The Economic Ramifications of Pediatric Distal Tibial Physeal Fractures

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Objectives: This study aimed to assess how existing literature evaluates the cost associated with pediatric distal tibial physeal fractures.

Design: A scoping review was conducted following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Searches were performed in PubMed and MEDLINE for relevant keywords related to pediatric distal tibial physeal fractures, cost, and imaging.

Main Outcome Measurements: Cost-effectiveness

Results: The initial search yielded 131 studies; 105 titles and abstracts were screened, 41 full-text manuscripts were reviewed, and 7 articles were eligible for inclusion. Four studies focused on lowering costs by reducing additional imaging studies, utilizing the Low-Risk Ankle Rule (LRAR), weight-bearing computed tomography (WBCT) with cone-beam technology, or not requiring comparison views in pediatric ankle fractures. One study found that the Ottawa Ankle Rules (OAR) had sufficient sensitivity in the pediatric population. Another study discussed the need for computed tomography (CT) scans in Salter-Harris (SH) class III or IV fractures due to the improved ability to apply proper treatment modalities despite an increased cost.

Conclusions: The scoping review identified a limited number of studies addressing cost analyses for pediatric distal tibial physeal fractures. The included studies focused primarily on reducing costs by optimizing imaging protocols and implementing clinical decision rules. Further research is needed to comprehensively evaluate the cost-effectiveness of various treatment modalities and the long-term economic implications of these fractures.

Level of Evidence: IV; Systematic Review of level IV or higher evidence

Key Words: Business, management, human resources, cost, value, efficiency

INTRODUCTION

Physeal fractures of the ankle are the second most common type of physeal injury, accounting for a significant 18% of all physeal injuries[1, 2]. These fractures are particularly concerning due to the involvement of the growth plate, which plays a crucial role in the normal growth and development of bones. Studies have shown that between 2-40% of physeal fractures of the ankle can lead to growth arrest and potentially severe complications that can result in angular deformities and leg-length discrepancies [2]. These fractures commonly occur in teenagers and are classified by the SH classification system[3, 4]. Long-term treatment minimizes angular deformities and leg-length discrepancy by anatomically reducing the fracture with a step-off of less than one to two millimeters[5-7]. Nondisplaced fractures and SH I fractures may be treated with a cast or a boot and may even be diagnosed with ultrasound[5, 8-11]. SH II-IV fractures are typically treated with closed reduction and a cast or open reduction and internal fixation (ORIF) [3, 12-16].

Despite the availability of several treatment modalities, there is a lack of studies examining the cost analysis of these different approaches. Emphasis on increasing cost-effectiveness and high-value care is a priority in the healthcare system. However, these gaps in knowledge and the rising cost of healthcare are concerning. Furthermore, studies have shown that between 85% and 95% of pediatric ankle injury patients receive radiographs, with only 12% of those radiographs revealing fractures[17]. While implementing clinical decision rules, such as OAR, has been shown to reduce the number of unnecessary radiographs for ankle injuries by 64%, these rules have traditionally had limited use in pediatric populations[18]. Other studies have also found that the operating room's average cost is about $46.04 per hour[19]. Over the last 20 years, the number of cost-effectiveness studies has increased drastically, though there continue to be substantial gaps in cost-effectiveness analyses[20, 21].

The importance of cost-effectiveness analyses in managing pediatric distal tibial physeal fractures cannot be overstated. By understanding the economic implications of different treatment modalities and diagnostic approaches, healthcare providers can make more informed decisions, optimize resource allocation, and improve patient outcomes while minimizing unnecessary expenses. This scoping review aims to assess the existing cost analyses of pediatric distal tibial physeal fractures and how the current literature evaluates the associated costs, with the hypothesis that conservative treatment will cost less than surgical interventions, as the latter is typically reserved for more severe fractures.

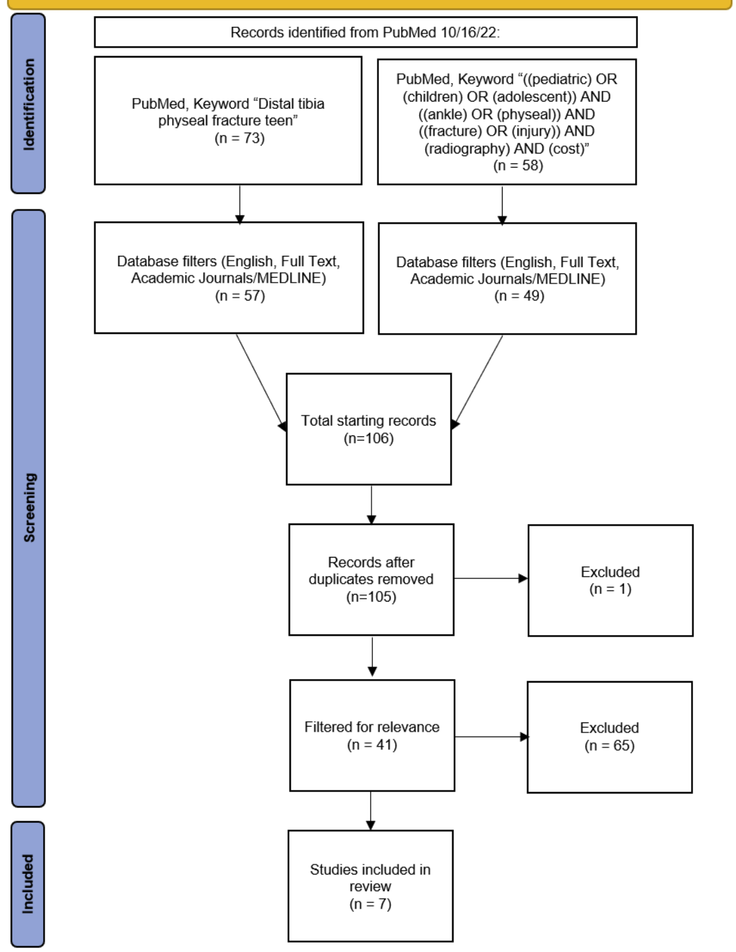
METHODS

Search Strategy

Our search strategy was following the PRIMSA guidelines (Figure 1). The search was performed in PubMed for the following keywords: “distal tibial physeal fracture teen.” Results were obtained from as early as 1982 through 2022. A second search was performed in MEDLINE on PubMed for the following keywords: ((pediatric) OR (children) OR (adolescent)) AND ((ankle) OR (physeal)) AND ((fracture) OR (injury)) AND (radiography) AND (cost). Results were obtained from as early as 1979 through 2022. For both search results, English, Full Text, and Academic Journals/MEDLINE database filters were applied. Duplicates were removed from the two searches before inclusion and exclusion criteria were applied. Exclusion criteria included adult patients (> 18 years old), letters to the editors, expert opinions, book chapters, non-English literature, and no-cost reports. Eligibility criteria were determined by study design and reporting of relevant outcome data. Study designs included cohort, trial, review articles, or case series. The publication date was not considered when determining inclusion or exclusion.

The aim of the study is to assess the cost associated with the treatment of distal tibial physeal fractures, with special attention to cost-effectiveness measures such as cost per quality-adjusted life year (QALY) or incremental cost-effectiveness ratio (ICER). Secondary aims included measures of initial fracture displacement, number of attempts at fracture reduction, patient follow-up, outcomes, and complications. Studies eligible for inclusion reported one of the following: reduction in cost, improvement in cost analysis, or cost-effectiveness.

Figure 1: PRISMA flow diagram of studies from search through screening to inclusion and exclusion



Data Extraction

Three authors (M.R, C.A.R, and D.S.) surveyed the literature independently to screen for relevant information per selected articles. Articles were selected according to title, abstract, and full-text information following an initial search screening using predefined keywords. Articles were compared to the specified exclusion criteria to determine eligibility for inclusion in the study. A thorough text review was performed to extract data relevant to the study.

Each article was reviewed, and information extracted included: (1) patient population (including study size and patient demographics), (2) types of intervention (LRAR and OAR), (3) imaging (including ultrasound, magnetic resonance imaging (MRI), CT, and radiograph), (4) management (including ankle bracing, ankle casting, and ORIF). Additionally, contextual details such as study aim, study type, population, number of subjects, description of intervention, primary endpoints, co-interventions, control description, outcome measures, costs, quality of life measures, statistical methods employed conclusions, limitations, and recommendations were collected to stratify article information into variables of interest. The references of included articles were examined for potential articles relevant to our inclusion criteria. Articles relevant to our study were added and examined according to our data extraction methodology. Incongruencies in inclusion criteria or collected data were evaluated by the authors (M.R, C.A.R, and D.S.), and a discussion with all authors for resolution of differences ensued thereafter.

RESULTS

Electronic Search Yield

The initial search yielded a total of 131 studies, out of which 105 titles and abstracts were screened. Subsequently, 41 full-text manuscripts were reviewed, and 7 articles were determined to be eligible for inclusion (Figure 1).

Cost analysis literature

Table 1 presents the seven included studies. Four of the seven studies aimed to reduce costs by decreasing the need for additional imaging studies. Two of them discussed the implementation of the LRAR, while one explored the use of WBCT with cone-beam technology, and another suggested that comparison views should not be required for pediatric ankle fractures. However, one study found that the LRAR lacked sufficient sensitivity for use in the pediatric population, whereas the OAR demonstrated adequate sensitivity and could be utilized to reduce unnecessary imaging and associated costs. One study focused on the potential cost-effectiveness of different treatment modalities, although specific details were not provided. Another study recommended obtaining CT scans for Salter-Harris III or IV fractures identified on radiographs to improve the ability to apply the proper treatment modality despite potentially increasing costs associated with additional imaging.

As the number of included studies was limited, Tables 2 (indexed) and 3 were created to incorporate relevant information from the orthopedic and emergency medicine literature, respectively. These studies did not directly address cost but focused on optimizing outcomes and diagnostic approaches.

Orthopaedic literature

Table 2 (indexed) comprises 28 orthopedic studies that fail to mention cost. However, they provide value in optimizing outcomes for various treatment modalities and fracture patterns of the ankle. Ten studies were primarily centered on growth arrest due to SH-classified fractures, with five studies specifically

Table 1. Summary of Findings About Cost Analysis

Author	Year	Summary Statement
McCauley [25]	1979	For pediatric extremity fractures, comparison views of the contralateral extremity were requested in 8% of cases and never changed the initial diagnosis. Selective use of comparison views decreases radiation exposure and cost.
Boutis [3]	2007	In children with low-risk ankle fractures, a removable brace is more effective than a cast by faster return to activities, patient preferences, and cost-effectiveness.
Boutis [17]	2015	Widespread implementation of the LRAR can lead to a safe reduction in radiograph use in children with ankle fractures while also reducing patient costs.
Nenopoulos [27]	2015	CT imaging improves fracture classification and treatment decisions, especially in patients with transitional fractures and those with SH III or IV fractures and should be used despite the higher cost containment.
Ramasubbu [18]	2015	Implementation of the LRAR has the potential to reduce costs and radiation on pediatric ankle injuries, while having a high sensitivity for high risk ankle fractures.
Ellenbogen [22]	2017	LRAR have too low of a sensitivity to be implemented in the pediatric population, and we continue to support the use of the OAR implementation which already have shown reduced healthcare costs while providing adequate sensitivity.
Holbrook [26]	2022	Weight-bearing CT through cone-beam technology offers another imaging modality to examine ankle pathology as well as providing the benefits of reduced radiation exposure and costs on the pediatric population.
CT = computed tomography, SH = Salter-Harris, LRAR = Low Risk Ankle Rules, OAR = Ottawa Ankle Rules		

examining SH II fractures with an initial displacement greater than three millimeters, which was associated with an increased risk of premature physeal closure (PPC). Five studies highlighted the need for additional imaging modalities to better understand and characterize ankle fractures, while one study focused on reducing the number of follow-up radiographs. Three studies analyzed the correlation between specific ankle fracture patterns and the risk of PPC, with two finding no correlation between SH fracture patterns and PPC, and the third suggesting that the Dias-Tachdjian Classification was correlated with PPC formation.

Emergency Medicine literature

Table 3, comprising six emergency medicine studies, focuses on identifying ankle fractures. Three studies mentioned the OAR, with one incorporating a tuning fork alongside the OAR to increase its specificity in

Table 3. Summary of Findings from Emergency Medicine Literature

Author	Year	Summary Statement
Petit [51]	2001	Cases of pediatric fractures with high clinical suspicion of fracture rarely showed unexpected or abnormal findings indicating a need to implement the OAR to reduce radiograph exposure.
Leddy [23]	2002	Implementation of the OAR in a university sports medicine center identified all significant fractures with a sensitivity of 100%, making these rules particularly useful in the athletic field.
Dissmann [24]	2006	The use of a 128 Hz tuning fork in Ottawa positive patients increased the screening test sensitivity and specificity from 100% and 61% respectively to 100% and 95% respectively. The study suggests that Ottawa and tuning fork positive patients may reduce the number of ankle radiographs.
Taggart [10]	2012	In order to reduce radiation to children, point-of-care ultrasonography can be used to detect SH I fractures.
Park [40]	2019	SH-II fractures and triplane fractures have a high risk of periosteal entrapment, especially in the anterolateral corner.
Ramasubbu [18]	2019	Radiography is necessary for the management of ankle fractures.
SH = Salter-Harris, OAR = Ottawa Ankle Rules		

identifying fractures. Two studies discussed different imaging techniques, such as ultrasound and radiographs, for diagnosing physeal fractures. One study specifically mentioned using ultrasound to identify SH I fractures, while another emphasized the necessity of obtaining radiographs for suspected ankle fractures. Additionally, one study noted that SH II and triplane fractures have an increased risk of entrapment, potentially requiring more urgent intervention.

DISCUSSION

This scoping review initially aimed to perform a cost analysis of distal tibial fractures in the pediatric population. However, due to the limited number of included studies (n=7), this study shifted to a scoping review regarding how existing literature on pediatric distal tibial physeal fractures addresses their cost. The limited data and literature surrounding distal tibial fractures highlight a substantial knowledge gap in this area, which is concerning given the rising healthcare costs and the increasing emphasis on cost-effectiveness and high-value care. Of the 41 relevant studies, only seven mentioned pediatric physeal ankle fracture costs and found that most studies focused on reducing cost by decreasing the need for imaging. Furthermore, Tables 2 and 3 consist of 33 other studies written by and published in orthopaedic and emergency medicine journals, respectively. While these studies do not reference cost directly, they provide value surrounding distal physeal fractures in pediatric patients. Table 2 summarizes many articles that focused on optimizing outcomes for various treatment modalities and fracture patterns of the ankle. Table 3 focuses on how to identify ankle fractures. In the PRISMA diagram in Figure 1, the orthopaedic-focused paper came from the "distal tibia physeal fracture teen" search.

In contrast, the emergency medicine-focused studies largely came from the "((pediatric) OR (children) OR (adolescent)) AND ((ankle) OR (physeal)) AND ((fracture) OR (injury)) AND (radiography) AND (cost)" search. Despite an overlap of topics between the two searches, only one study was excluded for duplication. This can potentially be attributed to the differences in terms used, orthopaedic journals are more likely to use the words distal tibia physeal fracture to describe a fracture of the region, whereas emergency medicine is more likely to be less specific and use "ankle" or "injury" to describe the fracture.

Across our search, implementing LRAR in three Canadian emergency departments decreased total healthcare costs by 37 Canadian dollars, which was statistically significant. In the study, LRAR had a 100% sensitivity with no statistical changes in the length of stay (LOS) or missed fractures[17]. Both Boutis et al. and Ramasubbu et al. found that implementing LRAR would reduce the number of radiographs by roughly 64%[17, 18]. However, Ellenbogen et al. found that in 28 high-risk fractures, LRAR had a sensitivity and specificity of 85.7% and 64.9%, respectively. However, OAR had a sensitivity and specificity of 100% and 33.1%, respectively[22, 23]. Interestingly, a 128 hz tuning fork improved OAR's specificity to 95%[24]. However, no study looked at OAR with a 128 hz tuning fork correlated with decreasing cost to the patient. In the included studies, one study looked at treatment modalities that found that using a brace over a cast had a cost-effective need acceptability curve more significant than 80% due to the brace having a lower cost and being more effective at treating ankle fractures[3]. The remaining studies included are focused on imaging. In 1979, McCauley et al. found reference radiographs, those taken of the contralateral extremity, did not make a statistical difference in the treatment of the fracture, allowing for potentially reduced radiation and cost to the pediatric population[25]. There are also new WBCT methods that reduce the amount of radiation per image while reducing the cost to the patient[26, 27]. While minimizing radiation is essential, the need for good diagnostic imaging is more important to avoid missed fractures. One study found that CTs are worth the additional cost to accurately diagnose and treat transitional fractures and SH III and SH IV fractures. While only one study explicitly mentions costs that met the scoping review's criteria, Table 2 shows that multiple other studies mention the benefits of imaging SH ankle fractures, such as improving the entry point and direction of the screw, detecting occult fractures, detecting fibular fractures, detect ligament injuries, and determine the risk of PPC[14, 28-40]. There was not a focus in the literature between cost and fracture patterns or outcomes despite plenty of research between fracture patterns and outcomes.

There is a severe lack of information regarding specific costs in treating distal physeal ankle fractures in the pediatric population despite being a common fracture with growth arrest complication rates of 2-40%[2]. There are multiple pathways to reduce cost. A study examining nearly 12,000 patients found a 1.5 times increase in direct hospital cost when any complication resulted from surgical intervention, regardless of the complication[41]. Another method to reduce the cost to the patient would be to decrease the need for an extended length of stay (LOS). A reduction in LOS by 0.5 days would save a patient $457 to $846 per hospitalization, which equates to $500-$900 million annually in the United States[42]. A third way to mitigate costs would be through decreasing readmission rates. In shoulder arthroplasties, each readmittance costs $13,871.00 ± $14,301.06. Due to this high cost, AI is conducting research to detect the patients with the highest likelihood of readmission[43]. Finally, a decision tree model can be made so that the physician and patient can better understand the costs and benefits of an intervention[44]. Creating definitive, efficient patient care pathways can lead to better patient outcomes at a lower cost[45, 46]. Currently, the risk of PPC occurring increases dramatically with the number of reduction attempts, with one attempt having an 11% rate of PPC, two attempts having a 25% rate of PPC, and four attempts having a 50% rate of PPC[13, 47, 48]. Additionally, surgical fixation with anatomic reduction does not reduce the incidence of PPC and may increase the need for follow-up surgeries[15]. Decreased complication rates, decreased LOS, decreased readmissions, and an accurate decision tree would reduce the cost of distal physeal ankle fractures in the pediatric population and allow them to make better health decisions.

Reducing initial imaging and diagnostics could benefit the patient by reducing costs. While this topic has some published data, the studies contradict each other, and there is no consensus regarding when imaging is required and when it is not[14, 26, 28-34, 49-51]. Collectively, these findings suggest that while cost considerations are crucial, they must be balanced against the need for appropriate diagnosis and treatment to optimize outcomes and minimize long-term complications in this pediatric population. Based on other surgical interventions, the cost can be decreased through lowering complication rates, decreasing LOS, decreasing readmissions, and creating a cost-effective decision tree to better educate physicians and patients.

Limitations

This scoping review faced several limitations that should be considered when interpreting the findings. Firstly, there was a significant paucity of literature regarding the cost and cost-effectiveness analysis of distal tibial physeal fractures in the pediatric population, with only seven studies mentioning costs. The limited available evidence makes it challenging to draw comprehensive conclusions and highlights the need for more robust research. Additionally, the included studies exhibited substantial heterogeneity in their methodologies, outcome measures, and study populations, hindering practical synthesis and comparison of the findings. Furthermore, the geographical scope of the included studies was predominantly limited to North America, potentially restricting the generalizability of the results to other regions with distinct healthcare systems and economic contexts. Lastly, due to the scoping nature of the review and the limited number of relevant studies, a quantitative meta-analysis could not be performed, and the findings were synthesized narratively, which may be subject to interpretation bias.

Future Directions

Future research endeavors should prioritize conducting comprehensive cost-effectiveness analyses of various treatment modalities, imaging techniques, and management strategies for distal tibial physeal fractures in the pediatric population. These studies should adopt a holistic approach by considering both direct and indirect costs, long-term outcomes, and potential complications associated with different interventions. Developing decision-analytic models, such as decision trees or Markov models, could prove invaluable in evaluating the cost-effectiveness of diverse treatment strategies while accounting for uncertainties and patient preferences. Furthermore, fostering interdisciplinary collaboration between orthopaedics and emergency medicine could bridge the existing communication gap and potentially identify areas for cost-effective management of these fractures across the continuum of care. Conducting multicenter and international studies would enhance the generalizability of the findings and account for variations in healthcare systems, resource availability, and economic contexts across different regions.

Importantly, future research should prioritize incorporating patient-reported outcomes, such as quality-of-life measures and functional assessments, to provide a more comprehensive understanding of the impact of different treatment strategies on patient well-being and satisfaction. By addressing these critical areas, future research can contribute to developing evidence-based guidelines and informed decision-making, ultimately improving the quality of care and optimizing resource allocation for managing distal tibial physeal fractures in the pediatric population.

CONCLUSION

This scoping review has highlighted the limited research on the cost and cost-effectiveness of distal tibial physeal fractures in the pediatric population. The findings suggest that reducing unnecessary imaging and optimizing treatment modalities may contribute to cost savings, but further comprehensive and well-designed economic evaluations are needed. Future research should focus on conducting cost-effectiveness analyses, developing decision-analytic models, promoting interdisciplinary collaboration, and incorporating patient-reported outcomes to inform evidence-based, cost-effective management strategies for these fractures. Addressing this research gap is crucial to ensure the efficient allocation of healthcare resources while providing high-quality care and optimal outcomes for pediatric patients with distal tibial physeal fractures.

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Table 2. Summary of Findings from Orthopaedic Literature

Author	Year	Summary Statement
Cass [52]	1983	SH Type-IV fractures are common in young children and carry more risk than of premature growth arrest due to the other two variations, lateral and triplane, commonly happen in older individuals.
Karrholm [14]	1983	SH classification was unable to predict growth patterns in distal tibial and fibula fractures. Progressive growth retardation or growth arrest are associated with ORIF due to displacement.
Karrholm [11]	1983	Classification of ankle fractures helps to identify diagnosis and treatment.
Kling [6]	1984	SH II, III, IV commonly cause growth arrest and varus angulation if not anatomically reduced.
Hynes [34]	1988	Future function of the physis may be predicted from the appearance of growth disturbance lines and used in the assessment for corrective treatment.
Petit [35]	1996	In regards to distal physeal tibial fractures, MRI should be limited to assessment of complications and complex fractures.
Lohman [28]	2001	Plain radiography is the main diagnostic imaging for pediatric ankle fractures, however ligament injuries and bone bruises will remain undetected.
Nenopoulos [29]	2003	In rotational injuries of the distal tibial, a radiological sign called "open fish mouth" on a lateral view in association with the injury mechanism should raise suspicion for fibula fracture or rotational deformity.
Cutler [30]	2004	Recommend routine use of CT scans preoperatively to improve entry point and direction of screw.
Sailhan [31]	2004	MRI with fat suppression is an effective method to assess for bone bridges and determine treatment modality.
Lalonde [32]	2005	Frequent follow-up on distal tibial physeal injuries is important to avoid major corrective surgery.
Nenopoulos [47]	2005	Growth deformities occurred in 14.8% of SH III and IV fractures of the medial distal tibial epiphysis.
Marsh [48]	2006	An arthroscopic approach has similar results to open surgical techniques (87% excellent or good results) in physeal bar resection following PPC.
Leary [13]	2009	Quantified the risk of PPC per number of reduction attempts with 1 being 11%, 2 was 24% and 4 was 50%.
Schurz [7]	2010	Complete anatomical reduction in all planes is the most important factor to minimize angular deformity and growth discrepancies, regardless of open or closed methods used as the intervention.
Podeswa [49]	2012	The mechanism of injury combined with a thorough physical exam will help assess imaging and develop an initial treatment. PPC risk factors include high-energy fractures, significant initial displacement, mechanism of injury and multiple attempts at close reduction.
Gufler [33]	2013	MRI is an effective method to detect occult fractures of the distal tibia.
Russo [15]	2013	Surgical fixation with anatomic reduction does not reduce the incidence of PPC and may increase the number of follow-up surgeries, but may be needed to improve joint alignment.
D'Angelo [36]	2017	Anatomic reduction and intact fibula in distal tibial physeal fractures have a positive influence on fracture outcomes.
Karlikowski [37]	2018	Periosteum interposition is another serious complication of distal tibia and fibula physeal fractures that is usually undermined by post-traumatic growth plate dysfunction.
Park [8]	2018	In patients that had an SH II fracture with greater than 3 mm displacement, PPC was associated with an older age at injury and PER-type injury regardless of type of intervention. Conservative treatment also showed PPC associated with ABD-type injuries.
Pomeranz [38]	2019	The Dias-Tachdjian Classification describes fractures based on the physis and the mechanism of injury. This classification using the mechanism of injury can lead to less missed injuries.
Stenroos [50]	2019	Follow-up radiographs in distal tibial physeal fractures that were satisfactory anatomically aligned are unnecessary. Peterson type fractures II-VI require radiographic monitoring past bone union.
Margalit [12]	2020	Patients who had an SH II fracture due to a high-grade mechanism or severe initial maximum displacement had 12-14 times greater chance of developing PPC. Of those that developed PPC with less than 1.5 years of growth, no surgical intervention was required.
Rachel [4]	2020	SH Type-II Fractures should be reduced to a displacement of 3mm or less, starting with closed reduction and moving on to ORIF if reduction is not satisfactory.
Jung [2]	2021	Physeal growth arrest 13% predicted by initial fracture displacement measured on CT.
Yuan [16]	2021	In patients who received ORIF for SH II fracture with a displacement greater than 3 mm, patients who had an associated fibular fracture had a 7 times higher chance of developing PPC.

SH = Salter-Harris, ORIF = open reduction and internal fixation, MRI = magnetic resonance imaging, CT = computed tomography, PPC = premature physeal closure, PER = Pronation-External rotation, ABD = Pronation-Abduction,