence of pin tract infection, no wire loosening or breakage occurred in their study.

Regarding neurovascular compromise, none of the cases in our study developed vascular insult or compartmental syndrome. Only one case developed temporary EHL (extensor hallucis longus) paresis, which resolved at the 8-week follow-up. **McCarthy *et al.*** [12] reported no neurovascular complications in his study. **Othman *et al.*** [17] also reported a case of temporary EHL paresis in their study, which resolved with conservative treatment. **Rozbruch *et al.*** [18] reported that 1.9% of cases developed common peroneal nerve affection, which resolved after a slow rate of correction. The main complaint in our patients was deformity and an awkward gait. There was no limitation in range of motion (ROM) preoperatively or postoperatively at the final follow-up visit, except in 2 cases that developed knee stiffness with limited flexion range due to long segment lengthening < 3cm in dysplastic bone (PFFD) those 2 cases required mini-open release.

Regarding residual deformity, only two cases had residual leg length discrepancy post-frame removal, despite restoration of coronal malalignment. Lengthening was stopped due to pain intolerance and knee joint stiffness. Both cases were of femoral origin one being congenital limb length discrepancy (LLD) and the other resulting from post-traumatic physeal injury. **McCarthy *et al.*** [12] reported one case (3.8%) of residual deformity in the form of varus malalignment.

Regarding regenerate fractures, McCarthy reported no fractures in his study. However, **Fadel *et al.*** [19] reported regenerate fractures in 2 cases (9.1%) due to early frame removal before achieving mature consolidation. One case of regenerate fracture occurred in our study at 1.5 months post-frame removal. This patient had poor quality regeneration, likely due to early frame removal without adequate consolidation plus simple frame application with PC gigli saw corticotomy. This patient was readmitted to emergency unit, where the frame was reapplied and an acute correction of deformity was performed, post-operative long film was required showing residual varus, which was gradually corrected, by the end of follow up. The patient showed adequate bone consolidation with no residual deformity or joint stiffness.

CONCLUSION

This study highlighted several important advantages of using the Ilizarov external fixator for the gradual correction of coronal plane deformities. The Ilizarov method allows for accurate deformity correction, limb length equalization, and provided the flexibility to make adjustments during the correction process. The stability of the fixator also enabled early weight-bearing, contributing to shorter hospital stays. Furthermore, the gradual correction approach appeared to reduce the risk of neurovascular complications and compartment syndrome, which are more commonly associated with acute corrections.

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