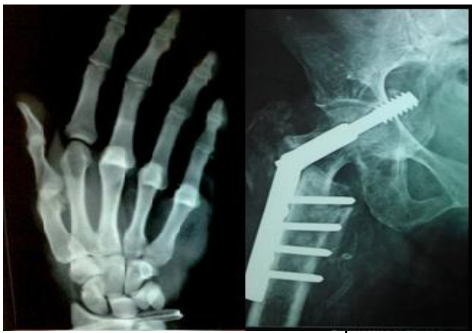

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Post-physeal deformity around the ankle treated by acute or gradual correction

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Abstract

Introduction: Post traumatic distal tibial deformities can cause long term complications. Type 3,4,&5 Salter harris physeal injuries have higher propensity for deformities and limb length discrepancy. Furthermore, altered mechanical alignment in these patients can lead to arthritis in adjacent joints. Management options are varied from acute correction using internal fixation to gradual correction using ringed external fixators. In this study we have detailed the outcomes of patients with post-physeal injury deformity around the ankle treated by acutre and gradual correction.

Methodology: Fifteen patients with fractures involving the distal tibial epiphysis injury and deformity, presenting at Government medical college, Kozhikode, Kerala, India between 2010 and2018, were reviewed. All patients in age group of 5 to 15 years**,** both males and females, varus and valgus deformity of the ankle were included. Demographic data and hospital records were obtained, radiological records were taken from the patients at subsequent follow-ups at union and 2 years from last surgery.

Results: There were nine boys and six girls with an average age at presentation of deformity was 14+ 0.528 years (range 9–15) years. 10 injuries were low energy type (sports/Running/slip and fall), while five were high energy type (motor vehicle accidents).Average duration of follow-up was 3.933 + 0.566 years with a range 2-10 years. Gradual correction of the deformity was done in 11 cases using a circular external fixator with hinges while acute correction was done in 4 cases. Average pre-operative deformity of the ankle was 30.4+7.17 degrees. Range -20 to 40 degrees (20 degrees). AOFAS was used to assess the improvement in the functionality of the ankle. The average improvement in the ankle score was 18 points after surgery. There was no significant difference between the varus and valgus ankles. On analysis of pre-operative and post-operative deformity, higher correction was achieved in varus ankles (27.11 degrees- p value-0.00087) as compared to average correction of 21.17 degrees (p value-0.0004) in Valgus ankles.

Conclusion: From our study we concluded that Salter harris 3 and 4 have higher propensity for physeal bar formation, greater degree of deformity and limb length discrepancy. In case of gross deformities (>20degrees) gradual correction with an Ilizarov has better clinical, functional and radiological outcomes. In case of smaller deformities (<20 degrees) internal and external fixation gives equivocal results. In management of pediatric ankle deformity, principles of deformity correction have to be followed irrespective of internal or external fixation, acute or gradual correction.

Keywords: Post-physeal, gradual correction, ankle

Introduction

Distal tibia is the most common location for type 3 and 4 salter harris physeal fracture. It is among the most common physeal injuries after distal radius in pediatric population. These fractures may lead to growth arrest with resultant angular deformity or limb-length discrepancy (LLD). Several treatments have been tried excision of physeal bar, osteotomy, or epiphyseodesis [1-4]. Here we discuss our results of patients with post traumatic ankle deformity of distal tibia treated by supramalleolar osteotomy with acute and gradual correction and having a follow-up of atleast 2 years.

Methodology

Fifteen patients with fractures involving the distal tibial epiphysis injury and deformity, presenting at Government medical college, Kozhikode, Kerala, India between 2010 and 2018,

were reviewed. All patients in age group of 5 to 15 years**,** both males and females, varus and valgus deformity of the ankle were included. Demographic data and hospital records were obtained, radiological records were taken from the patients at subsequent follow-ups at union and 2 years from last surgery.
Patients with multiple segmental fractures, previous surgeries, history of infection at the fracture site were all included from the study. Every patient's clinical chart, and every X-ray and/or CT scan was reviewed. Demographic data, the type of injury, diagnostic and therapeutic procedures and the follow-up treatment were reviewed by hospital records. All fractures were classified according to the Salter Harris Classification: I, epiphyseal separation; II, epiphyseal separation and metaphyseal fracture; III, epiphyseal separation and epiphyseal fracture; IV, epimetaphyseal fracture; and V, crush injury. Assessment of normal limb alignment was done. Malalignment test were performed in all cases. CORA (Center of rotation and angulation) was identified and deformity correction planned. Correction method was chosen depending on the site of the deformity, magnitude of the deformity, soft tissue status, neurovascular status, associated problems co-morbidities, age and patient compliance.
The decision to go for an acute or gradual correction was decided based on the preoperative deformity, the local soft tissue status, compliance of the child to wearing the external fixator. Subjective and functional evaluations with parameters of pain, activity, range of motion, and leg length discrepancy were done. American Orthopaedic Foot and Ankle Society (AOFAS) was used to assess the clinical improvement. Radiographic evaluation included antero-posterior (AP), lateral views of the joints both pre and post operatively evaluated to ascertain the correction achieved. Magnetic resonance imaging (MRI), was used to do the physeal mapping and to assess the extent of physeal injury, presence and location of physeal bar. This also helped in the planning of the incision as well need for fat transposition pre-operatively.
The American Orthopaedic Foot and Ankle Society (AOFAS) Score is a clinical rating system, developed by Kitaoka *et al.* which combines subjective scores of pain and function provided by the patient with objective scores based on the surgeon's physical examination of the patient (to assess sagittal motion, stability and alignment). The scale includes nine items that can be divided into three subscales (pain, function and alignment). Pain consists of one item with a maximal score of 40 points, indicating no pain. Function consists of seven items with a maximal score of 50 points, indicating full function. Alignment consists of one item with a maximal score of 10 points, indicating good alignment. The maximal score is 100 points, indicating no symptoms or impairments. This scoring system has been used to analyse the outcomes of ankle replacement, ankle arthrodesis, ankle instability operations, subtalar arthrodesis, subtalar instability operations, talonavicular arthrodesis, calcaneocuboid arthrodesis, calcaneal osteotomy, calcaneus fracture, talus fracture and ankle fractures [5].

Pre-operative planning
Surgical planning in all cases began with a complete history and thorough clinical examination. Evaluation included limb length discrepancy, stability and range of movement of of knee and ankle were assessed. Assessment of skin and soft tissue in ankle and distal tibia was done. The surgical approach and incision was planned according to the previous scar and soft tissue flap condition. For planning the corrective osteotomy with ilizarov a standing full-length x ray both AP and Lateral view was taken. Malalignment test was done and CORA (Center of rotation and angulation) was found. corticotomy was done at the CORA or just above so that to reduce the translation to as minimum as possible that is Osteotomy rule number one. Osteotomy direction was decided on the basis of preoperative planning in a such a way that it won't interfere with the correction, as well as there wont be any undue prominenence on the bone or spikes impinging on the soft tissues. A humpectomy (removal of step formed following large deformity correction and involved translation) was performed for any bumps that developed on the medial side so as to prevent the skin stretching,tenting and pain. All the simulations of osteotomy including the level, direction, alteration of the alignment were pre-operatively analysed using the Bone Ninja^{TM} application for better understanding of the deformity and avoiding intra-operative mistakes.

Acute correction with plate
In acute correction, wedge of bone is removed either from medial or lateral side depends on varus or valgus deformity. The approach commonly used is universal ankle approach which is extended to anterolateral approach to tibia. In order to avoid skin necrosis a thick flap including the periosteum was elevated.
A medial closing wedge osteotomy was done in case of valgus deformity and a low profile lower tibial locking plate was applied on the medial side. The plate was applied on the medial side in case valgus deformity. The first screw was applied parallel to the joint in the epiphysis and rest screws were applied after correcting the deformity and as confirmed by C arm and also by cautery cord test ie. Clinical assessment of mechanical axis from hip to ankle using a cautery wire.
In case of varus deformity a medial opening wedge was applied with plate on medial side. No additional bone grafting was done. Only in condition where medial skin and soft tissue was compromised a lateral pate was preferred.

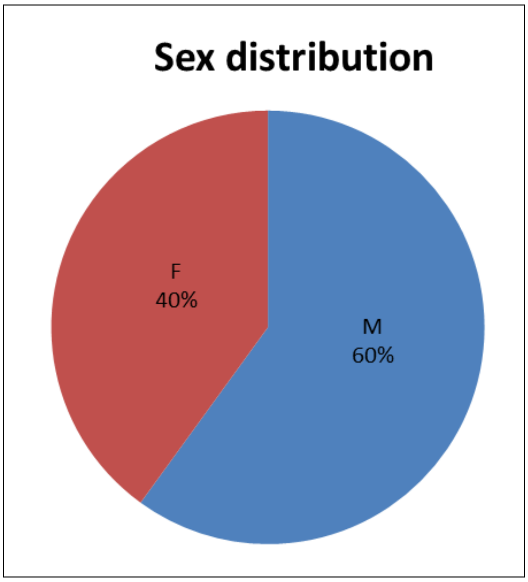
Gradual correction using ringed external fixator
Gradual correction with ringed external fixator requires considerable surgical skill and pre-operative planning. A three ring preconstructed frame with hinge between the distal and middle ring was made on the preoperative day. First a proximal tibial ring block is applied with a 1.8 mm wire being parallel to the knee joint line. A distal tibia ring was fixed with two or three tensioned 1.8 mm wires parallel to the ankle joint and an anteromedial half-pin was added to increase the stability. A percutaneous osteotomy of the distal tibia was done at the CORA along with a fibulectomy at the middle third distal third junction and gradual correction of the deformity was done. An additional 5/8th calcaneal ring or foot plate was used in cases which needed additional stability or correction of the hind foot deformity. Hinges were placed at the axis of the ankle. The hinge position in all gradual correction cases were kept at the convex border in the bisector line or away from the convex border along the bisector line in case lengthening was required. A motor was placed perpendicular to the hinge axis. Gradual distraction was started on 8th day. Once the deformity was corrected the hinges were replaced by straight rods. Full weight bearing was started once the deformity was optimally corrected and hinges were replaced by straight rods. After that every 3 weeks follow up was done. Once osteotomy site was united, usually after 3-4 months, rings were removed on the OPD

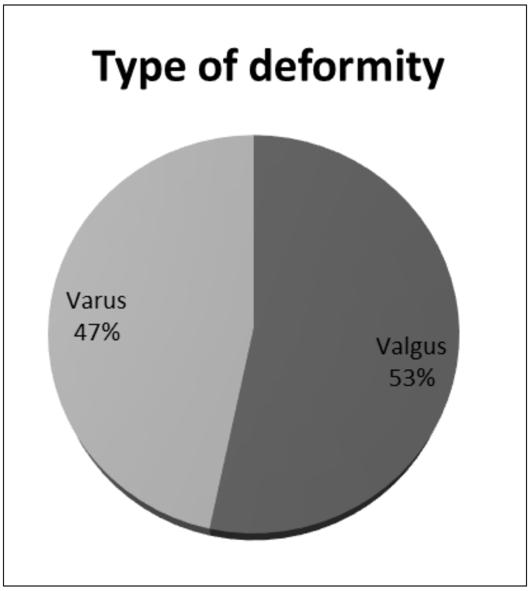
basis. After the fixator removal patient was mobilized with a below knee walking brace.

Results

Outcomes 15 patients were analysed. 12 patients were treated by conservative management with a plaster cast while 3 patients had received operative treatment after the initial trauma. It was treated with closed reduction and fixation using k wires in all the three cases.

There were nine boys and six girls with an average age at presentation of deformity was 14+ 0.528 years (range 9–15) years. 10 injuries were low energy type (sports/Running/slip and fall), while five were high energy type (motor vehicle accidents). Average duration of follow-up was 3.933 + 0.566 years with a range 2-10 years. Gradual correction of the deformity was done in 11 cases using an circular external fixator with hinges while acute correction was done in 4 cases.





Average pre-operative deformity of the ankle was 30.4+7.17 degrees. Range -20 to 40 degrees (20 degrees).

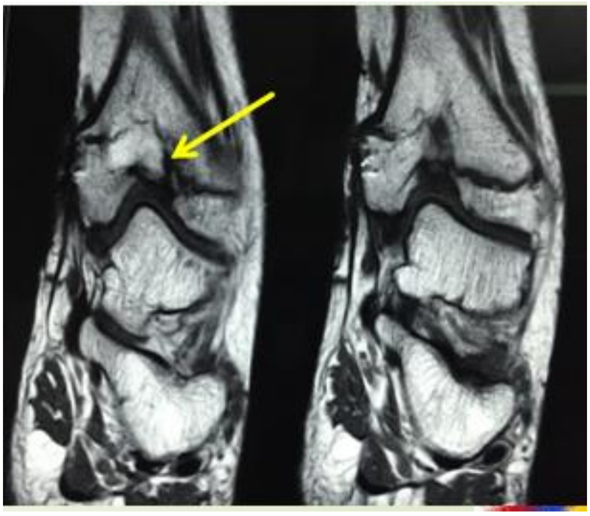
Analysis of data was done using the Paired t test for with degree of deformity correction, ankle foot score, improvement in range of movements as the end points. On analysis of pre-operative and post-operative deformity, higher correction was achieved in varus ankles (27.11 degrees- p value-0.00087) as compared to average correction of 21.17 degrees (p value-0.0004) in Valgus ankles.

AOFAS was used to assess the improvement in the functionality of the ankle. The average improvement in the ankle score was 18 points after surgery. There was no significant difference between the varus and valgus ankles. Average preoperative shortening was 1.36 + 0.21 cm which was corrected fully in 10 patients

Case 1 :13 year old boy with post traumatic ankle varus deformity one year following conservative management of Type 4 S/H epiphyseal injury to the ankle.

a) Standing view of ankle showing varus deformity with restriction of dorsiflexion

b) Weight bearing radiograph showing angular deformity of distal tibia and fibula with CORA (Center of rotation and angulation) at the physis



c) MRI showing physeal bar (Yellow).

d) Intra-operative pictures of fixator application and osteotomy.

Fig 1: 13 year old boy with post traumatic ankle varus deformity

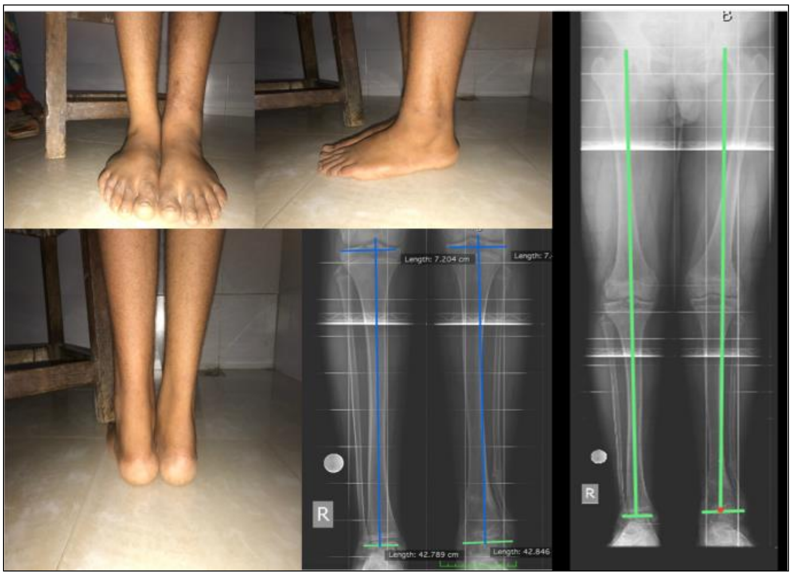


Fig 2: Post-operative patient status showing corrected mechanical axis and clinically acceptable plantigrade foot.

Case 2: 10 year old child with post-traumatic valgus deformity of the ankle following a Type 3 S/H epiphyseal injury to the ankle two years ago.

Fig 3: Standing weight bearing Clinical alignment showing valgus deformity of ankle (20 degrees)

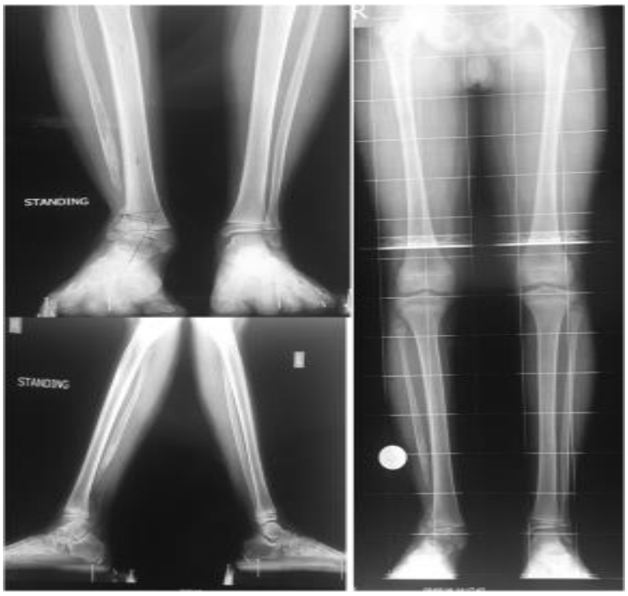


Fig 4: Plain radiographs showing the altered mechanical alignment.

Fig 5: Intra-operative pictures showing the site of osteotomy and acute correction of deformity with stabilization using a locking low profile medial distal tibial plate.

Fig 6: Post-operative picture showing the corrected alignment.

Table 1. Master Chart

Patient no	Age (yrs) at presentation with the deformity	Duration of follow-up	Type of Epiphyseal injury(S/H)	Conservative /Operative	sex	Clinical evaluation: Deformity (Pre-op)	Deformity (Postop)	ROM (Dorsi Flex) Pre	ROM (Dorsi Flex) Post	ROM (Plantar flex) Pre	ROM (Plantar flex) Post	Radiological evaluation: M LDTA	MAD (Pre-Post)	LLD Pre-op	LLD Post-op	AF score (pre-post)
1	13	3	4	Conservative	M	Varus 40	Neutral 0	30	40	40	40	128	5	2.5	0	20
2	10	2	3	Conservative	M	Valgus 20	Valgus (5^0)	26	40	38	40	68	4	1	0.5	18
3	15	4	4	Conservative	M	Varus (30)	Neutral	20	38	40	40	122	0	1.5	0	20
4	14	2	4	Conservative	M	Valgus (40)	Valgus -30	24	45	45	45	52	4	1.5	0	14
5	13	5	3	Conservative	M	Varus (32)	Varus (7)	0	30	36	36	125	3	1.5	1	16
6	16	2	3	operative	F	Varus (40)	Varus (10)	10	32	30	30	129	6	2	1	18
7	11	7	2	Conservative	F	Valgus (22)	Valgus (12)	26	32	40	40	66	3	0.5	0	10
8	14	2	4	Conservative	F	Varus (20)	Varus (11)	30	34	40	40	108	4	1.5	0.5	14
9	12	3	3	Conservative	M	Valgus (26)	Valgus (13)	32	30	30	30	64	3	1	0	18
10	15	2.5	2	Operative	F	Valgus (36)	Valgus (3)	40	30	45	45	53	4	2	0	20
11	10	3.5	2	Operative	M	Varus (38)	Varus (8)	10	32	38	40	128	5	2.5	0	24
12	13	5	2	Conservative	M	Valgus (28)	Valgus (7)	30	32	40	40	64	4	1	0	16
13	13	4	3	Conservative	M	Valgus (30)	Valgus (4)	28	38	45	45	60	3	2	1	16
14	14	4	4	Conservative	F	Valgus (30)	Valgus (6)	34	38	38	40	58	4	1	0.5	18
15	9	10	3	Conservative	F	Varus (24)	Varus (12)	16	32	40	40	114	3	1	0	12

Discussion

Although rare, distal tibial physeal injuries are prone to long term complications including growth arrest, tibial shortening, rotational malalignment, ankle instability and in turn early osteoarthritis of ankle.

Physeal injury leading to growth plate arrest can be a devastating complication unless appropriately managed, which can be treated conservatively and operatively. They include shoe lifts, knee-ankle foot orthosis, excision of the bone bridge, leg lengthening, contra and ipsilateral epiphysiodesis, corrective osteotomies [6, 7].

Pre-mature growth arrest can be partial or complete depending on the presence and extent of physeal bar.Physeal bar may be defined as the bony bridge between the epiphysis and metaphysis through a breach in the physis. Physeal bar formation may begin as early as 1month post injury but its clinical outcomes may not be evident until years later.

Certain regions in the body are prone to physeal arrest that includes distal tibia and distal femur.This is probably due to the presence of undulating physis which gets unevenly injured. Its presence in distal tibia is usually at the anteromedial physis and is known as klump's bump. It is theorized that injury to the germinal and proliferative zones of the growth plate occurs at these undulations. Other factors to consider include the age of the child, the type of injury, the force of injury, compression, displacement, and infolding of the periosteum [8, 9].

The most common injuries to the distal tibial physis are caused by an adduction trauma of the ankle in 60.9%, followed by abduction in 14.6%, external rotation in 13%, and plantar flexion in 11.5% [10].

Limb length discrepancy following damage to the physis is occasionally due to an overgrowth noted in the involved leg. This phenomenon has been postulated to be secondary to indiscriminate stimulation of all physeal plates of the extremity due to increased blood perfusion leading to leg length discrepancy [11-12].

Although hyperemia has been thought to be the cause of longitudinal deformity, angular adaptations have not been well explained. When adaptive, the changes may be described by the Heuter-Volkmann's law, which states that physeal structures respond to excessive compressive forces by increased activity and to tensile forces by decreasing activity.

Progression of deformity

Several factors influence the outcome of a physeal injury. Kling *et al.* found that younger patients had the greatest chance of developing a growth disturbance. These patients have a longer period of growth remaining which increases the potential for deformity. Fractures requiring multiple attempts at reduction or grossly displaced fractures are at higher risk of growth arrest [13].

Several previous studies compared growth arrest in patients treated with closed or open reduction. They found a higher rate of growth disturbance with closed treatment. They recommended open anatomic reduction in all cases. No gap or rotational displacement should be accepted because of the propensity for growth arrest. Multiple attempts at closed reduction are to be avoided as they can extend the cartilage breach prompting physeal bar formation and worsening the outcome [14-16]. Hynes and O'Brien *et al.* suggested using growth disturbance lines to predict the function of the distal tibial physis after injury. They found that focal defects or change in alignment of growth disturbance lines may indicate growth impairment. They concluded these lines may be used to plan for surgery before deformity occurs, since they appear as early as 3 months after injury [17].

Physeal injury deformity can be a result of the traumatic event itself or due to the management technique, both in cases managed by conservative and operative management. Improper reduction, soft tissue interposition within the fracture site, displacement within plaster cast can be all cause loss of alignment and progression to deformity.

According to de Sanctis *et al.*, growth disturbance can be caused by the use of inadequate surgical fixation. The risk of physeal damage with a smooth wire (Kirschner wire) of appropriate size are minimal as compared with the insertion of a screw near a proliferative layer of physis, which may cause growth arrest [18].

Cottalorda believes that type 3 and 4 physeal injuries which are intra-articular demand anatomical reduction and compression which is better achieved using lag screwa. To achieve anatomical reduction his team used an epiphyseal lag screw for cancellous bone to achieve better compression of the fracture line. They showed that risk of iatrogenic physeal injury is very low if the surgery is done under C-arm guidance. Their results demonstrated that open anatomical reduction with realignment of the physis can result in continued longitudinal growth without deformity. In their study the long term outcomes suggested that open reduction as a safe procedure for type 3 and 4 epiphyseal injuries. Consequently larger the fracture gap, the bigger the bone bridge. Therefore, displaced type III and IV Salter-Harris fractures require an early anatomical reduction by closed or open means [19].

We observed that the risk of complication is higher in Salter-Harris type Ill and IV lesions, in accordance with other previous report. [20-23]

Physeal bar mapping

Magnetic resonanace imaging (MRI) is an ideal imaging study to assess growth arrests. T1-weighted images reveal growth recovery lines and large physeal bridges that have high signal intensity. Smaller bridges have variable signal intensity. Intermediate and T2-weighted images demonstrate the cartilage extensions from the growth plate into the metaphysis, which are common after physeal injury. In gradient-recalled images, bone bridges are seen as low-signal-intensity interruptions in the high-signal-intensity physeal cartilage (24-25). In all our cases the resection of physeal bar was done along with fat interposition.

Physeal bar resection

Treatment options in physeal bar are bar resection, epiphysiodesis, lengthening, deformity correction or combination of these.

Lalandle *et al.* [26] insisted on bar excision if there was a partial physeal arrest. They proceeded with an ipsilateral epiphysiodesis of the tibia and fibula if the patient was near the end of his or her growth. They also stated that if a child still has any great degree of growth to attain and the leg-length discrepancy is predicted to exceed 5 cm, leg lengthening with an external fixator or an intramedullary device must be considered. Finally, if the angular deformity is clinically significant, supramalleolar osteotomy can be performed for angular correction. According to Langenskiöld's original article, at least a year of growth should remain if resection of a bony bar is attempted. Optimal correction results when two years of expected longitudinal growth remains and when the physeal bridge involves less than 50% of the growth plate area [27].

Acute vs gradual correction of deformities

The surgical principle of attaining the correction and maintaining it applicable not just for fractures but also for all deformities. Acute correction of deformity has been followed for more than half a century starting from a wedge correction of a cast to open reduction, wedge resection and internal fixation of complex deformities.

But with the advent of Ilizarov technique and better understanding of deformity correction principles there is a gradual shift towards gradual correction for complex deformities.

In the majority of our cases we preferred gradual correction using Ilizarov as a method of treatment. This was done especially in large deformities (>20 degrees) with limb length discrepancy. The advantages of using Ilizarov for deformity correction includes its minimally invasive technique especially in patients with multiple previous procedures and scar tissue, no resection of bone is required hence anatomical correction can be achieved without bone loss/loss of length, and most importantly the lower risk of neurovascular damage. Furthermore post-operative early weight bearing is possible only with an Ilizarov which inturn lessens the severity of the disuse osteoporosis. A technical advantage of ilizarov is that compression can be given to small fragments compression using multiple k wires and olive wires thereby increasing the stability of the construct.

Ringed external fixators are not without disadvantages. The bulky hardware, need for specialized surgical expertise and chance of pin tract infection are all the possible complications.

Prevention of deformity and recurrence

Gill and Abbott *et al.* presented a treatment plan for growth disturbance after fractures of the ankle. They recommended early epiphyseodesis before angular deformity occurs. If a deformity was established they recommended opening wedge osteotomy with epiphyseodesis of the unaffected part. Langenskiold reviewed 4 cases of distal tibial growth disturbances with deformity. He recommended epiphyseodesis combined with osteotomy to prevent recurrent detormity. [27] Other authors have presented cases for treatment of growth disturbances after ankle tractures. Cass and Peterson reviewed Salter Harris Type 4 fractures of the distal tibia with growth disturbances. They also found that fractures of the medial malleolus were more likely to result in growth disturbances [29-30].

Spiegel *et al.* identified the groups at the highest risk for growth disturbance, SH3 and SH 4 distal tibia fractures with 2mm or more displacement and SH5 fractures were at the highest risk for this complication [31].

Kling *et al.* found that younger patients had the greatest chance of developing a growth disturbance. Younger patients were found to have a higher rate of partial physeal arrest after Salter Haris type 3 fractures These patients have a long period of growth remaining which increases the potential of future deformity. Other factors favoring growth disturbance have been identified including fractures requiring reduction because of displacement. They also compared growth arrest in patients treated with closed or open reduction. They found a higher rate of growth disturbance with closed treatment. They felt this was due to inadequate reduction of these fractures. Open anatomic reduction was recommended. No gap or rotational displacement should be accepted because of the propensity for growth arrest [13, 17, 32, 24].

According to Sferopoulos, a Salter-Harris type V injury is usually considered radiographically occult. These injuries may have no obvious fracture line extending to the physis, but the persistence of significant pain at the level of the physeal plate for over a week, and the radiographic appearance of impaction or diminution of the width of the growth plate are all suggestive features of such an injury and warrents an MRI for confirmation of the diagnosis. He also stated that the appearance of bone contusions across the physis in the setting of acute injury could be a strong indication of a Salter-Harris type V injury [33].

Similarly, Carothers and Crenshaw in their article with 54 physeal ankle fractures in 1955, stated that the “SalterHarris type V physeal injury is difficult, if not impossible, to diagnose acutely”. The only radiographic indication may be decrease in the normal width of the radiolucent physis [34].

Therefore a strong clinical suspicion combined with adequate imaging studies are required to assess physeal injuries and predict as well as treat the associated deformities.

Acute correction	Gradual correction
Advantages ➨ Immediate correction **Disadvantages** ➨ Shortening ➨ Soft tissue compromise ➨ Chance of neurovascular compromise. ➨ Bone grafting needed. ➨ Chance of non union.	**Advantages** ➨ Biology is not destroyed ➨ Healing will be good ➨ No Grafting required ➨ No Neurovascular injury ➨ No shortening ➨ Follows the principle of distraction osteogenesis. **Disadvantages** ➨ Bulky hardware. ➨ Patient compliance. ➨ pin tract infection

External Fixation (Ilizarov)	Internal Fixation
➨ NO Limb length discrepancy after correction ➨ Osteotomy away from epiphysis. ➨ Immediate weight bearing possible ➨ No need to remove wedges (Only oblique Osteotomy). ➨ Distracting callus ➨ Late distraction and subsequent correction possible. ➨ pin tract infection.	➨ Transphyseal plating possible. ➨ Correction closer to physis hence reduces translation. ➨ Possibility of flap necrosis and surgical Site Infection due to subcutaneous plate. ➨ Wedge needs to be removed in case of closing wedge. ➨ Shortening of the limb following osteotomy.

Conclusion

From our study we concluded that Salter harris 3 and 4 have higher propensity for physeal bar formation,greater degree of deformity and limb length discrepancy. In case of gross deformities (>20degrees) gradual correction with an Ilizarov has better clinical, functional and radiological outcomes. In case of smaller deformities (<20 degrees) internal and external fixation gives equivocal results. In management of pediatric ankle deformity, principles of deformity correction have to be followed irrespective of internal or external fixation, acute or gradual correction.

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