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Original Article

Management of post-traumatic ankle deformities in children

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Abstract: The objective of this clinical appraisal was to assess the clinical-radiological results of ankle deformity correction secondary to physeal injury, utilizing the methods based on the age of the child, site & severity of the deformity, remaining growth potential, condition of the soft tissue envelop and integrity of neurovascular status. Fifteen subjects ≤ 16 years of age, with angular deformities of the ankle secondary to physeal injury, were included. Deformities secondary to infection and pathological fractures were excluded. Demographic data, type of injury, treatment method, and follow-up were recorded from the case files. Treatment categories included osteotomies for acute correction (> 10 years) and growth modulation (≤ 10 years). Male to female ratio was 7:8, with an average age of 11.8 ± 2.31 years (range 9-16 years). The right and left ratio was 7:8. Mean duration of follow-up was 1 year and 4 months. Gradual deformity correction was done in 2 cases utilizing the principle of growth modulation, while acute correction by osteotomy was done in 13 cases. The average pre-operative ankle deformity was 20.8 ± 3.11 degrees (Range -25 to 24 degrees). Radiological union was attained at a mean of 11 weeks (8-24). Nine patients achieved neutral ankle alignment. The mean residual varus was 2.3°, and the valgus was 4°. There was a statistically significant improvement of the AOFAS score by 17 points from a mean pre-operative score of 57 (44-84) to 74 (56-100) points at the final follow-up (*p*-value < 0.001). The average pre-operative shortening was 2.36 ± 0.21 cm, which was completely corrected in 9 individuals. Management of angular deformities around the ankle calls attention to correcting the resultant angular deformity and/or limb length disparity, utilizing acute or gradual correction. A successful outcome depends on early recognition and patient-specific treatment of paediatric ankle fracture patterns. Correlating the results of our study with the available literature, we feel that both acute or gradual correction for angular deformities around the ankle is a feasible solution as long as principles of deformity correction are adhered to. Techniques for salvaging and restoring the viability of injured physeal plate warrant additional research.

Keywords: Children, post-traumatic, physeal injury, ankle, growth modulation, distraction osteogenesis/histiogenesis, osteotomy

Introduction

Physeal injuries around the ankle account for 15-20% of all physeal injuries, making them the most prevailing physeal injuries in the lower extremities [1-3]. Distal tibial physeal injuries have the highest rate of complications among all physeal injuries, presenting with premature physeal arrest, physeal bar formation, angular deformities, and joint incongruity [4, 5]. Among all the Salter-Harris classification types, III and IV are the most notorious for disturbing the normal physeal growth and consequent effects. The distal tibial physis contributes 40% of the total tibial growth and 17% of the growth of the lower extremity, at a rate of 3 to 4 mm of growth per year. In young individuals, distal tibial growth is proportional to proximal tibial growth [6], putting the individual at risk of limb length discrepancy in case of physeal injuries.

Ankle deformities secondary to physeal injury may have a varied presentation and natural history such as Limb length discrepancy, tibial

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shortening, rotational malalignment, ankle instability [7]. Therefore, it is challenging to develop a routine strategy for treating patients with ankle deformities secondary to physeal injuries [8]. However, the standard treatment methods include shoe raises, physeal bar excision, growth modulation, and acute or gradual correction utilizing internal or external fixation techniques [8-10]. Gradual correction with distraction histiogenesis offers significant correction of angular deformity with restoration of limb length also [11]. Although osteotomies around the ankle offer immediate correction of angular deformities and restore the mechanical axis in children close to skeletal maturity, there is a risk of recurrence of deformity in younger children with considerable physeal growth remaining and incomplete physeal bar. Bar excision can be attempted in such cases, although it is a complex surgery with variable results [12]. Although several management strategies have been proven valuable, there is no uniform procedure for treating an ankle deformity secondary to physeal injury [9, 10]. So, the objective of this clinical appraisal was to assess the clinico-radiological results of ankle deformity correction secondary to physeal injury, utilizing the methods based on the age of the child, site & severity of the deformity, remaining growth potential, condition of the soft tissue envelope and integrity of neurovascular status.

Material and methods

Study design

This was a retrospective study of the management of paediatric ankle deformities secondary to physeal injury from October 2017 to September 2022. The study was approved by the institutional ethical committee. The study was performed according to the ethical standards of the 1964 Declaration of Helsinki as revised in 2000.

Inclusion and exclusion criteria

We included all subjects up to the age of ≤ 16 years of age, with angular deformities of the ankle secondary to physeal injury. Deformities secondary to infection, and pathological fractures were excluded. Also, patients with inadequate follow-ups were excluded. Fifteen patients with post-traumatic ankle deformity were included. Demographic data, type of injury, treatment method, and follow-up were recorded from the case files. Treatment categories included osteotomies and growth modulation.

Treatment protocol and pre-operative planning

In all the patients, surgical planning began with a comprehensive clinical examination and a detailed history. Limb length disparity, normal limb alignment, stability, and range of motion of the knee and ankle were all evaluated. In all cases, the center of rotation and angulation (CORA) was located, and deformity correction was planned. The distal tibial articular surface and the tibia's anatomical axis combine to produce the lateral distal tibial angle (LDTA), which has a normal value of 89° ± 3° (**Figure 1A**). In the sagittal plane, the mechanical axis of the tibia and the ankle's joint orientation line produce the anterior distal tibial angle (ADTA), which has normal values of 80° ± 3° (**Figure 1B**) [13]. The mid-diaphyseal line intersects the line that starts at the middle of the joint and runs perpendicular to the aberrant ADTA or LDTA (LDTA in this picture), which is the center of rotation of angulation (CORA). The CORA can be found proximally at the tibia (**Figure 2A**) or at the joint line level (**Figure 2B**) [13]. The correction method was dictated by the child's age, site & severity of the deformity, remaining growth potential, condition of the soft tissue envelope, and integrity of neurovascular status. Antero-posterior (AP) and lateral views of the ankle joint were examined for signs of premature or asymmetrical physeal closure, leg length disparity, angular deformity, and joint incongruity. Comparison radiographs of the contralateral ankle were also obtained. Pre and post-operative radiographs were used to determine the degree of correction achieved. Additional imaging, like magnetic resonance imaging, was also utilized to chart the physis and determine the severity and precise location of physeal bars when needed.

Patients with > 10 years of age were managed with acute correction utilizing the osteotomies to correct the angular deformities and restore the mechanical axis. Patients with ≤ 10 years of age with considerable years of growth remaining were managed with growth modula-

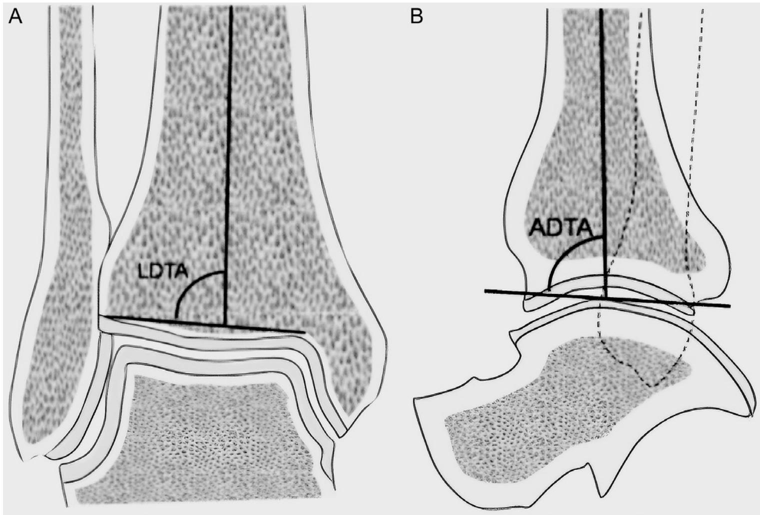

Figure 1. A: The distal tibial articular surface and the tibia's anatomical axis combine to produce the lateral distal tibial angle (LDTA), which has a normal value of 89° ± 3°. B: In the sagittal plane, the mechanical axis of the tibia and the ankle's joint orientation line produce the anterior distal tibial angle (ADTA), which has normal values of 80° ± 3°.

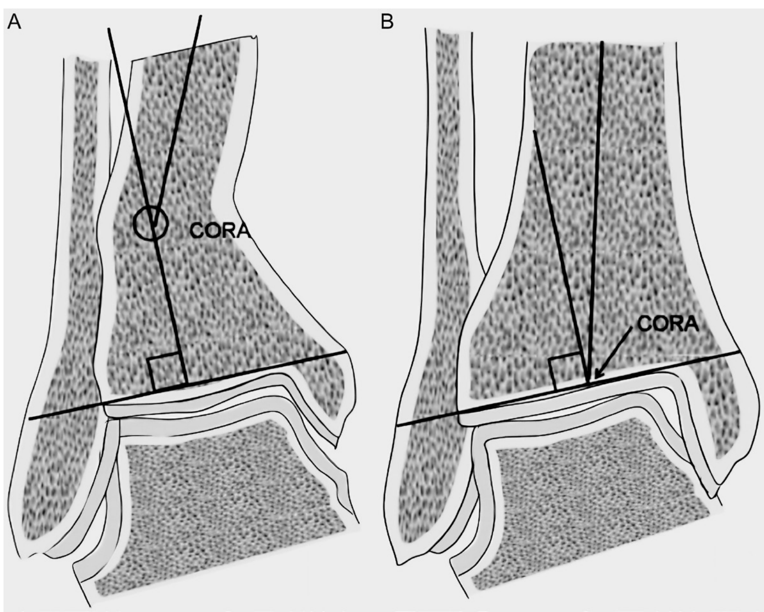

Figure 2. (A, B) The mid-diaphyseal line intersects the line that starts at the middle of the joint and runs perpendicular to the aberrant ADTA or LDTA (LDTA in this picture), which is the center of rotation of angulation (CORA). The CORA can be found proximally at the tibia (A) or at the joint line level (B).

tion. In osteotomy cases, a wedge of bone is removed from either the medial or lateral side, depending on whether the deformity is varus or valgus. To prevent skin necrosis, a thick flap containing the periosteum was lifted. A medial opening wedge osteotomy was used for varus deformity correction, and a free fibula graft was put in with K wire fixation and slab application (**Figure 3**). In the case of valgus deformity correction, a medial closing wedge osteotomy was performed (**Figure 4**). The fibular osteotomy was repaired with a plate in the instance of an older child who had less growth remaining. In the case of valgus deformity secondary to premature physeal closure of the fibula, growth modulation was done with cancellous screws for medial malleolus physis and corticotomy with distraction for the fibula (**Figure 5**). Following the procedure, patients were kept non-weight bearing for roughly 4 weeks, gradually progressing to weight bearing as tolerated by 6 to 8 weeks. Patients had antero-posterior (AP) and lateral radiographs taken at each follow-up visit.

Statistical analysis

Statistical analysis of data was done utilizing the SPSS software (version 20). Degree of deformity correction, AOFAS score, and improvement in range of movements were used as the end points, and Paired t-test was used. A *p*-value of < 0.05 was considered significant.

Results

The outcomes of 15 patients were analyzed. There were 7 boys and 8 girls, and the average age at presentation was 11.8 ± 2.31 years (range 9-16 years). The mode of injury was fall while playing in 6 and motor vehicle accidents in 9. The right and left ratio was 7:8. Four patients had radiological evidence of skeletal maturity, while 11 did not. The mean duration of follow-up was 1 year and 4 months (range of 6 months to 2 years). Gradual deformity correction was done in 2 cases utilizing the principle

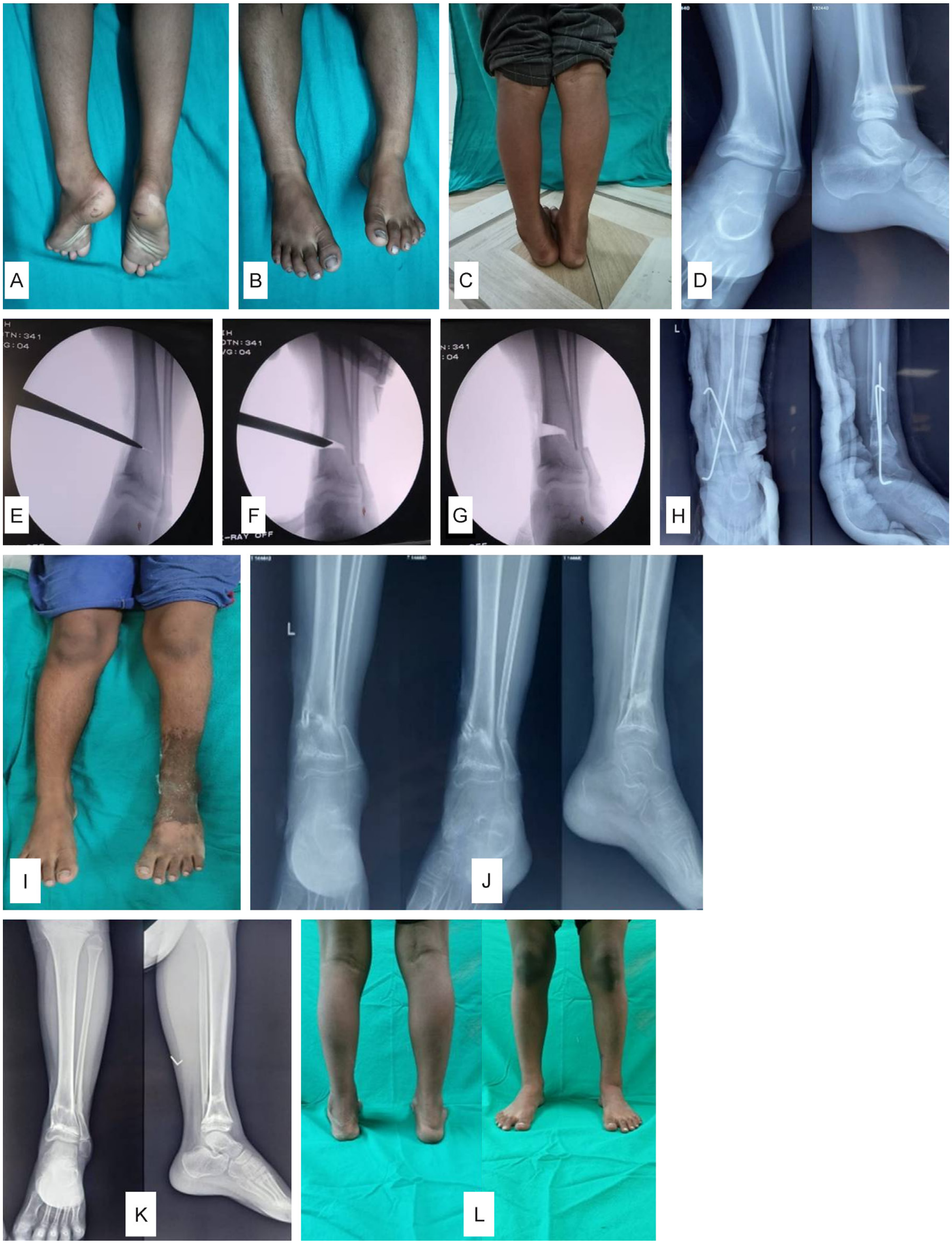

Figure 3. A-L: Management of varus deformity secondary to premature physeal closure in 10 year, male child. A-D: The image showing the pre-operative clinical & radiological evaluation of varus deformity. E-G: The image showing sequential steps for correction of varus deformity. Supramalleolar medial opening wedge osteotomy of the tibia was done on the medial side with osteotomy of the fibula. A small fibular graft (harvested from fibular osteotomy cut) was put in with K-wire fixation and slab application. H: The image showing immediate post-operative radiograph following deformity correction. I, J: Clinical and radiological evaluation at 10 weeks of operation, demonstrating ongoing healing of osteotomy and good ankle alignment achieved. K, L: Clinical and radiological evaluation at 1 year of operation demonstrates complete osteotomy healing with good ankle alignment.

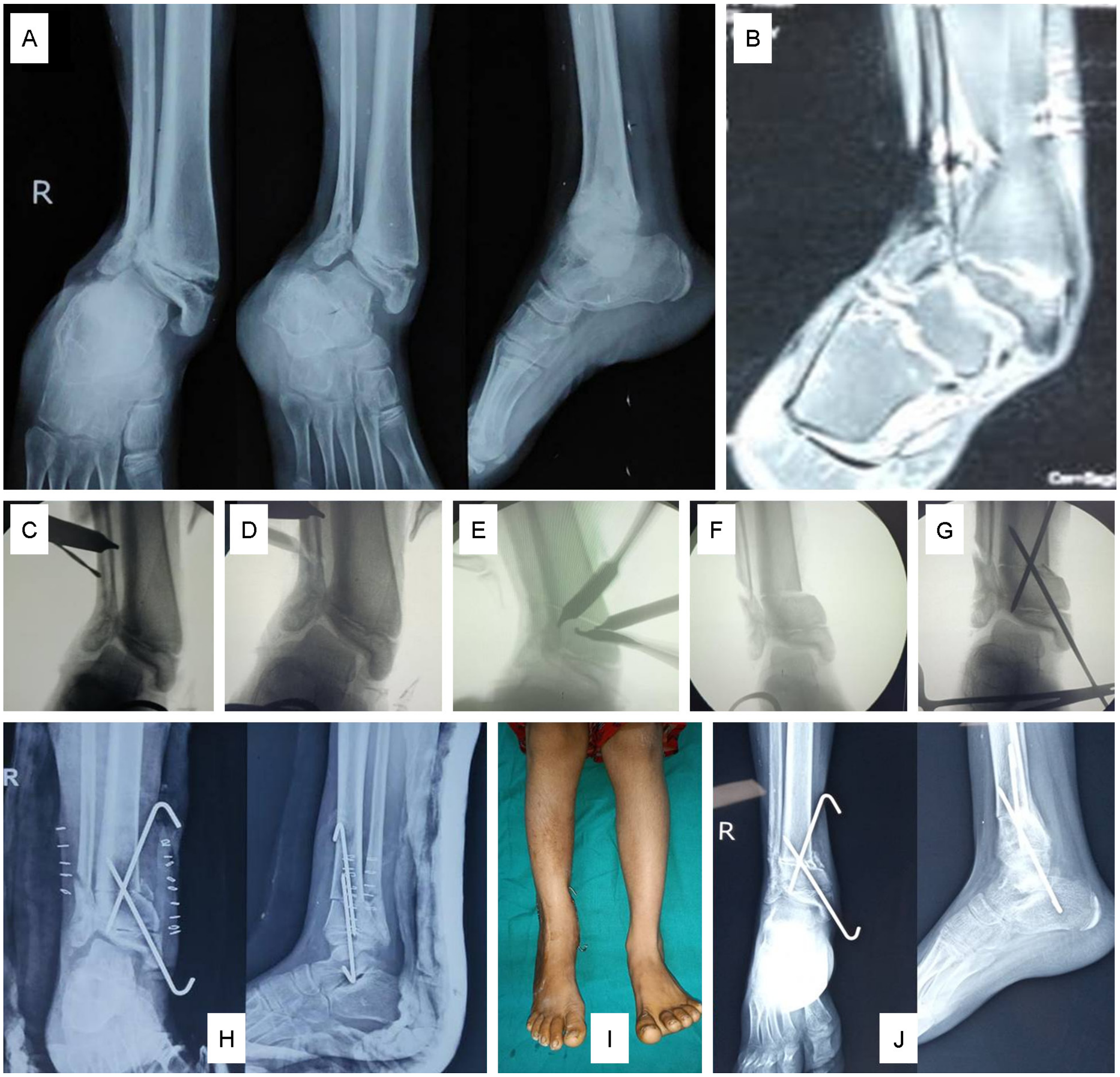

Figure 4. A-J: Management of valgus deformity secondary to premature physeal closure in 11 year, female child. A, B: Pre-operative X-rays and MRI of the patient showing premature fusion of lateral tibial physis and subsequent valgus deformity at the ankle. C-G: The image showing sequential steps for correction of valgus deformity. First, fibular osteotomy was done, followed by supramalleolar tibial osteotomy to correct valgus. Tibial osteotomy was fixed with K-wire. H: The image showing immediate post-operative radiograph following deformity correction. I: Clinical photograph showing correction of deformity with good ankle alignment. J: Radiological evaluation at 6 weeks of operation, demonstrating ongoing healing of osteotomy with good ankle alignment.

of growth modulation, while acute correction by osteotomy was done in 13 cases (**Table 1**). The average pre-operative ankle deformity was 20.8 ± 3.11 degrees (Range -25 to 24 degrees). There were no peri-operative complications and no neurovascular complications. All osteotomies united. Radiological union was attained after a mean of 11 weeks (8-24). There was a significant difference in the degree of deformity correction when pre- and post-correction angulation was analyzed, but, there was no statistically significant difference between varus and valgus ankles. Nine patients attained neutral ankle alignment. The mean residual varus was 2.3°, and the valgus was 4°. There was a statistically significant improvement of the AOFAS score by 17 points from a mean pre-operative score of 57 (44-84) to 74 (56-100) points at the final follow-up (p-value < 0.001). The average pre-operative shortening was 2.36 ± 0.21 cm, which was completely corrected in only 9 individuals (**Table 2**).

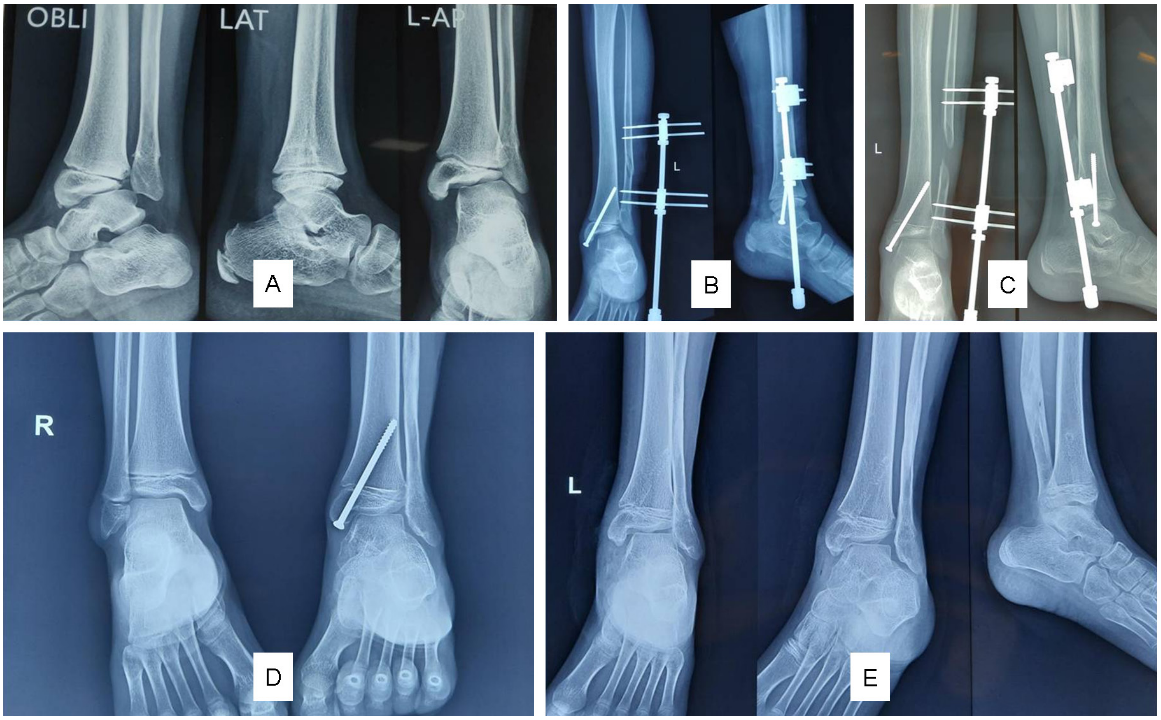

Figure 5. A-E: Management of valgus deformity secondary to premature physeal closure of fibular physis in a 9-year-old female child. In this case, growth modulation was done with a screw for medial malleolus physis and fibular corticotomy with distraction for lengthening. All the implants were removed after deformity correction. A: Pre-operative X-ray of the patient showing premature fusion of fibular physis and subsequent valgus deformity at the ankle. B: Post-operative radiograph showing growth modulation using screw across the tibial physis & fibular corticotomy to lengthen (distraction histiogenesis using distractor) the fibula. C: The image showing ongoing lengthening of fibula with gradual correction of ankle valgoid alignment. D: Radiograph showing correction of deformity with good ankle alignment at removal of the distractor. E: Radiological evaluation at 1-year follow-up, demonstrating consolidation of regenerate with good ankle alignment.

Discussion

Patients with angular ankle deformities secondary to physeal injuries experience major functional issues. The most typical concerns are with normal walking, wearing shoes and braces, and concerns related to soft tissue envelop [7]. Even if rare, distal tibial physeal injuries can direct to long-term consequences such as growth arrest, tibial shortening, rotational malalignment, ankle instability, and ultimately ankle osteoarthrosis. Growth plate arrest secondary to a physeal injury can be a devastating complication unless appropriately managed, which can be treated conservatively and operatively [7, 14]. About 15% of distal tibia physeal fractures are Salter-Harris type I fractures [14, 15]. The incidence of growth arrest has traditionally been reported to be less than 5% [15]. Depending on the presence and extent of physeal bar, premature growth arrest can be partial or complete. The distal tibia and distal femur are particularly vulnerable to physeal arrest. This is likely due to undulating physis, which is injured unevenly. It is known as Klump's bump when it appears in the distal tibia at the anteromedial physis. Additional factors to consider are the child's age, the type of injury, the force of injury, compression, displacement, and infolding of the periosteum [16, 17]. Adduction trauma to the ankle is responsible for 60.9% of distal tibial physeal injuries, followed by abduction trauma in 14.6%, external rotation in 13%, and plantar flexion in 11.5% [18]. Limb length discrepancy after physis injury is occasionally related to an overgrowth in the afflicted leg which is thought to be caused by indiscriminate stimulation of all physeal plates of the extremities as a result of enhanced blood circulation, resulting in a leg length disparity [19, 20]. Patients with a longer time of growth remaining are more likely to develop deformities. Fractures that require many reduction attempts or are substantially displaced are

Table 1. Demographic data, management & AOFAS of the study population

S. No.	Age/Sex	Follow-up	Ankle alignment (Pre-op)	Ankle alignment (Post-op)	ROM Dorsi-flexion (Pre/Post-op)	ROM Plantar-flexion (Pre/Post-op)	Treatment	AOFAS (Increase in score following correction)
1	10/M	1 y	Varus 22	Neutral	32/38	40/40	Medial Opening Wedge osteotomy with K-wire fixation	20
2	14/M	1 y	Varus 25	Varus 3	28/38	36/40	Medial Opening Wedge osteotomy with K-wire fixation	15
3	9/F	1 y	Valgus 20	Neutral	22/36	34/40	Growth modulation with screw for medial malleolus & distractor application for fibula	18
4	16/M	6 months	Varus 16	Neutral	26/36	32/38	Medial opening wedge osteotomy with K-wire for tibia and plate fixation for fibula	20
5	9/F	6 months	Valgus 18	Neutral	30/40	32/36	Medial closing Wedge osteotomy with K-wire fixation	15
6	12/M	13 months	Varus 22	Neutral	20/36	34/40	Medial Opening Wedge osteotomy with K-wire fixation	22
7	10/F	20 months	Valgus 24	Neutral	24/38	40/40	Medial closing Wedge osteotomy with K-wire fixation	20
8	13/F	11 months	Varus 24	Varus 2	28/36	36/40	Medial opening Wedge osteotomy with K-wire fixation	18
9	15/M	14 months	Valgus 26	Valgus 5	24/34	34/38	Medial closing Wedge osteotomy with K-wire fixation	15
10	11/F	9 months	Valgus 18	Valgus 4	20/30	34/36	Medial closing wedge osteotomy with K-wire fixation	16
11	9/M	1 y	Varus 20	Neutral	20/34	32/36	Medial opening wedge osteotomy with K-wire fixation	22
12	13/M	20 months	Valgus 18	Valgus 3	30/40	36/36	Medial closing Wedge osteotomy with K-wire fixation	14
13	14/F	13 months	Varus 22	Varus 2	28/40	34/38	Medial opening wedge osteotomy with K-wire fixation	18
14	12/F	18 months	Varus 14	Neutral	28/40	40/40	Medial opening wedge osteotomy with K-wire fixation	16
15	10/F	2 y	Valgus 24	Neutral	24/36	38/40	Growth modulation with distractor application for fibula and screw for medial malleolus	20

Table 2. Changes in the observed indicators before and after intervention

	Pre-operative	Final follow-up	*p*-value
AOFAS	57 (44-84)	74 (56-100)	< 0.001
Ankle deformity	20.8 ± 3.11° (Range -25 to 24°)	3.16 ± 1.16° (Range -3 to 5°)	< 0.001
Mean varus	20.6 ± 3.81°	2.3 ± 0.57°	< 0.001
Mean valgus	21.4 ± 3.44°	4 ± 0.82°	< 0.001
Shortening	2.36 ± 0.21 cm	1.1 ± 0.11 cm	> 0.05

more likely to cause growth arrest [21]. Physeal injury deformity can occur as a result of the traumatic event itself or as a result of the management strategy, in both conservative and operatively managed cases. Improper reduction, soft tissue interposition inside the fracture site, and displacement within the plaster cast can all lead to loss of alignment and progression to deformity. Cottalorda [22] indicated that open anatomical reduction with physis realignment results in continuing longitudinal growth without deformity, and their long-term results suggested that open reduction is a safe surgery for type 3 and 4 epiphyseal injuries. Narrower is the fracture gap, smaller is the bridge and hence lesser chances of growth arrest. MRI is method of choice for evaluating physeal bridge. It provides images of excellent quality without the risk potential radiation hazard. In the case of a physeal bar, treatment options include bar excision, epiphysiodesis, lengthening, deformity correction, or a combination of these. Different corrective procedures have been mentioned in the literature [23-26]. Both acute and gradual correction utilizing different procedures have the same goal, to rectify the deformity and, hopefully, avoid recurrence, thereby alleviating the difficulties created by the initial ankle malalignment [7]. Lalandle [27] insisted on bar excision in partial physeal arrest and epiphysiodesis if less growth remains. They stated that if much growth remains and the limb length difference is expected to be greater than 5 cm, limb lengthening using an external fixator or an intramedullary device should be done. In cases of significant angular deformity, supramalleolar osteotomy can be performed [27]. We performed growth modulation with osteotomy and distraction histiogenesis wherever feasible in younger patients, and supramalleolar corrective osteotomy was delayed until single definitive correction could be made. Sharrard and Webb [28] performed supramalleolar osteotomy in 16 patients with ankle deformities with a mean follow-up period of 2 years. Immediate correction was obtained, but there were two relapses in varus ankle deformities. In the Sharrard and Webb series, patients younger than 10 years of age had no relapse [28]. Abraham [23] studied 35 patients with valgus ankle deformities and did supramalleolar corrective osteotomy with a mean follow-up of 7 years and 6 months. In each case, the authors performed fibular osteotomies to achieve better compression and centralization at the tibial cut surfaces. Ninety-one percent of the results were rated excellent and good [23]. In our study, supramalleolar osteotomy was performed in 13 patients, of which 7 (54%) attained neutral alignments. No patient had relapse after the correction was achieved as compared to 2 relapses in Sharrard and Webb [28] study. This could be due to less growth remaining at the distal tibial physis. Gradual correction by growth modulation and distractor application was performed in 2 patients who had much growth remaining and full correction was achieved in both of them. Lonner in year 1995 [11] treated 10 patients on the principle of distraction histiogenesis and achieved complete correction of limb length in only five cases (50%) and correction of angular and rotational deformity to within 5° in seven cases. Laursen in year 2000 [29] treated 16 patients on the same principle and the limb-length discrepancy reduced to within 1.5 cm of the contralateral leg. In our study limb length discrepancy was fully corrected in 9 patients, rest of the 6 patients did not have any significant problem and were managed with shoe raise. In our study, the average overall post-operative varus deformity was 2.3° and valgus was 4° while nine ankle attained neutral alignment which was comparable to the study by Lubicky [7] in which the mean postoperative varus deformity was 5.7° and the mean post-operative valgus deformity was 3.7°. Despite some patients having persistent radiological valgus or varus ankle deformities in our study, none of the patients had difficulty in their daily routine activities. All osteotomies healed without non-union or pseudoarthrosis. No patient developed a recurrence of their deformity during the follow-up period nor developed pressure sores after surgery. These findings were similar to study conducted by Lubicky [7]. Measurement of functional improvement by AOFAS score showed statistically significant change in post-operative values with mean improvement of 17 points which is similar to study by Horn [30].

Strengths and limitations

The results presented here originated from the undersized and heterogeneous sample, which confines the power of conclusions that can be derived from the current study. The inclusion of only post-traumatic cases with definitive treatment protocol with standard evaluation tools is the strength of the current study.

Conclusions

The general concepts and principles of paediatric ankle fracture treatment are comparable to those of other paediatric physeal injuries. Management of angular deformities around the ankle calls attention to correcting the resultant angular deformity and/or limb length disparity, utilizing acute or gradual correction. A successful outcome depends on early recognition and patient-specific treatment of paediatric ankle fracture patterns. Correlating the results of our study with the available literature, we feel that both acute or gradual correction for angular deformities around the ankle is a feasible solution as long as principles of deformity correction are adhered to. Techniques for salvaging and restoring the viability of injured physeal plate warrant additional research.

Disclosure of conflict of interest

None.

Abbreviations

CORA, Center of rotation and angulation; AOFAS, American Orthopaedic Foot & Ankle Society; ROM, Range of motion; LDTA, Lateral distal tibial angle; ADTA, Anterior distal tibial angle.

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References

[1] Landin LA and Danielsson LG. Children's ankle fractures. Classification and epidemiology. Acta Orthop Scand 1983; 54: 634-640.
[2] Mizuta T, Benson WM, Foster BK, Paterson DC and Morris LL. Statistical analysis of the incidence of physeal injuries. J Pediatr Orthop 1987; 7: 518-523.
[3] Peterson CA and Peterson HA. Analysis of the incidence of injuries to the epiphyseal growth plate. J Trauma 1972; 12: 275-281.
[4] Langenskiöld A. Traumatic premature closure of the distal tibial epiphyseal plate. Acta Orthop Scand 1967; 38: 520-531.
[5] Salter RB. Injuries of the ankle in children. Orthop Clin North Am 1974; 5: 147-152.
[6] Beals RK and Skyhar M. Growth and development of the tibia, fibula, and ankle joint. Clin Orthop Relat Res 1984; 289-292.
[7] Lubicky JP and Altiok H. Transphyseal osteotomy of the distal tibia for correction of valgus/varus deformities of the ankle. J Pediatr Orthop 2001; 21: 80-88.
[8] Miller ML and Gordon JE. Decision making in lower extremity deformity correction. In: Sabharwal S, editors. Pediatric Lower Limb Deformities. Cham: Springer International Publishing; 2016.
[9] Berson L, Davidson RS, Dormans JP, Drummond DS and Gregg JR. Growth disturbances after distal tibial physeal fractures. Foot Ankle Int 2000; 21: 54-58.
[10] Williamson RV and Staheli LT. Partial physeal growth arrest: treatment by bridge resection and fat interposition. J Pediatr Orthop 1990; 10: 769-776.
[11] Lonner JH, Koval KJ, Golyakhovsky V and Frankel VH. Posttraumatic nonunion of the distal tibial metaphysis. Treatment using the Ilizarov circular external fixator. Am J Orthop (Belle Mead NJ) 1995; Suppl: 16-21.
[12] Tunçez M and Kazımoğlu C. Treatment of ankle varus deformity due to physeal bar formation: a case report. Ulus Travma Acil Cerrahi Derg 2022; 28: 1359-1362.
[13] Bonasia DE, Dettoni F, Femino JE, Phisitkul P, Germano M and Amendola A. Total ankle replacement: why, when and how? Iowa Orthop J 2010; 30: 119-130.
[14] Kay RM and Matthys GA. Pediatric ankle fractures: evaluation and treatment. J Am Acad Orthop Surg 2001; 9: 268-278.

[15] Spiegel PG, Cooperman DR and Laros GS. Epiphyseal fractures of the distal ends of the tibia and fibula. A retrospective study of two hundred and thirty-seven cases in children. J Bone Joint Surg Am 1978; 60: 1046-1050.

[16] Ecklund K and Jaramillo D. Patterns of premature physeal arrest: MR imaging of 111 children. AJR Am J Roentgenol 2002; 178: 967-972.

[17] Barmada A, Gaynor T and Mubarak SJ. Premature physeal closure following distal tibia physeal fractures: a new radiographic predictor. J Pediatr Orthop 2003; 23: 733-739.

[18] Schurz M, Binder H, Platzer P, Schulz M, Hajdu S and Vécsei V. Physeal injuries of the distal tibia: long-term results in 376 patients. Int Orthop 2010; 34: 547-552.

[19] von Laer L. Frakturen und Luxationen im Wachstumsalter. Stuttgart: Thieme; 1991.

[20] Brunner C. Frakturen des proximalen femurendes. In: Weber BG, Brunner C, Freuler F, editors. Frakturenbehandlung bei Kindern und Jugendlichen. Berlin, Heidelberg, New York: Springer; 1979. pp. 318-327.

[21] Kling TF Jr, Bright RW and Hensinger RN. Distal tibial physeal fractures in children that may require open reduction. J Bone Joint Surg Am 1984; 66: 647-657.

[22] Cottalorda J, Béranger V, Louahem D, Camilleri JP, Launay F, Diméglio A, Bourelle S, Jouve JL and Bollini G. Salter-Harris type III and IV medial malleolar fractures: growth arrest: is it a fate? A retrospective study of 48 cases with open reduction. J Pediatr Orthop 2008; 28: 652-655.

[23] Abraham E, Lubicky JP, Songer MN and Millar EA. Supramalleolar osteotomy for ankle valgus in myelomeningocele. J Pediatr Orthop 1996; 16: 774-781.

[24] Malhotra D, Puri R and Owen R. Valgus deformity of the ankle in children with spina bifida aperta. J Bone Joint Surg Br 1984; 66: 381-5.

[25] Wiltse LL. Valgus deformity of the ankle: a sequel to acquired or congenital abnormalities of the fibula. J Bone Joint Surg Am 1972; 54: 595-606.

[26] Kumar SJ, Keret D and MacEwen GD. Corrective cosmetic supramalleolar osteotomy for valgus deformity of the ankle joint: a report of two cases. J Pediatr Orthop 1990; 10: 124-127.

[27] Lalonde KA and Letts M. Traumatic growth arrest of the distal tibia: a clinical and radiographic review. Can J Surg 2005; 48: 143-147.

[28] Sharrard WJ and Webb J. Supra-malleolar wedge osteotomy of the tibia in children with myelomeningocele. J Bone Joint Surg Br 1974; 56B: 458-461.

[29] Laursen MB, Lass P and Christensen KS. Ilizarov treatment of tibial nonunions results in 16 cases. Acta Orthop Belg 2000; 66: 279-285.

[30] Horn DM, Fragomen AT and Rozbruch SR. Supramalleolar osteotomy using circular external fixation with six-axis deformity correction of the distal tibia. Foot Ankle Int 2011; 32: 986-993.