Effectiveness of surgical versus conservative treatment for distal femoral growth plate fractures: a systematic review

Submitted by

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Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

I give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

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It has certainly been a stimulating and rewarding continued effort to produce this material. I look forward to seeing the future impact of this work, not necessarily for the outcomes uncovered but the identification of the methods to collaborate with future research in mind.

Abstract

Background

Injury to the distal femoral growth plate in children is typically due to a high-energy trauma such as contact sports or motor vehicle accidents. There is no clear evidence as to whether surgery or application of a plaster or splint is the best option for these injuries in terms of growth arrest and growth deformity. Different graded distal femur physeal fractures are known to be associated with poorer outcomes.

The objective of this review was to determine whether surgery, in comparison to conservative treatment, is a safe and effective intervention for the management of distal femoral growth plate fractures.

Methods

This study included children 18 years of age or younger with a traumatic injury to a previously normal distal femoral physis.

Primary outcomes of interest were rates of growth arrest and angular deformity. Secondary outcomes included patient factors such as knee range of motion, treatment factors such as loss of position of the fracture and hospital factors such as length of inpatient stay.

A three-step search strategy for PubMed, Embase and Scopus databases was utilized to identify current studies from 1 January 1990 tol 8 January 2017. Papers selected for retrieval were assessed by two independent reviewers for methodological validity prior to inclusion in the review using standardized critical appraisal instruments from the Joanna Briggs Institute.

Results

Of the 7740 studies identified with the search, 15 case studies with data inclusive of outcomes of interest were selected for inclusion. A total of 466 patients were included.

The rate of complication in the surgical population was 37.8%. In the conservative population the rate of complication was 34.0%. Five of the 15 papers showed Salter-Harris (SH) classification to correlate with prognosis, three papers showed presence of displacement to correlate with prognosis which would have had an influence on the results of these higher graded injuries likely to have been managed operatively. A high rate of position loss and subsequent growth abnormalities was observed when conservative management was instituted.

Follow-up for three months detected complications at a rate of 19.3%, compared to a complication rate of 71.4% for follow-up of 12 years or more.

Secondary outcomes such as return of function, pain levels, non-union, specific complications of surgery and length of hospital stay were not provided in sufficient detail for judgements to be made.

This review was conducted according to the *a priori* with additional results from particular studies described. One study suggested that the presence of displacement as well as the SH classification influenced the outcome of the patient in terms of growth and angular deformity. Other studies noted a high complication rate of growth deformity in SH II fractures. Rang Type VI injuries were observed in this review, with predominately conservative management associating with satisfactory outcomes.

Conclusions

Due to the nature of the studies located and included, it is unclear whether surgical intervention is more effective than conservative intervention and which modalities of each are most beneficial in terms of growth arrest, leg length discrepancy and angular deformity. The rate of complication is marginally higher in the surgical population than that in the conservative population.

The diversity of paediatric injuries and clinician training suggests that each case must be assessed and treated on an individual basis with available resources in mind.

Chapter 1: Introduction

1.1 Anatomy at the distal femur

The growth plate, or physis, is located between the epiphysis and metaphysis at the end of long-bones in children and young adults (Figure 1.1). It is the region of the bone where tightly-regulated endochondral ossification is responsible for longitudinal growth (1, 2). The distal femoral physis is anatomically significant in that it contributes to 70% of the longitudinal growth of the femur, equating to approximately 40% of the length of the lower extremity (3-6). Previous studies analysing growth plate fractures have found that physeal fractures account for approximately 15-30% of paediatric fractures and up to 4% of total paediatric fractures involve the distal femoral physis (7, 8). At the distal femoral physis, the major anatomical structures are the lateral notch, anteromedial notch, central ridge, lateral ridge and medial peak (Figure 1.2) (9). During childhood bony development, the central ridge has the most pronounced decrease in height and surface area, whilst the lateral notches deepen (9).

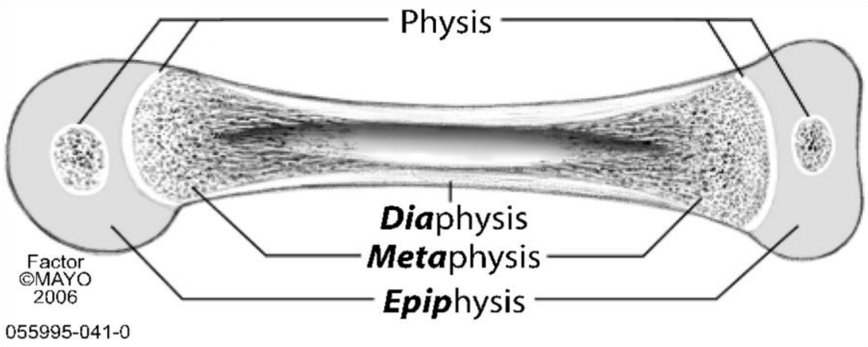

Figure 1.1: The growth plate or physis at the distal femur. The distal end is on the right (10)

From birth, there are three distinct, accelerated periods for the growth of long bones (11). They are from birth to five years, from five years to puberty, and from puberty onwards. The most accelerated phase of childhood growth occurs at puberty (11, 12). As skeletal maturity occurs, the central ridge of the distal femoral physis decreases the most in size relative to the neighbouring anatomical structures (Figure 1.2). This alters the morphology which allows for a decrease in mechanical stability, predisposing the physis to injury (9). With growth, the epiphysis becomes less cartilaginous (13). Riseborough et al. (13) observed distal femoral physeal injuries in children, noting a greater distribution of higher energy injuries in the younger cohort, hypothesizing that a thicker periosteum protects the physis from the lesser forces.

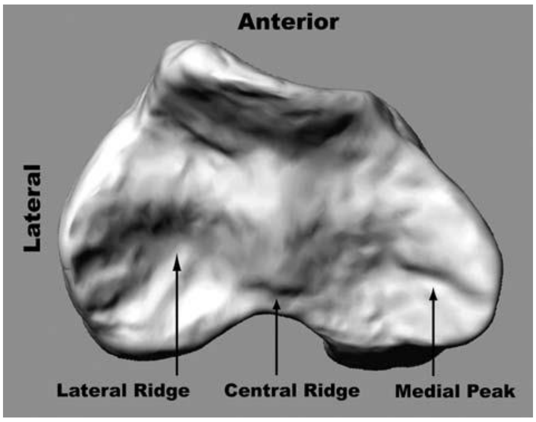

Figure 1.2: Cross section of the distal femoral physis (10)

1.2 Mechanism of distal femoral growth plate injury

The physis of the distal femur is inherently weaker than the ligaments of the knee. Therefore, if an injuring force is applied to this area, a physeal fracture will more readily be produced rather than a disruption to the surrounding ligaments of the knee (10, 14). A fracture to the distal femoral epiphyseal plate injury is frequently the result of high-energy forces. Common mechanisms of injury include motor vehicle accidents (including pedestrians and cyclists), sports-related injuries and falls (15-17). Historically, when wagons and carts were common modes of transportation, a child's foot lodging in a spoke would readily result in a distal femoral physeal fracture, causing significant morbidity and mortality (18). Abduction, adduction, hyperflexion and hyperextension are known mechanisms of distal femoral physeal fractures (5).

1.3 Treatment considerations

In treating distal femoral physeal fractures, surgery is thought to have less risk of re-displacement of the facture, yet this treatment modality is not without risks (19). Potential surgical complications include osteomyelitis, injury of surrounding structures including vascular injury, nerve injury and growth plate injury (5, 15, 19). For conservative treatment, complications relate to re-displacement of the fracture (17).

To date, there are no known biological therapies that can regenerate cartilage, recreate physeal physiology and prevent the undesired bony repair (20).

1.4 Significance of distal femoral physeal injuries

A distal femoral physeal injury in children is fraught with numerous potential complications (3, 5, 16, 21, 22). Complete or partial growth arrest is commonly seen, which may manifest clinically in leg length discrepancy and angulation deformity (5). Additionally, limitation on knee motion, quadriceps atrophy, osteomyelitis or osteoarthritis may result from this injury (5, 23, 24). A meta-analysis by Basener (23) studying distal femoral physeal fractures reported an incidence of 52% in growth disturbance, with 22% of the growth disturbance greater than 1.5cm. Arkader et al. (22), similarly reported a complication rate of 40% following distal femoral physeal fracture with growth arrest being the most common.

It has been suggested that growth disruption and angular deformity follow peripheral bridging as a result of disruption to the zone of Ranvier, the surrounding edge of the growth plate (5, 10). A radiological study proposed a graduation of the physeal injury, suggesting it begins as an incomplete bridge at the central area with a dense sclerotic core, causing continued disruption at this area (25). It has been postulated that fracture type, fracture mechanism, direction of injury, displacement, nature of physis and treatment mode may correlate with the clinical outcome of a distal femoral physeal injury (12, 16, 19, 22, 26). Some authors have suggested follow-up until skeletal maturity, as the potential for late complications may exist (3, 16, 19).

For epiphyseal fractures of the distal femur, modes of diagnosis and further evaluation include plain radiography and computed tomography. Magnetic resonance imaging (MRI) can provide gradient sequences to readily highlight the physis and is the most suitable method for detecting bone-bridge formation (27, 28). A systematic approach utilising a trauma team must be employed when assessing these patients to ensure all injuries are detected and managed appropriately.

1.5 Classification of growth plate injuries

Numerous classification systems for physeal fractures have been proposed and developed over the years. Foucher in 1863 (30) first categorised these injuries according to the separation of the epiphysis in relation to the diaphysis (see Figure 1.1). The Salter-Harris (SH) classification, described in 1963, now appears to be the most commonly used (16, 22, 29). This system is able to correlate the mechanism of injury with the appearance of the fracture lines, repair and suggest growth prognosis (30, 31). Additions and further modifications to the SH classification have been made in recent years (10, 32-35).

A SH I fracture is considered to involve the cartilage of the growth plate. SH II involves bony disruption from the metaphysis to the growth plate. A SH III fracture is from the epiphysis to the growth plate. A SH IV injury is through the metaphysis, physis and epiphysis, whereas a SH V fracture is a crush injury to the physis. A type VI injury was added to the initial SH classification by Rang and is a displacement of the perichondrial ring that can also avulse the lateral collateral ligament (35, 36). Further to these classifications, a physeal bar may form when the destroyed part of a growth plate is left to heal naturally, with ossification and partial closure of the growth plate (37).

An injury or fracture is considered to be 'open' if there is a wound in close proximity to the fracture rather than a direct 'tract' between the wound and the fracture.

1.6 Clinical context

1.6.1 Approach to trauma

For an injury to the distal femoral physis to occur, a high-energy mechanism of injury is usually involved (22). Clinicians must be vigilant in seeking to detect other injuries. This is because the pain associated with a distal femoral physeal fracture may distract the patient from additional sinister injuries such as those of a spinal or visceral nature.

A co-ordinated, team based trauma response with simultaneous examination and management of the patient is necessary to promptly identify and treat potentially co-existing life-threatening conditions. In fact, trauma is the leading cause of mortality and morbidity in the paediatric Western population, having been reported as approximately 3.7% in recent years (38-40).

Specialized trauma teams prioritise life-threatening injuries via a systematic and sequential approach in the primary and secondary survey of the patient. The primary survey first addresses the patient's airway for obstruction, whilst maintaining cervical spine precautions. This is followed by Breathing, Circulation (including pelvic and femoral fractures), then Disability and Exposure. Often, in a trauma hospital there are multiple doctors with these designated roles to attend to these components simultaneously. When the primary examination is complete, it is then repeated. If the patient is stable, the team may progress to the secondary survey to diagnose and manage more peripheral injuries. Close observation of vital parameters such as the respiratory rate, oxygen saturations, heart rate blood pressure, capillary refill, as well as the patient's airway and mental state must be maintained throughout (41, 42).

Suggestions of a fracture include pain, additional swelling, haematoma or visible deformity. The musculoskeletal examination must include particular attention to the neurovascular examination to ensure the popliteal artery, tibial and peroneal nerves are not injured. For ligamentous injuries, stress testing should be performed on post-union examination.

1.6.2 Paediatric differences

Clinicians must note that children are not simply small adults. Their physiology varies considerably, even throughout their development as a neonate, infant, young child and adolescent. These factors are important when seeking to maintain a patient's normal physiology.

In general, the skeleton of a paediatric patient is more elastic, protecting the more condensed thoracic and abdominal structures (38). A child has less fat and more elastic connective tissue (38). Any force therefore is distributed more widely throughout the body. However their shorter stature predisposes them to a higher incidence of abdominal trauma in motor vehicle accidents (41). Their larger body surface area with smaller absolute blood volume means they are more susceptible to hypothermia, fluid losses and shock, although their compensatory mechanisms may allow a blood loss of 25-30% before this is reflected in the blood pressure (41).

From a musculoskeletal viewpoint, the periosteum is thicker, providing better protection from deforming forces as well as bony displacement should a fracture occur. Although the periosteum is less likely to rupture completely, especially on the compression side of the fracture, it may be more easily elevated from the diaphyseal and metaphyseal bone. Ligaments and joint capsules are more tolerant of high-energy forces than bone, cartilage or the physis and are therefore less prone to injury. The paediatric patient is unique in that their remodelling capacity is far superior to that of an adult following an equivalent fracture. The potential for remodelling is dependent on the age of the child, the distance from the end of the bone and the degree of angulation of the fracture (5, 41).

Children are more vulnerable to injury due to clumsiness, poor judgement and lack of awareness of the consequences of their actions. An analysis by Bijur (45) found that predictors of injury in the paediatric population included being younger than five years, male sex, young maternal age and having more older and fewer younger siblings.

The clinician and the treating teams must remain vigilant in ensuring the long-term safety of the patient. Child abuse or non-accidental injury is a spectrum involving emotional, physical and sexual abuse. There is no discrete diagnostic pattern, rather suspicions being raised in the setting of a vague history, inconsistent mechanism of injury with the fracture pattern, delayed presentation and repeated injuries (43).

1.7 Management goals

For growth plate fractures, the aim of management is to keep the metaphysis, epiphysis and physis (see Figure 1.1) separate so that the physeal cartilage is able to repair freely within. In turn, this is believed to prevent growth deformity (37). Management decisions regarding distal femoral physeal injuries are generally constructed around the degree of displacement and the SH grading (see Section 1.5) (16, 21, 22, 24, 29).

1.8 Interventions

The goal in fracture management is to gain reduction whereby the bones are returned to their pre-injury position. Secondly, the priority is to hold the reduction in place. Fractures in a good position do not require reduction but the degree of fixation (device to hold the fracture) must be appropriate.

Conservative interventions for distal femoral physeal fractures may range from no active treatment to physical manipulation of the fracture with immobilisation in a plaster cast or a splint.

In contrast, these injuries may also be managed operatively or surgically. This can be defined as treatment either by incision or physical manipulation with hardware fixation by a surgical doctor in a surgical theatre. Examples include open reduction (the fracture is directly visualised surgically) with plate and screw or Kirschner wire fixation. Non-surgical or conservative treatment includes all other therapies.

1.9 Literature gap

In a search of available literature, no systematic literature review was located evaluating the most effective treatment methods for distal femoral physeal fractures. Published studies show a degree of inconsistency in implementing surgical and conservative treatments for similar fractures and presentations.

1.10 Current practice

Generally, current practice for distal femoral physeal fractures is for non-displaced SH I fractures to be managed conservatively in a full-length leg cast or hip spica. If displacement does exist, closed manipulation with a cast may be used. Internal fixation involving K wires or pinning through the epiphysis offers another option for this fracture type. Non-displaced SH II fractures may be managed non-surgically but must be monitored closely for loss of reduction. Displaced SH II as well as SH III and IV have been managed surgically, although exact methods of surgical approach and devices vary (16, 21, 22, 24, 29).

The decision regarding the exact management of these fractures is made by the treating specialist. It may be influenced by factors such as the surgeon's knowledge base, experience and expertise, and available resources.

As distal femoral physeal fractures are known to be associated with a high incidence of complications, surgeons advocate ideal follow-up to until skeletal maturity; despite this follow-up is commonly only until one year following injury.

The clinical presentation and trajectory can be illustrated with the inclusion of a case presentation. The clinical course of a distal femoral physeal fracture of 10-year-old boy described here demonstrates the importance of prompt recognition as well as implementation of timely, appropriate treatment. This particular patient was managed surgically and acquired no complications.

1.11 Case study of a SH II distal femoral physeal fracture managed surgically

JW is a 10-year old male, recently emigrated with his family from Africa. He presented with pain and deformity over his distal thigh following a fall whilst jumping over bins at school. X-rays performed showed a displaced SH II distal femoral fracture (Figure 1.3). JW underwent reduction and internal fixation with a 6.5mm partially threaded screw and two retrograde crossed 3.2mm K wires. An image intensifier confirmed anatomical reduction and satisfactory hardware position (Figure 1.4). The fixation was supplemented by a Zimmer straight leg splint. To maintain the reduction, the child was informed not to place weight through this limb for six weeks. At six weeks post-operatively, the fracture had united and the K wires were electively removed. The physis remained intact. At one year post injury, the patient was pain-free and had returned to school sport.

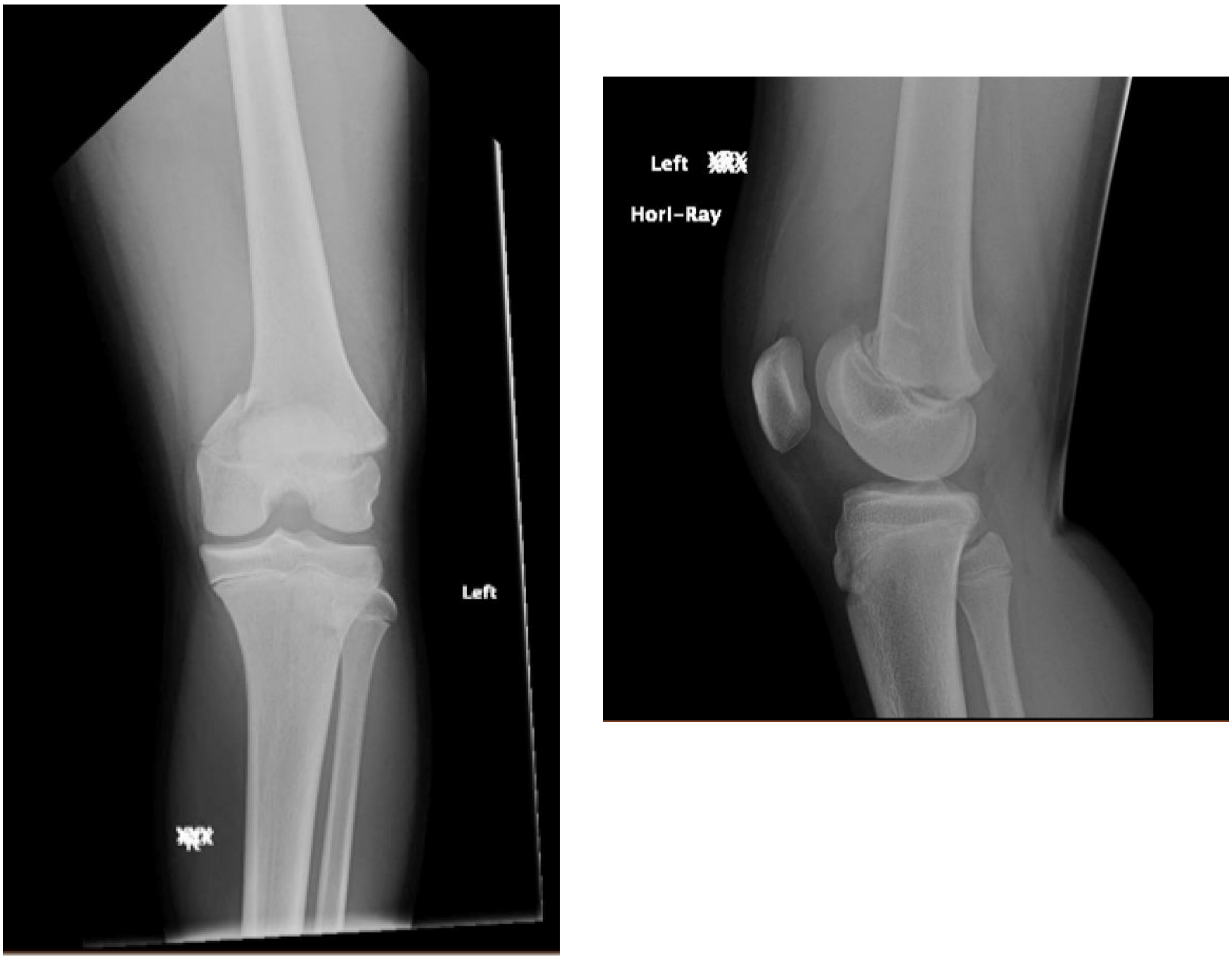

Figure 1.3: Case study (initial plain radiographs). This demonstrates a SH II distal femoral physeal fracture with anterior displacement of the distal fragment.

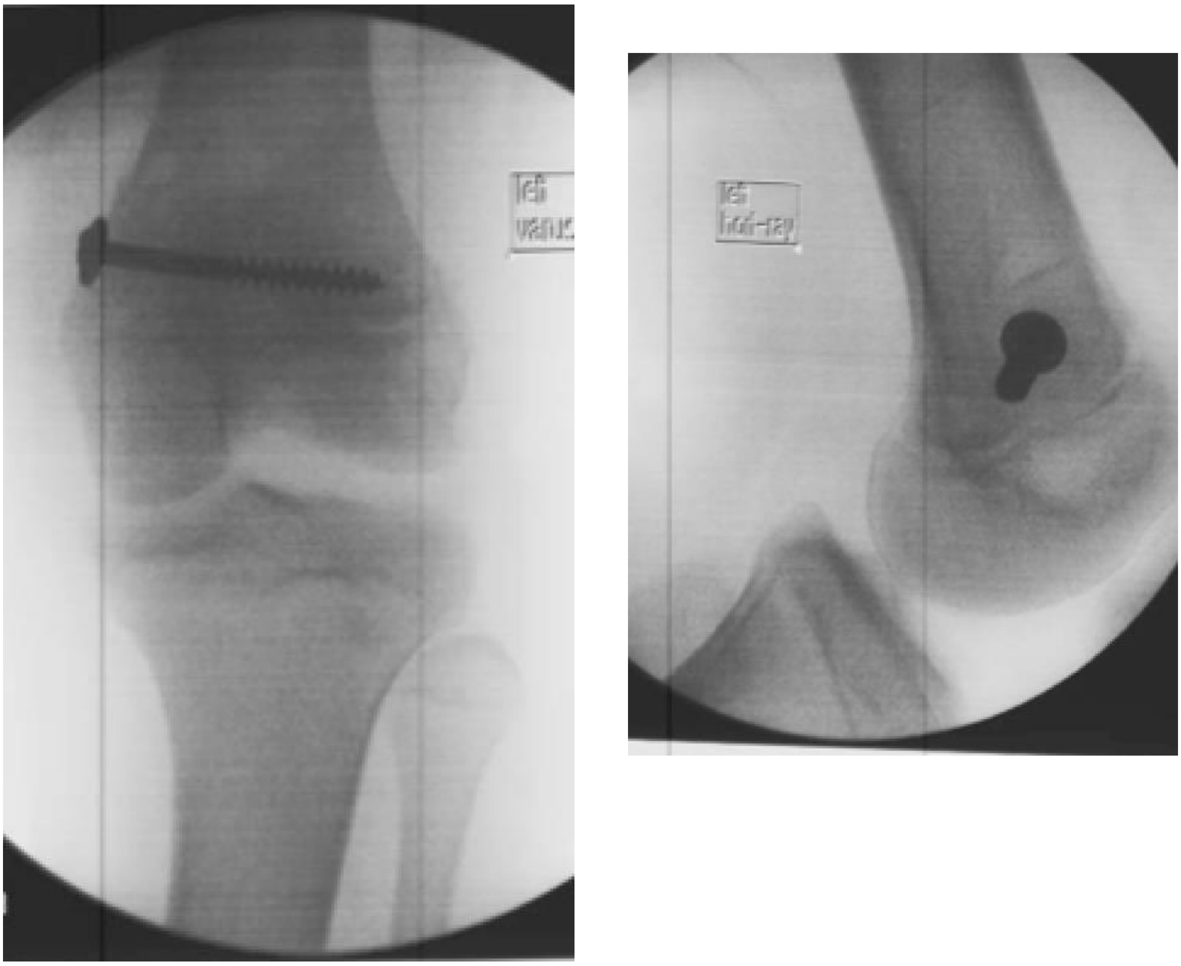

Figure 1.4: Case study. Plain radiographs at 6 weeks show the fracture internally fixed with a single metaphyseal screw, with maintained reduction and no signs of growth deformity following removal of the K wires.

1.12 Purpose of this review

The purpose of the systematic review presented in this thesis was to synthesize the best available evidence to determine whether surgery and conservative management options are safe and effective interventions for the management of distal femoral growth plate fractures in children. .

More specifically, the objectives were to compare:

i. Different methods of surgical treatments in the acute management of distal femoral growth plate fractures in children and adolescents.
ii. Different methods of non-surgical treatments in the acute management of distal femoral growth plate fractures in children and adolescents.

iii. Surgical versus non-surgical treatments in the acute management of distal femoral growth plate fractures in children and adolescents.

iv. Different outpatient follow-up strategies, in particular, frequency of visits, frequency of radiographic evaluation and duration of patient follow-up following treatment of distal femoral growth plate fractures in children.

Chapter 2: Systematic review methods

The systematic review was performed in accordance with the methodology of and utilising research tools of the Joanna Briggs Institute. Following development of the research question, a systematic review protocol was prepared and justified before a panel of Paediatric Orthopaedic Consultants and academics from the Joanna Briggs Institute (Appendix I). This presentation and indeed systematic review was prepared in accordance with the Joanna Briggs Institute Reviewers' Manual: 2014 edition (44).

2.1 Types of participants

This review considered studies that included male and female children, younger than or equal to 18 years of age, with a distal femoral physeal fracture. Children considered had either an isolated injury to the distal femoral physis or multiple injuries. The distal femoral physeal fractures evaluated were open or closed injuries.

This review did not consider children with osteochondritis disseats, Blount's Disease, or children with other comorbidities which may adversely affect the prognosis following repair of a growth plate fracture (45).

2.2 Types of interventions

This review considered studies that evaluated surgical and conservative treatments for distal femoral growth plate fractures in the acute hospital setting. This review also considered studies that evaluated different outpatient follow-up strategies. In particular, the frequency of outpatient follow-up visits, intervals between radiographic evaluation and the duration of patient follow-up were evaluated to determine the detection rate or incidence of outcomes such as growth arrest.

Surgery was defined as treatment either by incision or physical manipulation with hardware fixation by a surgical doctor in a surgical theatre, for example, open reduction internal fixation. In contrast, conservative treatment was defined as any treatment for a distal femoral physeal fracture not involving hardware fixation such as closed reduction and application of a splint.

2.3 Types of outcomes

This review considered studies that included the following outcome measures:

Primary outcomes:

1. Rate of growth of the distal femur with different treatment strategies determined by the presence or absence of Harris growth arrest lines on X-ray or measured by absolute or relative leg length discrepancy.
2. Angular or rotational deformity, measured radiographically in accordance with the appropriate technique described by Dror Paley (46).
3. Incidence of complications such as growth disturbance for different outpatient follow-up strategies, in particular, frequency of visits and duration of patient follow-up, following treatment of distal femoral fractures in children.

Secondary outcomes:

1. Patient factors: Return of function in terms of pain control or absence of pain, walking ability, knee range of motion, return to sport, muscle atrophy and ligamentous laxity.
2. Treatment factors: Failure of treatment including non-union, mal-union, re-displacement, and need for subsequent treatments or surgery. Complications of surgery or other treatments may include vascular injury, nerve injury, infection, thromboembolic disease, compartment syndrome or other secondary injury from the treatment.
3. Hospital factors: Length of stay in hospital and resources required to perform certain treatments, for example, the cost of a plate or screws with cast immobilisation in comparison to cast immobilisation on its own.

2.4 Types of studies

Priority was given to higher level evidence as described in the Joanna Briggs Institute Reviewers' Manual: 2014 edition (44). This review first considered any randomized controlled trials (RCTs) for inclusion. In the absence of RCTs, non-randomized controlled trials, quasi-experimental, before and after studies, prospective and retrospective cohort studies, and case control series were considered. This review considered descriptive epidemiological study designs, including case series and case reports, for inclusion.

2.5 Review method

2.5.1 Search strategy

A three-step search strategy was utilized in this review to identify both published and unpublished studies from 1 January 1990 until 8 January 2017. An initial limited search of PubMed, Embase and Scopus was undertaken followed by an analysis of the text words contained in the title and abstract, and of the index terms used to describe the article. A second search using all identified keywords and index terms was then undertaken across all included databases. Thirdly, the reference list of all identified reports and articles was searched for additional studies. Studies were considered from any country with the article available in English. Studies published from 1990 onwards were considered for inclusion in this review to ensure comparable and up to date treatment modalities.

An initial search strategy was developed for the PubMed database. It was then minimally modified to apply to the other selected databases. The databases searched included: PubMed, Embase and Scopus (Boxes 2.1, 2.2 and 2.3, respectively). Grey literature was searched through the Scirus database. Papers that met inclusion criteria presented at conferences or meetings hosted by state or national orthopaedic associations were also considered for inclusion.

An attempt to contact the Australian Orthopaedic Association for information related to previous research involving fractures of the distal femoral physis was unsuccessful. International orthopaedic associations were not contacted following this.

femur[mh] OR femur[tw] OR femoral[tw]

AND

epiphyses[mh] OR epiphys*[tw] OR growth plate*[tw] OR physe*[tw] OR physis[tw] OR salter harris[tw]

AND

Wounds and injuries[mh:noexp] OR injur*[tw] OR fractur*[tw] OR fractures, bone[mh:noexp]

Key
mh: MeSH heading
tw: Text word
noexp: Automatic MeSH explode off

Box 2.1: Search of PubMed database using keywords and synonyms to capture all potentially relevant studies. MeSH (Medical Subject Headings) use a controlled vocabulary thesaurus within the PubMed database.

'femur'/exp OR ‘femur’:de,ab,ti OR ‘femoral’:de,ab,ti

AND

'epiphysis'/exp OR 'growth plate'/exp OR ‘growth plate’:de,ab,ti OR ‘growth plates’:de,ab,ti OR epiphys*:de,ab,ti OR physe*:de,ab,ti OR ‘physis’:de,ab,ti

OR ‘salter harris’:de,ab,ti

AND

'injury'/exp OR 'fracture'/exp OR injur*:de,ti,ab OR fractur*:de,ti,ab

Key
exp: Explosion Emtree index term
de: Index term (Emtree subject descriptor)
ab: Abstract
ti: Article title

Box 2.2: The structure of the search was altered for Embase using the same approach. Embase functions such as the ‘Explosion Emtree index term’ were used to ensure potentially relevant studies were not missed.

TITLE-ABS-KEY(femur) OR TITLE-ABS-KEY(femoral)

AND

TITLE-ABS-KEY(epiphys*) OR TITLE-ABS-KEY("growth plate") OR TITLE-ABS-KEY("growth plates") OR TITLE-ABS-KEY (physe*) OR TITLE-ABS-KEY(physis) OR TITLE-ABS-KEY("salter harris")

AND

TITLE-ABS-KEY(fractur*) OR TITLE-ABS-KEY(injur*)

Key
ABS: Abstract
KEY: Keyword

Box 2.3: As with the Embase and PubMed searches, the Scopus search structure included variations on the three keywords to maintain consistency and maximise the capture of all potentially relevant studies.

2.5.2 Study selection and assessment of methodological quality

Citations retrieved from database and grey literature searching were downloaded into Endnote v7.0 (Clarivate Analytics, USA). First citation titles and subsequently abstracts were screened against the inclusion criteria for the review (see Sections 2.1-2.4). Full texts of potentially relevant studies were retrieved and further assessed against the review inclusion criteria to determine final eligibility. Eligible studies were assessed for methodological validity by two independent reviewers, Nicholas Hayes and Kandiah Umapathysivam. Reviewers discussed any differences and discrepancies upon completion of their independent review. Following discussion, there were no outstanding disagreements between the reviewers and as such discussion with a third reviewer was not required. The Joanna Briggs Institute Critical Appraisal Checklist for Descriptive Case Series provided a useful tool to ensure standardised, objective critical appraisal of the studies prior to inclusion in the review (Appendix II). A study was considered to be of poor quality if it scored less than 5 out of 9 possible points, medium quality if it scored 5 to 7 out of 9 points, and high quality if it scored 8 or more.

2.5.3 Data extraction

Data was extracted from the studies and integrated into a standardised data extraction proforma, modelled on the Joanna Briggs Institute quantitative data extraction tool from JBI-MAStARI (Appendices III and IV). This provided a structure for comparisons to be made between studies.

The data extracted included inclusion and exclusion criteria and patient factors such as age, sex and mechanism of injury. Where possible, individual patient data was extracted. Injury factors such as SH classification, grading of displacement, associated primary injuries including vascular injury, nerve injury, compartment syndrome and other bony injuries were considered. Treatments provided were recorded. Outcomes evaluated included normal growth, function or complications such as growth arrest, post-surgical infection, loss of reduction and patient limitations. The type of statistical analysis used was recorded, where described.

Attempts were made to contact corresponding authors or other contacts of all included papers to provide individual patient data to allow for a meta-analysis. The individual data included age and sex of the patient, mechanism of injury, SH classification, presence and direction of displacement, exact treatment with post-operative weight-bearing plan as well as frequency and physical examination findings at each follow-up appointment. Nil additional patient data was provided despite the requests made.

2.5.4 Data synthesis

Despite the methods detailed in the *a priori* protocol (Appendix I), there were insufficient studies with comparable patient characteristics and outcome measures to pool data for individual SH distal femoral physeal fractures. It was therefore not possible to perform meta-analysis on this dataset. Instead, a narrative synthesis accompanied by tabular presentation of the results was performed.

Chapter 3: Results

3.1 Process of study selection

From the search of databases and for grey literature, 7740 studies were identified. From these, 7425 were omitted after review of the title. There were 315 abstracts reviewed to determine eligibility. After review of the abstracts, and removing duplicates and studies outside the date criteria, 83 studies remained. Twenty-two studies were excluded as the articles were not in English. Sixty-one studies were retrieved for full text examination. After review of these full text articles, 45 studies were excluded as they did not satisfactorily meet the inclusion criteria as outlined in Appendix V. Sixteen case series studies were appraised, of which one study was excluded at this stage as there was inadequate detail of primary outcomes (47). The process of study identification, selection and inclusion is illustrated in Figure 3.1.

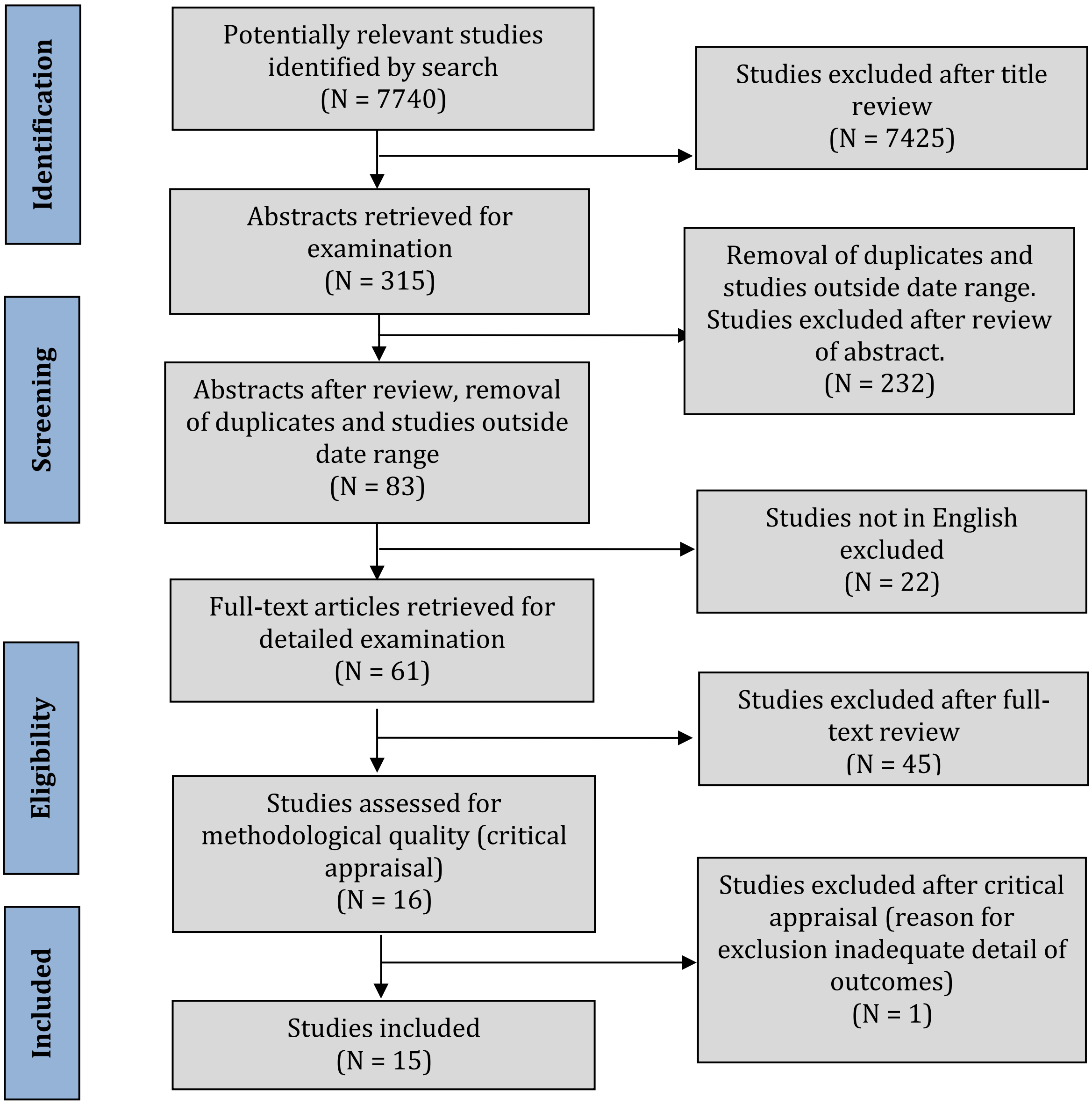

Figure 3.1: PRISMA flowchart of study selection and inclusion process.

3.2 Methodological quality of included studies

Overall, the majority of included studies were deemed to be of medium quality, scoring between 5 and 7 on the JBI Critical Appraisal Checklist for Descriptive/Case Series (Appendix II; Table 3.1). Two studies were rated as poor quality, scoring 4 out of 9 (Table 3.1). (17), (36).

A single study was excluded at this point (47) (Table 3.1). Whilst it contained four patients with appropriate injuries, the study did not provide the outcome of three of these. Therefore, with only one patient's outcome available, no comparisons could be made and the paper was excluded from the review.

The included case series demonstrated, across all papers, nil random sampling (Table 3.1, Q1), nil standardised comparison and heterogeneous patient populations in terms of age, mechanisms of injury, associated injuries and method of treatment selection. No paper adequately described the outcomes of people who withdrew and were included in the analysis.

Studies had well defined inclusion criteria (Q2). Standards such as the use of X-rays or clinical examination, whilst reasonably well described, were assessed and measured differently across the studies (Q4). Confounding factors such as the institution's preference for certain treatments was mentioned, yet there was no allowance to reduce this bias (Q3). The lower scores attained by studies were due to poor descriptions of the groups – comorbidities, specific ages for the treatment. Occasionally, the low score was due to a failure of studies to detail the specific treatments for specific patients; instead treatments were described as a whole. With respect to Question 7, which assessed description and any inclusion of the outcomes of patients who had withdrawn from the study, nil studies provided this information.

The experience and skill set of the treating surgeon and access to resources were a factor potentially affecting the overall outcome of the patient. Further, the interpretation of the patient's clinical and radiological features at follow-up points also varied and influenced the reporting of results.

There was significant heterogeneity across the studies in terms of patient numbers and SH types. Many of the papers only evaluated a single SH injury or single treatment of the distal femoral physis. As such, comparisons of patients managed at the same hospital, by the same surgeon and hospital staff, and with the same X-ray facilities and protocols could not be achieved across groups.

Table 3.1: Critical appraisal of included studies using the JBI-MAStARI tool for appraising descriptive studies

Study	Q1 Random sampling	Q2 Clearly defined inclusion criteria	Q3 Confounding factors accounted for	Q4 Objective assessment	Q5 Description of groups	Q6 Appropriate follow-up time	Q7 Withdrawals accounted for	Q8 Reliable outcome measures	Q9 Appropriate statistical analysis	Total
Arkader A., Warner W., Horn, D., Shaw R., Wells L., 2007 (21)	N	Y	Y	Y	Y	Y	N	Y	Y	7
Buess-Watson E., Exner G., Illo O., 1994(48)	N	Y	Y	Y	N	Y	N/A	Y	N	5
Caterini R., Farsetti P., d'Arrigo C., Ippolito E., 1991(49)	N	Y	Y	Y	Y	Y	N/A	Y	N	6
Edmunds I., Nade S., 1993(15)	N	Y	Y	Y	Y	Y	N/A	Y	U	6
Eid A., Hafez M., 2002 (16)	N	Y	Y	Y	Y	Y	N/A	Y	Y	7
Fiala O., Mihula A., Dedek T., Grmela M., Zahorak K., Ulybin B. 1992(47)	N	Y	Y	N	Y	N	N/A	N	N	3
Garrett B., Hoffman E., Carrara H., 2011(29)	N	Y	Y	Y	Y	Y	N	Y	Y	7
Graham J., Gross R., 1990(17)	N	Y	Y	Y	N	N	N/A	Y	N	4

Havranek P., Pesl T., 2010(36)	N	Y	U	Y	N	Y	N/A	Y	N	4
Ilharreborde B., Raquillet C., Morel E., Fitoussi F., Bensahel H., Penneçot G., Mazda K., 2006(50)	N	Y	Y	Y	Y	Y	N/A	Y	N	6
Kritsaneepaiboon S., Shah R., Murray M., Kleinman P., 2009(51)	N	Y	Y	Y	Y	Y	N/A	Y	N	6
Krueger-Franke M., Siebert C., Pfoerringer W., 1992(52)	N	Y	Y	Y	Y	N	N/A	Y	N	5
Lippert W., Owens R., Wall E., 2010(53)	N	Y	Y	Y	Y	N	N/A	Y	Y	6
Partio E., Tuompo P., HIrvensalo E., Böstman O., Rokkanen P., 1997(54)	N	Y	Y	Y	Y	Y	N	Y	N	6
Plánka L., Skvaril J., Stary D., Jochymek J., Gál P., 2008 (28)	N	Y	Y	Y	Y	N	N	Y	N	5
Thomson J., Stricker S., Williams M., 1995(19)	N	Y	Y	Y	Y	Y	N/A	Y	Y	7

Appraisal questions are available in Appendix III. Y, Yes; N, No; N/A, Not Applicable.

3.3 Characteristics of included studies

3.3.1 Study design

All 15 studies were retrospective case series with patient numbers of between six and 151 patients. All were Level 4 evidence, according to the JBI Levels of Evidence (44). There were no higher-level evidence papers identified by the search. Although typically containing a small number of subjects, this study design allowed moderately detailed descriptions of the subjects, injuries and outcomes.

Patients were followed up between two months to 19 years post injury but follow-up durations also included until skeletal maturity or the conclusion of growth (52).

3.3.2 Geographical location

Europe was the most common continent of origin, accounting for seven out of the 15 selected studies. The remaining papers originated from North America, Australia, Egypt and South Africa (Appendix VII).

3.3.3 Study population

Overall, from the 15 included studies, 466 patients were evaluated. Patients ranged in age, from 0 to 18 years. The majority of patients were male (213 males, 64 females) (Table 3.2). Exact participant discrepance could not be determined as not all studies listed their patients' sex, others included data from other physeal fractures, and also patients lost to follow-up were not accounted for in the demographic data (Appendix VII).

The injuries studied were generally due to high-energy mechanisms of injury and were of low incidence within tertiary paediatric hospitals. The most common mechanisms of injury included motor vehicle accidents, motor cycle accidents, sport related accidents including American Football, bicycle injuries, winter sports such as skiing and crush injuries (see Table 3.2). Two obstetric injuries were also included.

There were 70 cases of SH I, 276 of SHII, 58 of SHIII, 45 of SH IV, three of SHV and eight of SHVI (Table 3.2). Ten open fractures were included. Sixteen cases had neurovascular injuries on presentation. This included 12 peroneal palsies and four vascular injuries (Table 3.2, Appendix VII).

Table 3.2: Study numbers, SH classification, aetiologies of injury and age distribution in included studies

Study	SH I	SH II	SH III	SH IV	SH V	Type VI	Males	Females	Total no. of patients	Aetiology of injuries	Age range	Avg. age at injury	F/u range (avg. f/u)
Arkader A., Warner W., Horn, D., Shaw R., Wells L., 2007(21)	18	43	4	7	1	0	67[a]	16[a]	73	MVA including pedestrian vs. motor vehicle Sports related (most common American Football)	0.41 to 17 years	10 years	1.5 to 7 years (2 years)
Buess-Watson E., Exner G., Illo O., 1994(48)	1	9	4	0	0	0	28[b]	15[b]	14	High energy trauma at winter-sports Bicycle Athletics/pedestrian/fall	6.25 to 14.75 years	11.75 years	- (13 years)
Caterini R., Farsetti P., d'Arrigo C., Ippolito E., 1991(49)	1	4	0	2	0	0	5	2	7	2/7 obstetric injuries, otherwise not mentioned	Birth to 14.5 years	8.77 years	12.08 to 36.67 years (22.69 years)
Edmunds I., Nade S., 1993(15)	0	16	4	2	1	0	23[a]	10[a]	23	Motor vehicle vs. pedestrian or cyclist Fall Motorcycle accident Motor vehicle accident Sporting accident	4 to18 years	12 years	'1 year minimum' (4.8 years)

Eid A., Hafez M., 2002 (16)	39	65	19	22	6	0	129	22	151	Sports-related activities Road traffic accidents Various falls	0.83 to 16 years	12.3 years	2 to 19 years (not provided)
Garrett B., Hoffman E., Carrara H., 2011(29)	4	46	2	3	0	0	-	-	40	Motor vehicle accident, including those involving a pedestrian or cyclist Crush injuries Falls Sports-related	-	10 years (median)	2 years until skeletal maturity (not provided)
Graham J., Gross R., 1990(17)	2	7	0	1	0	0	9	1	10	(American) Football Other sports Auto-pedestrian accident	Nil provided	13 years	- (not provided)
Havranek P., Pesl T., 2010(36)	0	0	0	0	0	8	21[b]	15[b]	8	All Type VI bony injuries of body: Athletic sports, Soccer, Gymnastics Stumbling/ fall from height Traffic injuries Gunshot wounds	4 to16 years	11.6 years (median)	2 to 4 years (not provided)
Ilharreborde B., Raquillet C., Morel E., Fitoussi F., Bensahel H., Penneçot G., Mazda K., 2006(50)	0	20	0	0	0	0	16	4	20	MVA versus pedestrian or cyclist Sports related (ski, soccer, judo) Fall	8 to 15 years	11 years	0.25 to 11 years (4.08 years)

Kritsaneepaiboon S., Shah R., Murray M., Kleinman P., 2009(51)	0	6	0	0	0	0	6	0	6	Hyper-extension injury Direct injury to the knee	8 to 16 years	12.5 years	0.15 to 1.5 years (not provided)
Krueger-Franke M., Siebert C., Pfoerringer W., 1992(52)	2	4	2	2	0	0	60[b]	25[b]	10	Soccer Skiing Gymnastics Other	4 to 17 years	12.3 years (male), 12.9 years (female)	'Conclusion of growth' (not specifically provided)
Lippert W., Owens R., Wall E., 2010(53)	0	0	14	0	0	0	2	12	14	Fall/ fall down stairs/ from bicycle Tombstone fell on leg (American) football	7.67 to 17.92 years	13.87 years	0.167 to 3.92 years (1.79 years)
Partio E., Tuompo P., HIrvensalo E., Böstman O., Rokkanen P., 1997(54)	0	2	5	1	1 *	0	8	1	9	Motorbike accidents Ice hockey Fall whilst horse riding/ from bicycle	13.42 to 16.58 years	15.5 years	1 to 2.83 years (1.79 years)
Plánka L., Skvaril J., Stary D., Jochymek J., Gál P., 2008 (28) (55)	3	26	2	0	0	0	16	15	31	'Mainly sports and traffic accidents'	2 to 16 years	11.9 years	0.25 years only
Thomson J., Stricker S., Williams M., 1995(19)	0	24	2	4	0	0	22	7	29 (30 injuries)	Nil recorded	0.5 to 15 years	10.9 years	1 to 8 years (3.80 years)

Avg, Average; F/u, Follow-up; MVA, Motor Vehicle Accident

3.3.4 Intervention characteristics

In total, of the 466 patients, 206 were listed as being managed conservatively and the remaining 233 were managed surgically. Details of the type of intervention used are available in Tables 3.3, 3.4, 3.6. Twenty-seven patients did not have their specific treatment listed.

There appeared to be little change in treatment methods throughout the studied period, with the exception of traction which is now used less frequently in Western countries (17). Where possible, factors which might influence the outcome of the treatment were noted.

Mentioned in less than a third of the studies, the decision on how the patient was treated varied considerably from surgeon preference to departmental protocol.

3.3.4.1 Surgical treatment

Surgical or operative treatments ranged from closed reduction and percutaneous pinning to debridement for open fracture, followed by open reduction and osteosynthesis (Tables 3.3, 3.4 and 3.5). The experience level of the surgeon involved in the surgery was not described throughout.

It was noted that fractures were managed differently in the presence of an overlying wound (open fracture). The accepted treatment was an open washout, debridement with or without initial or delayed primary closure, but with external fixation to allow soft tissue recovery. The study by Havranek et al. (38) noted a large number of open scalding injuries, managing with open washout and fixation when soft tissues permitted. This is representative of local practice.

To further evaluate and compare the studies, treatment factors that could potentially influence the outcome of the patient were identified, with few results. A percutaneous, minimally invasive surgical approach and incision was commonly utilised, as described in Table 3.5. Partio et al. were able to describe their open approach in some detail, having used a medial or lateral exposure (54). A medial approach was the only surgical exposure described by Ilharreborde et al. (50). No alternative operative approach was identified.

In terms of reduction and fixation for Open Reduction Internal Fixation (ORIF) treatments, only Partio et al. described their method using a gloved digit to ensure anatomical reduction whilst utilising clamps (54). The material of the fixation devices in the Partio et al. study was described as self-reinforced absorbable polyglycolide (SR-PGA) and poly-L-lactide (SR-PLLA) for their screws (54). The material in hardware devices including K wires, plates and screws from other studies was not mentioned but would likely have been stainless steel or a titanium alloy.

Post-operative immobilization time also varied considerably. Partio et al. managed their population in a plaster cast for four to eight weeks post-operatively, but this was also seen to be applied for zero to three weeks (54). Eid et al. managed their post-operative patients in a long leg cast for six to eight weeks for all cases (16). Caterini et al. (49) managed their SH IV injury in a hip spica for 12 weeks following ORIF and K wire fixation.

3.3.4.2 Conservative treatment

Conservative treatments ranged from no treatment to closed reduction and casting, as demonstrated in Tables 3.3, 3.4 and 3.6. If closed reduction was performed, it was performed in the emergency department or theatre.

Whether the cast was circumferential or a backslab was not mentioned. Seven of the studies did indicate use of a plaster cast, which would be presumed to be a circumferential Plaster of Paris cast, heavier and less durable than modern synthetic materials. The medical experience of the technician applying the cast was not described, nor was the brand or material of the cylinder splints applied to the patients.

The duration of treatment varied within and between studies. Caterini et al. (49) managed one SH I injury of the distal femur in bilateral hip spica casts for eight weeks, yet in the same population, managed a SH II injury in a (unilateral) hip spica cast for eight weeks (Appendix VII). It is presumed that when Graham et al. followed up patients for four to six weeks to ensure maintenance of reduction, this was also the period of immobilization (17). Similarly, Plánka et al. removed spica casts after five weeks (28). No further information was identified relating to the period of non-weight-bearing for conservatively managed patients.

Table 3.3: Key intervention characteristics of included studies (comparative studies of surgical and conservative interventions)

Study	Surgical interventions	Conservative interventions	Outcomes reported	Based on reported outcomes, was surgical management associated with better/worse outcomes†?
Arkader A., Warner W., Horn, D., Shaw R., Wells L., 2007 (21, 56)	Closed reduction (CR) with percutaneous crossed Steinman pins Annulated screws Multiple pin fixation External fixation	Long leg cast +/- pelvic band Posterior splint Cylinder cast	Complications: Growth arrest, LLD, angular deformity, need for surgical correction, loss of reduction, superficial Steinman pin infection	Worse
Ilharreborde B., Raquillet C., Morel E., Fitoussi F., Bensahel H., Penneçot G., Mazda K., 2006(50)	ORIF of the metaphyseal fragment by cortical screws Debridement for open fracture followed by open reduction and osteosyntheis	Plaster cast immobilization only CR + plaster cast	LLD, Angular deformity, limitation in ROM, epiphysiodesis, ligamentous laxity	Worse
Plánka L., Skvaril J., Stary D., Jochymek J., Gál P., 2008 (28)	Repositioning, transfixion by K wires or 1-2 cannulated tension screws.	Spica cast	Angulation, shortening, development of porosis, limitation in hip and knee ROM, re-dislocation, re-surgery, damage to neurovascular plexus, complete healing of epiphysiolysis	Worse
Eid A., Hafez M., 2002 (16)	ORIF with 2 K wires or cancellous screws which do not cross the	Immobilised in long leg cast	Subjective complaints, gait, lower limb deformity, range of movements in the knee,	Worse*

	physis	CR + long leg cast CR + hip spica	ligamentous laxity, thigh atrophy, limb length discrepancy clinically, angular deformity clinically, premature growth arrest or angular deformities on XR, limb length discrepancy on XR	
Garrett B., Hoffman E., Carrara H., 2011(29)	CR + internal fixation with 2 smooth percutaneous K wires or Steinmann pins (1.8 to 3.2mm) crossing the physis ORIF with above K wires/ pins or screws	Cast only Closed reduction	Physeal bar formation	Worse (trend only)
Buess-Watson E., Exner G., Illo O., 1994(48)	Open reduction internal fixation (ORIF) CR + percutaneous pinning	Cast immobilization CR + cast immobilization	Asymmetric growth arrest/axis deviation, LLD, (re)operation, stability	Worse for secondary operations only
Caterini R., Farsetti P., d'Arrigo C., Ippolito E., 1991(49)	ORIF with K wire + hip spica cast	None (no treatment) Bilateral hip spica cast for 8 weeks Hip spica cast	Symptoms, physical examination findings, XR examination of complications	[Sample size too small for comparison. 1/7 patients surgically managed]
Lippert W., Owens R., Wall E., 2010(53)	Closed reduction percutaneous pinning ORIF	Cast Knee immobilizer	LLD/ growth disturbance, ROM deficit, pain, physical limitations	No difference reported/ detected
Edmunds I., Nade S., 1993(15)	Closed reduction and percutaneous fixation with wires or screws	Robert Jones bandage only	LLD, angular deformity, limitation in ROM,	Better

	Closed reduction and traction Open reduction and internal fixation (fixation with K wires, AO screws, Herbert screws)	Plaster of Paris only Closed reduction and Robert Jones Closed reduction and cast	osteomyelitis, lost position, further treatment required	
Thomson J., Stricker S., Williams M., 1995(19)	Reduction, internal fixation with screw or pin	CR in Emergency Room or theatre	LLD, malalignment, loss of ROM, loss of reduction, further bony surgery	Better (trend only)

Patient characteristics for each study are presented in Table 3.2. † Based on descriptive studies only. Conservative management preferentially used in lower SH Injuries, potentially influencing the results (see Section 4.1.1). CR, Closed Reduction; ORIF, Open Reduction Internal Fixation; LLD, Leg Length Discrepancy; ROM (Knee) Range Of Motion; K wire, Kirschner wire; AO screws, Arbeitsgemeinschaft für Osteosynthesefragen screws

Table 3.4: Key intervention characteristics of included studies (studies observing but not comparing surgical and conservative interventions)

Study	**Surgical interventions**	**Conservative interventions**	**Outcomes reported**	**Based on reported outcomes, was surgical management associated with better/worse outcomes†?**
Havranek P., Pesl T., 2010(36)	All Type VI bony injuries of body: Surgery in open/gunshot injuries – repeated debridement and subsequent skin grafting with	All Type VI bony injuries of body: Immobilisation	Partial growth arrest, leg length	Not compared

	(anticipatory) Langenskiold procedure using free fat interposition Osteosynthesis with K wires or other			
Krueger-Franke M., Siebert C., Pfoerringer W., 1992(52)	'Managed operatively'	'Managed conservatively'	Varus/valgus deformity, rotational deformity, LLD	Not compared

Patient characteristics for each study are presented in Table 3.2. † Based on descriptive studies only. Conservative management preferentially used in lower SH Injuries, potentially influencing the results (see Section 4.1.1). K wire, Kirschner wire

Table 3.5: Key intervention characteristics of included studies (studies evaluating surgical interventions only)

Study	**Surgical interventions**	**Outcomes reported**	**Based on reported outcomes, was surgical management associated with better/worse outcomes†?**
Partio E., Tuompo P., HIrvensalo E., Böstman O., Rokkanen P., 1997(54)	ORIF	Maintenance of reduction, angulation, ROM, LLD, Epiphysiodesis, ligamentous laxity, muscle atrophy, comments on daily living	Not compared

Patient characteristics for each study are presented in Table 3.2. † Based on descriptive studies only. Conservative management preferentially used in lower SH Injuries, potentially influencing the results (see Section 4.1.1). CR, Closed Reduction; ORIF, Open Reduction Internal

Fixation; LLD, Leg Length Discrepancy; ROM (Knee) Range Of Motion

Table 3.6: Key intervention characteristics of included studies (studies evaluating conservative interventions only)

Study	**Conservative interventions**	**Outcomes reported**	**Based on reported outcomes, was a particular conservative management associated with a better/worse outcome?**
Graham J., Gross R., 1990(17)	Traction alone Closed reduction and casting (with a spica or long leg cast) Closed reduction and casting	Loss of reduction, asymmetric growth arrest within 6 months manifesting as angular deformity, shortening, flexion deformity	Not compared
Kritsaneepaiboon S., Shah R., Murray M., Kleinman P., 2009(51)	HKB and physio Long leg cast (one patient only)	Return to normal activities, LLD Detection of assoc. radiographic bony and soft tissue injuries	Not compared

HKB, Hinged Knee Brace; LLD, Leg Length Discrepancy

3.4 Review findings

3.4.1 Outcomes

This review set out to assess outcomes for treatments of distal femoral physeal fractures. Due to inadequate patient data, it was not possible to assess the primary outcomes (rate of growth, angular or growth deformity, and incidence of complications) for each SH type of distal femoral physeal fracture, according to the specific surgical or non-surgical treatment provided. Secondary outcomes such as return of function, pain levels, non-union, specific complications of surgery and length of hospital stay were not provided in sufficient detail to enable assessment.

Rates of complications were not specifically reported for each follow-up frequency and duration in any of the papers. However, this was on occasion attainable when individual patient data was reported.

For X-ray investigations, aside from the mention of 'anterior-posterior' and 'lateral' X-Ray, there did not appear to be any clear radiographic protocol for how the X-ray was taken, i.e. the distance, exposure and magnification of the image. None of the studies described presence of Harris growth arrest lines – the widely accepted method of radiologically diagnosing growth arrest. For leg length discrepancy, no studies differentiated between absolute or relative leg length discrepancies. The method of measuring an angular deformity was not described throughout.

Length of stay in hospital and a comment on the cost and resources required to perform certain treatments were not provided.

3.4.1.1 Overview of main findings – surgical and conservative outcomes with follow-up strategies

Studies either lacked patient numbers or did not explore primary and secondary outcomes in sufficient detail to provide an assessment of the effectiveness of treatment strategies (Tables 3.3 and 3.4).

Whilst one of the 15 papers showed that surgical intervention was associated with a better outcome than conservative means, another showed a trend towards this (15, 19). Three other papers contradicted this, indicating that an operation would yield a worse outcome (28, 56, 57). Given these papers had very small patient numbers and insufficient patient detail, no conclusions can be drawn to suggest a superior management strategy.

Throughout the total population of surgical and conservatively managed patients, leg length discrepancy was noted in 55 cases; there were 122 cases of angular deformity present in 122 cases and radiological evidence without clinical signs was seen in 37 patients. Growth arrest that might have had angular deformity, leg length discrepancy or both was seen 87 times (Appendix VI).

Overall, across the 15 studies, the complication rate in the surgical population was 37.8% in comparison to 34% in the conservatively managed patients with distal femoral physeal fractures.

Of all cases reported, 15 predominantly conservatively managed cases lost reduction. In total, 34 of the cases required further corrective surgery. Five cases of significant pain were reported and infection arose in five cases of the surgically managed patients. There were 57 cases of knee limitation in range of motion, 22 cases of ligamentous laxity, and 42 cases of thigh atrophy. It is not understood at which point these outcomes were measured and what further treatment for the knee stiffness, thigh atrophy and ligamentous laxity was undertaken to make further comment on its effect on the patient.

Of the 15 papers, five showed SH classification to correlate with prognosis (15, 29, 49, 52, 56). In contrast, only one paper highlighted a varying outcome based on displacement whilst another paper showed the injury mechanism related to the outcome (29). Patient age was also seen by another paper to influence the result for patients (16) (Table 3.7).

Follow-up ranged from three months to 36 years. From the study by Plánka et al. that followed patients for three months only, six of their 31 patients were noted to have complications of leg length discrepancy and angular deformity (28). This represented a complication rate of 19.3%. In contrast, Caterini et al., that followed patients for 12 to 36 years, reported a complication rate of 71.4% (49). Caterini et al. also noted that some cases of growth arrest were only evident many years after initial injury (49). Specifically, one patient’s LLD was 1 cm at nine years of age; at 15 years, this LLD had progressed to 6 cm (49).

3.4.1.2 Overview of surgical outcomes

The surgical interventions ranged from closed reduction with percutaneous pinning to debridement for open fracture, followed by open reduction and osteosynthesis. This is outlined in Tables 3.3 and 3.5.

Only one study looked at surgical interventions without a comparator (54). Their method of managing distal femoral growth plate fractures with bio-absorbable implants was associated with a 50% rate of failure of fixation and a leg length discrepancy averaging 4mm in eight out of their nine adolescent patients (54).

3.4.1.3 Overview of conservative outcomes

There were two studies observing only conservative treatments in a total of 16 patients. In the study by Graham et al., a high incidence of late deformity was seen, such that nine out of 10 patients developed growth deformity, either angular deformity, LLD or flexion deformity (17). Kritsaneepaiboon et al. was able to observe posterior periosteal disruptions on MRI in SHII fractures as well as associated injuries, which included a 33% rate of associated ACL injuries (51).

The type of immobilization used varied greatly across studies and is outlined in Table 3.3 and 3.5.

Similarly, no direct comparisons of different conservative treatment methods could be made from the review due to lack of patient specific data. Studies evaluating conservative treatments only are described in Table 3.6. Graham et al (17) observed conservative interventions to associate a high incidence of late deformity, such that 9 out of 10 patients developed growth deformity, either angular deformity, LLD or flexion deformities. Seven of these patients had SH II injuries (17). The study by Kritsaneepaiboon et al. (51) observed SHII fracture patterns on MRI assessing for posterior periosteal disruption. In doing so, the authors were able to assess for other associated ipsilateral knee injuries which included two of the six patients having a concurrent Anterior Cruciate Ligament (ACL) injury (51). One of the six patients was noted to have increased growth of this limb of 1cm at an unknown time period.

Table 3.7: Association between improved clinical outcomes and patient and injury characteristics

Study	Particular SH class	Reduced or particular position of fracture displacement	Lower energy injury mechanism	Patient age at time of injury
Arkader A., Warner W., Horn, D., Shaw R., Wells L., 2007 (21)	Y	Y[a]	N	N
Buess-Watson E., Exner G., Illo O., 1994(48)	N	-	-	N
Caterini R., Farsetti P., d'Arrigo C., Ippolito E., 1991(49)	Y	N	-	-
Edmunds I., Nade S., 1993(15)	Y	-	-	-
Eid A., Hafez M., 2002 (16)	N[b]	-	-	Y
Garrett B., Hoffman E., Carrara H., 2011(29)	Y	N	Y	T
Graham J., Gross R., 1990(17)	-	-	-	-
Havranek P., Pesl T., 2010(36)	-	-	-	-
Ilharreborde B., Raquillet C., Morel E., Fitoussi F., Bensahel H., Penneçot G., Mazda K., 2006(50)	-	Y	-	-
Kritsaneepaiboon S., Shah R., Murray M., Kleinman P., 2009(51)	-	-	-	-
Krueger-Franke M., Siebert C., Pfoerringer W., 1992(52)	Y	-	-	-
Lippert W., Owens R., Wall E., 2010(53)	-	-	-	-
Partio E., Tuompo P., HIrvensalo E., Böstman O., Rokkanen P., 1997(54)	-	-	-	-
Plánka L., Skvaril J., Stary D., Jochymek J., Gál P., 2008 (28)	-	-	-	-
Thomson J., Stricker S., Williams M., 1995(19)	N	Y	-	N

-, Association between factor and patient outcome not investigated by paper; Y, Association between factor and patient outcome found; N, Association between factor and patient outcome not found; T, Trend only, not statistically significant; [a], Presence, not direction of displacement; [b], Worsening prognosis from SH I, III, IV, II, V

Chapter 4: Discussion

4.1 Findings

Chapter 4 analyses the findings identified by this review, discusses their limitations and provides implications and suggestions for practice.

4.1.1 Key findings of surgical versus conservative management with follow-up strategies

With a range of treatment strategies, the rate of complication in the surgical population was 37.8%. In the conservative population the rate of complication was marginally lower at 34.0%. A reason that the complication rate was higher in the surgical group could be that a higher energy mechanism of injury would distribute a more violent force and disruption to the growth plate, resulting in fracture displacement. Displaced fractures are more commonly treated by open reduction as a closed reduction would be less successful in placing the fragments back in their original position. A systematic review by Basener et al. found that displaced fractures were associated with a four-fold higher risk of growth arrest than non-displaced fractures (22).

Another factor contributing to the poorer prognosis of surgically managed patients could be the SH classification of the fracture. As noted in Section 3.4, five of 15 papers showed that SH classification was correlated with prognosis, again potentially impacting the results if not factored in. An example of the reasoning is that a conservatively managed SH I injury is likely to have an improved outcome in comparison to a surgically managed SH V injury and should not be compared. This is in line with the literature for SH I injuries which also suggests that SH I injuries have a low complication rate (8).

Complications observed have ramifications on the patients' day-to-day life such as pain, reduced function, limp, as well as cosmetic concerns. This may be significant to warrant the need for corrective surgery and orthoses such as shoe raise. With this arise further cost ramifications.

Follow-up

The review did not identify sufficient data for comparisons of follow-up frequency to be made. In this case the clinician would be balancing out unnecessary radiation and inconvenient follow-up patient appointments with the early detection of a complication, which is more easily treated.

Factors affecting treatment

In certain SH grade and displaced fractures, surgical treatment was observed more commonly than conservative treatments as surgery may provide better reduction of the fracture fragments as well better maintenance of the bony position with hardware fixation. Other factors influencing the treatment decision included the child's weight, associated injuries, as well as institutional, surgeon, economic and social considerations. This can be observed in day-to-day clinical life and is supported by a narrative literature review by Basset et al. in 2015 (58).

4.1.2 Overview of surgical outcomes

Surgical or operative treatments ranged from closed reduction and percutaneous pinning to debridement for open fracture, followed by open reduction and osteosynthesis, including with bio-absorbable fixation. The study utilising bio-absorbable fixation was noted to have a higher complication rate (54), as mentioned in Section 3.4. A factor potentially related to the high complication rate noted in this study of older populations could have been the adolescent population included. The bones of older children, who are closer to reaching their peak bone mass, have less elastic potential and less potential for remodelling or correcting deformity after an injury (59).

At the time of the study, bio-absorbable fixation was not a standard treatment. It has been seen to be associated with adverse tissue inflammatory reactions as it integrates with the bone and surrounding soft tissues at approximately 11 weeks following surgery (60). The rate of this was noted to be up to 5.3% in a study size of 2528 patients (60). The perceived benefit of this method of fixation is that if no reaction and union are achieved, the surgeon and patient do not require the implant to be removed.

4.1.3 Overview of conservative outcomes

The conservative interventions included no treatment as well as closed reduction and immobilisation.

Overall, conservatively managed distal femoral physeal fractures yielded a surprisingly high rate of complications, especially given that the injuries observed were predominantly classified as SH I or II. These were managed with traction alone, or closed reduction and casting. The reason for the high complication rate is not obvious. It could have been that anatomical reduction was not achieved as the reductions might have been done in the Emergency Department without on-demand XR facilities and with a lighter sedation, making the reduction more difficult. It is generally recognised that better reduction may be achieved in theatre where the use of image intensifier is more readily available.

This study by Graham et al. was performed from 1977 to 1987 and since then, there has been implementation of better, light weight immobilisation (17). This could contribute to better compliance of no weight bearing and not displacing the fracture, and improved mobility.

4.1.4 Overview of available information

Given the lack of results provided by studies that directly corresponded with the primary and secondary outcomes specified in the *a priori* protocol (Appendix I), specific results provided by the individual studies are reported below to illustrate particular findings.

One study demonstrated that the presence of displacement, not direction, as well as the SH classification, did influence the patient's outcome in terms of growth or angular deformity (21). They also demonstrated a trend, without statistical significance, that Steinmann pins across the physis led to double the number of complications compared to a physeal sparing approach. However, in 2011 another study showed that smooth pins across the physis were not statistically associated with physeal bar formation (29).

One study, with 14 patients, showed a high overall complication rate with SH II fractures, suggesting that this classification system at the distal femur was of little prognostic value (16). This is supported by two further studies ((17) One of the included studies included suggestions of the management of growth disturbance, either by osteotomies or the contralateral intertrochanteric shortening procedure (48). Another described completion of the epiphysiodesis and contralateral epiphysiodesis, either primarily or delayed (29). An alternative described was the use of external fixation as well as filling the defect with autospongioplastic material (28).

An included paper, analysing patients between 1944 to 1976, included patients managed predominantly conservatively, reflective of the clinical approach of that time (49). Included within this study were two obstetric distal femoral physeal injuries of fair to poor outcome. A study published in 1993 found, in their evaluation of 33 patients, an unacceptably high proportion of patients losing position without internal fixation. The authors subsequently advocated that all displaced SH II, III, IV fractures should be managed with internal fixation (15). This was supported by four other included studies (50). Other authors advocated further, especially in SH III and IV, that the reduction should be performed with an incision, under direct visualisation, to properly ensure the anatomy was restored, as a periosteal flap might prevent anatomical closed reduction (53). The loss of reduction without fixation was postulated to be due to the inherent instability of the undulating physis, and if displacement had occurred in any way, the only way for reduction to be maintained was with fixation.

The largest number of Type VI physeal injuries in the literature was included in this review (36). Of their eight minimally displaced distal femoral physeal fractures, the focus was on conservative management with minimal issues noted. In contrast, a different study with varying types of growth plate fractures, demonstrated a 75% complication rate in four patients managed with closed reduction in an emergency department (19).

With respect to imaging modalities, one study demonstrated that X-ray, in comparison to higher order imaging such as computed tomography (CT) or MRI, significantly underestimated the displacement of a fracture (52). Magnetic resonance imaging is advantageous in also detecting ligamentous, soft tissue injuries and early bar formation (52, 62).

4.2 Limitations of included studies

4.2.1 Differences in patient characteristics

Patients ranged in terms of age, fracture displacement, severity of injury as indicated by the SH Classification and mechanism of injury. In general, included participants appeared to be similar to an Australian paediatric population in terms of injury pattern, nutrition, genetic make-up and access to health care (15, 19, 53). As expected, males were over-represented relative to females. This is in keeping with the literature and may be due to higher participation rates in contact sport and/or risk taking behaviour (60).

What is not reported throughout the studies is how the fractures were stabilised – whether paramedics at the scene of injury placed them in a splint, or whether the patient had waited many days to have their fracture stabilised for the first time in surgery. Without stabilising a fracture, the fracture and bony fragments could cause further injury to the local soft tissues and impede the healing process, thereby increasing the chances of complications.

The SH classification is relatively easy to use for growth plate fractures. It also provides a correlation between the mechanism of injury and the appearance of the fracture lines, repair, and is able to suggest growth prognosis (16, 22, 29). However, it comes with limitations. The presence of displacement, energy of injury and comminution is not mentioned. Instead of having a tool to be able to objectively and consistently describe these factors, seen to influence outcome, the reader is reliant on the individual author's subjective description of these.

4.2.2 Outcome assessment

Outcomes were measured using a variety of indicators across the selected studies. There was significant heterogeneity in measurements of clinical and radiological data. Only four of the studies contained individualised patient data. The study by Garrett et al. indicated that the formation of bar was the primary outcome of interest (29). Most other studies investigated growth arrest in terms of angular deformity, leg length discrepancy and radiological evidence of growth arrest without clinical implications. It was noted that almost every study commented on growth arrest, whereas the remaining complications were not well represented across the studied populations.

Details of the use of X-rays – angle, exposure and frequency – were not mentioned across the studies. A study might have determined a leg length discrepancy of more than 2cm as being significant, yet others determined that 1.5cm was the cut-off point. The physical examination and clinical data recorded varied considerably between studies. One study at least mentioned that the primary author, an orthopaedic surgeon (completed training), was the clinician consistently examining the patients. Goniometers, the tool to objectively measure knee ROM, were not described throughout.

Performance bias by the clinicians with a particular training and clinical skills, and access to resources, would have added heterogeneity to the results. Their interpretation and treatment selection could thus be biased by these individual factors. Associated injuries such as neurovascular compromise and other bony injuries could also have influenced treatment selection. A detection bias could be present with the way a surgeon or institution measured an injury or complication of a patient presenting for follow-up compared to that at a different hospital, again influencing the results. If these variable parameters had been documented, there would be more consistent, robust and reliable data to be interpreted. For example, a goniometer could objectively measure the knee range of motion (ROM) of the patient.

Another factor potentially implicated in the patient's outcome relates to the compliance of the patient, particularly in the adherance to the non-weight-bearing instructions to prevent displacement. This is a factor not accounted for or mentioned in any of the studies.

4.2.3 Outcomes not reported

Additionally, it is unclear whether differences in patient age at the time of injury may impact the expected outcome. No study looked at this specifically, however Caterini et al. did report two obstetric distal femoral physeal injuries with fair to poor outcomes (48). Due to more remaining growth in younger children's physes, one would expect greater potential growth complications in the younger demographic.

Other factors that may influence the patient's outcome but not commonly reported in the literature could be the surgeon's treatment preference and skill set. They might feel more comfortable with a certain treatment based on their skill set and experience.

The surgical technique also would have a bearing on the results. If a percutaneous approach was utilised by the surgeon, the incision size would have been smaller, thus minimising further injury to the surrounding soft tissue. This however could be at the detriment of visualising and gaining reduction across the fracture site. Further, the reduction technique and tools to achieve the reduction vary in efficacy as well as on the amount of secondary trauma on the growth plate. Therefore, this factor should be better reported to inform the readers.

The anticipatory Langenskiold procedure was not utilised in any distal femoral physeal fractures in this review. This treatment could have been utilised as a means of interposition graft to prevent physeal bar formation in severe injuries of the physis (37).

Other factors were the different implants, i.e. whether one screw was composed of the same metals or strength of different diameter screws. Generally, access to these implants is universal, yet if there is an experimental or research component to be completed, restrictions may be in place. In other centres, outside that of Partio's study (53), access to bio-absorbable implants might have been different.

Further studies are required to observe and scrutinise different post-operative instructions such as longer or shorter time to weight-bearing and how this would affect the results. A surgeon would recommend sufficient union before weight-bearing so that fracture does not collapse but this should not be too long as to it could lead to atrophy, stiffness and restriction in the ability to perform activities of daily living.

The meta-analysis on distal femur physeal fractures performed in 2009 interestingly raised the point of a potential bias when surgeons rated interobserver reliability of the SH classification system(22). This could also extend to the surgeon's inter-observer reliability to rate reduction achieved, clinical examination including leg length discrepancy, as well as X-ray interpretation of complications incurred. This systematic review observed published studies from as far back as 1960, thus potentially limiting its application to today's practice.

The treating surgeon generally desires close scrutiny of their practice with detection of complications early to treat them early in order to minimise their impact. Practically, for a patient to be followed up in the clinic with X-ray interpretation often requires a substantial period of time set aside for preparing and arranging transport as well as the time spent in waiting rooms and radiologic departments, and finally the consult. Bearing this in mind, the surgeon find a balance between consideration of the patient's social situation and minimising X-ray exposure. Quite possibly, more frequent follow-ups, whilst not seen in this review, could allow for early detection and management of complications.

4.3 Limitations of the review process

Only studies available in the English language published since 1990 were included. This was in an attempt to ensure that up-to-date treatments comparable and provided by Australian Paediatric Tertiary Centres were included in the studies. Despite these parameters, a case treated in 1946 but published after 1990 was included in the review.

Efforts were made to contact all corresponding authors to identify patient level data so that meaningful comparisons could be made across all studies to measure clinical effects between different treatments for SH distal femoral fractures. The data presented did not allow for direct comparisons to be made to provide an assessment of effective treatment strategies in terms of growth or angular deformities.

4.4 Implications for practice

For a distal femoral physeal fracture, based on the evidence presented in this review, it is recommended that each patient's treatment should be considered on a case-by-case basis by an experienced paediatric orthopaedic surgeon. The treating surgeon should have a thorough knowledge of the inherent instability and associated risk of complications of displaced and higher SH graded distal femur growth plate fractures.

4.4.1 Imaging

Following clinical evaluation where there is suspicion of a fracture, plain radiography is indicated. Although only a two-dimensional depiction of three-dimensional bony and soft tissue structures, radiography provides important information regarding the osseous structures (61, 62). It is a readily available, quick, simple, cost-effective examination indicated in both the acute trauma setting and for follow-up assessment of angular deformity and growth arrest. Secondary signs of physeal complications may also be seen on X-ray. These include physeal widening, epiphyseal displacement, peripheral osteopaenia, indistinctiveness of the epiphyseal and metaphyseal sides of the physis, fragmentation and Harris Growth Arrest Lines (62, 63). Soft tissue structures such as the physis, cartilage, ligaments and tendons are radiolucent and thus not visible on plain radiography. Stress radiographs are not recommended due to patient discomfort and the availability of MRI.

Computed tomography is indicated where more detailed bony analysis is required, particularly in evaluating fracture extent, as well as bony and articular alignment. This is of assistance in planning the reduction of the displaced fracture (63). It may provide additional and three-dimensional detail about the exact location and size of a physeal osseous bar as well as physeal sclerosis or osteopaenia (62). However, early fibrous physeal bars are not apparent on CT. A further drawback of CT is the amount of associated ionizing radiation and the concern about the increasing risk of cancer, especially in the paediatric population. A large multicentre study conducted in Melbourne, Australia, assessed overall cancer risk after children were exposed to CT. They found the risk to be 24% greater than that in those not exposed, independent of age, sex and year of birth (64).

Magnetic resonance imaging provides the most superior quality imaging of the growth plate, articular cartilage, neurovascular structures, muscles, menisci, tendons and ligaments. The MRI signal depends on the cellular composition of collagen, proteoglycan and water as well as the MRI sequence selected (65). On T1 sequences, MRI is able to detect subtle metaphyseal characteristics such as the presence of growth recovery lines or growth arrest lines, and whether they are tilted, merging curved, delayed or absent (61, 66). Other signs of physeal damage on MRI include physeal widening, physeal irregularity and, in the metaphysis, focal defects and intrusions of physeal cartilage (62). At the growth plate, a fibrous bar may be directly evaluated by MRI only (62). With high spatial resolution, three dimensional capability and further software development, it is possible to accurately map the physeal shape, size and surface area, and the location of physeal damage (62). The early application of MRI has been suggested for high growth arrest risk areas such as the distal femur. In many cases, the application of MRI has identified additional aspects of a growth plate fracture, not detected on plain x-ray imaging which then alter its SH classification, thus providing important prognostic information and treatment considerations (61, 67). In summary, bony bar mapping is best performed using MRI, which is able to guide the clinician as to the best surgical or conservative approach for the patient (68).

4.4.2 Treatment recommendations

From this review, due to the lack of quantitative evidence, it appears that the best management of fractures of the distal femoral physis is based on the following principles, supported by expert opinion.

Patients with tenderness over the distal femoral growth plate and are unable to weight bear should be treated as an undisplaced SH I injury with a full leg cast for four weeks, a grade B recommendation according to the Joanna Briggs Grades of Recommendations (79). Magnetic resonance imaging is required for confirmation. If the child is obese or has a muscular thigh, a hip spica cast may provide improved stability across the fracture site (16). The risk of joint stiffness is less of an issue in the paediatric population.

Children with a displaced SH I fracture should be managed with a gentle closed reduction and cast in theatre with image intensifier validation of adequate joint reduction, a grade B recommendation (19,79). These fractures are more stable than SH II and over, thus they may not need any fixation. If there is concern about re-displacement, retrograde crossed physeal wires are suggested. These 'pins' are associated with a low risk of growth arrest and may be supplemented with a cast (29).

Undisplaced SH II fractures may be managed in a cast with repeat X-ray in one week (grade B recommendation) (79). At one week, if displacement exists, options include closed reduction and K wires or open reduction internal fixation (grade B recommendation) (79). If the displacement is detected beyond a week after the injury, mild displacement is better left to remodel.

For displaced SH II fractures, reduction and K wires are sufficient if it is a small metaphyseal fragment. For larger metaphyseal fragments, one to two cannulated screws may be used, supplemented by a long leg cast (grade B recommendations) (79).

Salter Harris III and IV fractures should all be managed surgically with fixation to prevent displacement from their inherent instability, a grade B recommendation (79). Higher order imaging is suggested to better appreciate displacement and articular step, and for pre-operative planning (52). For screw placement, a 'safe triangle' exists between the physis, the roof of the intercondylar notch (Blumensaat's line) and the trochlear groove (52).

Salter Harris V fractures are difficult to detect and in the largest case series, all six of the SH V fractures were initially missed (16). These have also been labelled Peterson Type 6 injuries (14). One must therefore have a high index of suspicion with these injuries and obtain higher order imaging such as CT or MRI for further evaluation. It is suggested that these injuries are managed with initial surgical debridement before a physeal bar is to be expected (grade B recommendation) (14, 79). The management is then directed at addressing of the angular and leg length discrepancy in the medium term.

The study by Havranek, the largest SH VI cohort published, suggested that for minimally displaced SH VI injuries of the distal femur, patients faired adequately with immobilisation in a plaster cast (36).

4.4.3 Length of follow-up examination

Follow-up examinations should be done by an experienced paediatric surgeon who will assess for complications of treatment and injury which should be detected in a timely manner and addressed before the growth spurt. The follow-up protocol should include clinical and radiographic assessment. Determining the history should include questions about pain and function, and clinical examination of leg length, angular deformity, ROM and Anterior-Posterior and lateral radiographs of the knee. Long length radiographs should be performed at regular intervals (grade B recommendations) (79).

The most important outcome for the surgeon is radiographic assessment of the fixation or angulation or leg length deformity. For the patient, generally their primary concern is pain, function and aesthetics.

Follow-up should be regular with long length alignment radiographs until skeletal maturity, as growth disturbances may not declare themselves until many years after the injury.

4.5 Implications for research

4.5.1 Biological therapy

To date, there are no known biological therapies that can regenerate cartilage, recreate physeal physiology and prevent the undesired bony repair (20). Various proteins, particularly vascular endothelial growth factor, bone morphogenic proteins, tumour necrosis factor alpha Wnt/B caterin, insulin like growth factors and parathyroid related hormone, have been studied in animal and human populations for their role in regulating bony and physeal repair (20, 69-74). Many attempts at implanting these proteins have been made using exogenous scaffolds, gene therapy and growth factors (74). The future direction appears to be a less cumbersome *in situ* cell-based therapy to prevent growth plate complications and subsequent operations (20, 74). This in turn would reduce the burden on patients and the healthcare system.

4.5.2 Future direction

The review identifies a need for further research to make better-informed decisions as to the most effective treatment strategies for distal femoral physeal fractures. This could be in the form of a registry, similar to what has been performed in Australia with artificial joint replacements to assess the outcomes of these injuries (75). From this review, a limiting factor when pooling the data was heterogeneous outcome measures and cut-off points for leg length discrepancy. The Core Outcome Measures in Effectiveness Trials (COMET) is a platform where a minimum list of outcomes and how they should be measured are registered with a central body (76). This provides for better comparisons to be made.

When future comparative research is considered to evaluate therapies for distal femoral physeal injuries, it would be suggested for data to include surgeon experience, preference, individual patient demographics including age, pertinent injury details, associated injuries and comorbidities. Follow-up should be a minimum of one year but ideally, until skeletal maturity is reached, with six-monthly X-rays, according to a set protocol. For the patients lost to follow-up, there should be descriptions of the available data and the reason why they could not complete the study.

This could proceed with a pilot study including the tertiary paediatric institutions within Australia, likely involving a meaningful sample size, whereby homogenous data is obtained. This would identify:

i. Procedures done
ii. Indication for the procedure
iii. Results of the different procedures matched to the injuries.

If this was successful and ethically appropriate and approved, a RCT may be able to compare specific interventions with a control group. Additional RCTs could be done in countries with similar healthcare systems to then repeat a further systematic literature review similar to the comparison joint registry studies between Scandinavian countries (77).

4.6 Conclusions

Due to the nature of the studies located and included, it is unclear whether surgical intervention is more effective than conservative intervention and which modalities of each are most beneficial in terms of growth arrest, leg length discrepancy and angular deformity. The rate of complication was marginally higher in the surgical population than the conservative population.

The diversity of paediatric injuries and clinician training suggests that each case must be assessed and treated on an individual basis with available resources in mind.

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Appendices

Appendix I: Systematic review protocol

Interventions for treating growth plate fractures of the distal femur: a systematic review protocol

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Review question/objective

1) What are safe and effective interventions for the management of distal femoral growth plate fractures in children in terms of rates of growth deformity and rates of growth arrest?

More specifically, the objectives are to compare

v. different methods of surgical treatments in the acute management of distal femoral growth plate fractures in children and adolescents;
vi. different methods of non-surgical treatments in the acute management of distal femoral growth plate fractures in children and adolescents;
vii. surgical versus non-surgical treatments in the acute management of distal femoral growth plate fractures in children and adolescents; and
viii. different outpatient follow-up strategies, in particular, frequency of visits, frequency of radiographic evaluation and longevity of patient follow-up, following treatment of distal femoral growth plate fractures in children.

Surgery will be defined as treatment either by incision or physical manipulation by a surgical doctor.

Background

DESCRIPTION OF THE CONDITION

The growth plate, or physis, is located between the epiphysis and metaphysis at the end of long-bones in children and young adults. It is the region of the bone where tightly-regulated endochondral ossification is responsible for longitudinal growth.(1, 2) The distal femoral physis is anatomically significant in that it contributes 70% of the longitudinal growth of the femur, equating to approximately 40% of the length of the lower extremity.(3-6) Previous studies analysing growth plate fractures found that physeal fractures account for approximately 15-30% of paediatric fractures and up to 4% of total paediatric fractures involve the distal femoral physis.(7, 8) At the distal femoral physis, major anatomical structures are the lateral notch, anteromedial notch, central ridge, lateral ridge, and medial peak.(9) During childhood bony development, the central ridge has the most pronounced decrease in height and surface area, whilst the lateral notches deepen.(9)

From birth, there are three distinct periods of growth velocity.(11) They are from birth to five years of age, from five years of age to puberty, and from puberty onwards. The most accelerated phase of childhood growth occurs at puberty.(11, 12) As skeletal maturity approaches, the central ridge has the highest relative decrease in size. This change in morphology accounts for a decrease in mechanical stability and therefore predisposes the physis to injury.(9) With growth, the epiphysis becomes less cartilaginous.(13) Riseborough et al observed distal femoral physeal injuries in children, noting a greater distribution of higher energy injuries in the younger of these, hypothesizing a thicker periosteum protects the physis from the lesser forces.(78)

The physis of the distal femur is inherently weaker than the ligaments of the knee. Thus, if an injuring force is applied to this area, a physeal fracture will more readily be produced rather than a disruption to these ligaments.(10, 14) A fracture to the distal femoral epiphyseal plate injury is frequently the result of a high energy injury. Common mechanisms of injury include motor vehicle accidents (including pedestrians and cyclists), sports-related injuries, and falls.(15-17) Historically, when wagons and carts were common transportation vehicles, a child's foot lodging in a spoke would readily result in a distal femoral physeal fracture causing significant morbidity and mortality.(18) Abduction, adduction, hyperflexion and hyperextension are known mechanisms of distal femoral physeal fractures.(5)

A distal femoral physeal injury is fraught with numerous potential complications.(3, 5, 16, 21, 22) Complete or partial growth arrest is commonly seen, which may manifest clinically in leg length discrepancy and angulation deformity.(5) Additionally, limitation on knee motion, quadriceps atrophy, osteomyelitis or osteoarthritis may result from this injury.(5, 23, 24) A meta-analysis by Basener studying distal femoral physeal fractures reported an incidence of 52% in growth disturbance with 22% of the growth disturbance greater than 1.5cm.(22) Arkader et al reported a complication rate of 40% with growth arrest the most common.(21)

It has been suggested that growth disruption and angular deformity follows peripheral bridging as a result of disruption to the zone of Ranvier.(5, 10) A radiological study proposed a graduation of the physeal injury, which may begin as an incomplete bridge at the central area with dense, sclerotic core causing continued disruption remaining.(25)

It has been postulated that fracture type, fracture mechanism, direction of injury, displacement, nature of physis, and the treatment mode may correlate with the clinical outcome of a distal femoral physeal injury.(12, 16, 19, 22, 26) Some authors have suggested follow up until skeletal maturity as potential for late complications may exist.(3, 16, 19)

For epiphyseal fractures of the distal femur, modes of diagnosis of and further evaluation include plain radiography and computed tomography. Magnetic resonance imaging is able to give gradient sequences to highlight the physis and is the most suitable method for detecting bone-bridge formation.(27, 28)

Numerous classification systems for physeal fractures have been proposed and developed since Foucher's grading in 1863. More contemporarily, in perusing the literature, the Salter Harris (SH) Classification, described in 1963, is most commonly used.(16, 22, 29) It was developed to correlate mechanism of injury to the appearance of the fracture lines, repair and growth prognosis.(30, 31) Additions and further suggestions to the SH Classification have been made in recent years.(10, 32-35)

A SH I fracture is considered to involve the cartilage of the growth plate. SH II involves bony disruption from the metaphysis to the growth plate. A SH III fracture is from the epiphysis to the growth plate. The SH IV injury is through the metaphysis, physis and epiphysis, whereas a SH V fracture is a crush injury to the physis.

For growth plate fractures, the aim of management is to keep the metaphysis, epiphysis and physis separate so that the physeal cartilage is able to grow in between to separate them.(37) Management decisions regarding these injuries are generally constructed around the degree of displacement and SH grading.(16, 21, 22, 24, 29)

In a search of available literature, there was no systematic literature review evaluating the most effective treatment methods for distal femoral physeal fractures. Published studies show a degree of inconsistency in treatment methods for similar fractures and presentations.

Generally however, for distal femoral physeal fractures, non-displaced SH I fractures are managed conservatively in a full length leg cast or hip spica. If displacement does exist, closed manipulation with a cast may be used. Internal fixation involving K wires or pinning through the epiphysis offers another option for this fracture type. Non-displaced SH II fractures may be managed conservatively but must be monitored closely for loss of reduction. Displaced SH II as well as well as SH III and IV have been managed operatively, although exact methods of surgical approach and devices vary.(16, 21, 22, 24, 29)

Whilst in some cases, surgery has shown less risk of re-displacement of the facture, this is a treatment not without risks.(19) Potential surgical complications include osteomyelitis, injury of surrounding structures including vascular injury, nerve injury and growth plate injury.(5, 15, 19)

The decision regarding the exact management of these fractures is made by the treating specialist. It may be influenced by factors such as knowledge-base, experience, comfort level of the surgeon and available resources.

The purpose of this review is to synthesize the best available evidence regarding the effectiveness of these interventions.

Inclusion criteria

Types of participants

This review will consider studies that include male and female children, younger than or equal to 18 years of age, with a distal femoral physeal fracture treated either operatively or conservatively, within 72 hours of presentation to hospital. Children may have a single or multiple injuries. The distal femoral physeal fractures considered may be open or closed injuries. Studies which follow-up these patients in the outpatient setting will also be reviewed to evaluate the incidence or detection rates of the later-appearing complications.

This review will not consider children with osteochondritis dissecans, Blount's Disease, or children with other comorbidities adversely affecting the repair of a growth plate fracture.

Types of interventions

This review will consider studies that evaluate surgical and conservative treatments for distal femoral growth plate fractures in the acute hospital setting. Following the initial treatment, this review will also consider studies that evaluate different follow-up strategies for these patients in the outpatient setting. In particular, the frequency of outpatient follow-up visits, intervals between radiographic evaluation and the longevity of patient follow-up will be evaluated to determine the detection rate or incidence of outcomes such as growth arrest.

Types of outcomes

This review will consider studies that include the following outcome measures;

Primary outcomes:

- Rates of growth of the distal femur with different treatment strategies. This may be determined by the presence or absence of Harris growth arrest lines on X-Ray or measured by an absolute or relative leg length discrepancy.
- Angular or rotational deformity, measured radiographically in accordance with the appropriate technique described by Dror Paley.(46)
- The incidence of complications such as growth disturbance for different outpatient follow-up strategies, in particular, frequency of visits and longevity of patient follow-up, following treatment of distal femoral fractures in children.

Secondary outcomes:

- Patient factors

Return of function in terms of pain control or absence of pain, walking ability, knee range of motion, return to sport, muscle atrophy, and ligamentous laxity.

- Treatment factors

Failure of treatment including non-union, mal-union, re-displacement, varus or valgus leg deformity and need for subsequent treatments or surgery. Complications of surgery or other treatments may include vascular injury, nerve injury, infection, thromboembolic disease, compartment syndrome or other secondary injury from the treatment.

- Hospital factors

Length of stay in hospital and a comment on resources required to perform certain treatments.

Outcomes will be categorized between immediate (occurring less than 2 weeks from injury) and non-immediate. The outcomes considered will be evaluated to determine if a relationship exists with the age, sex, and mechanism of injury, premorbid function and the comorbidities of the child. Injury factors such as SH classification, initial length discrepancy, as well as associated primary injuries including vascular injury, nerve injury, compartment syndrome, other bony injuries, will be considered. The experience level of the primary surgeon selecting and performing the chosen initial treatment will be considered.

Types of studies

Priority will be given to higher evidence-level study designs. This review will first consider randomized controlled trials (RCTs). In the absence of RCTs, non-randomized controlled trials, quasi-experimental, before and after studies, prospective and retrospective cohort studies, and case control series will be considered. This review will also consider descriptive epidemiological study designs, including case series and case reports for inclusion.

Search strategy

The search strategy aims to find both published and unpublished studies. A three-step search strategy will be utilized in this review. An initial limited search of PubMed and EMBASE will be undertaken followed by analysis of the text words contained in the title and abstract, and of the index terms used to describe article. A second search using all identified keywords and index terms will then be undertaken across all included databases. Thirdly, the reference list of all identified reports and articles will be searched for additional studies. The studies may be from any country with the article to be available in English. Studies published from 1970 onwards will be considered for inclusion in this review to ensure comparable treatment modalities.

The databases to be searched include: PubMed, EMBASE and Scopus. Grey literature will be searched through the Scirus database. Papers which meet inclusion criteria presented at conferences or meetings hosted by State or National Orthopaedic Associations will also be considered for inclusion, available through the relevant Association website or on request.

An example of a search strategy that will be used when searching the PubMed database include:

femur[mh] OR femur[tw] OR femoral[tw]

AND

epiphyses[mh] OR epiphys*[tw] OR growth plate*[tw] OR physe*[tw] OR physis[tw]

AND

wounds and injuries[mh:noexp] OR injur*[tw] OR fractur*[tw] OR fractures, bone[mh:noexp]

Assessment of methodological quality

Quantitative papers selected for retrieval will be assessed by two independent reviewers for methodological validity prior to inclusion in the review using standardized critical appraisal instruments from the Joanna Briggs Institute Meta-Analysis of Statistics Assessment and Review Instrument (JBI-MAStARI) (Appendix I). Any disagreements that arise between the reviewers will be resolved through discussion, or with a third reviewer.

Data collection

Quantitative data will be extracted from papers included in the review using the standardized data extraction tool from JBI-MAStARI (Appendix II). The data extracted will include specific details about the interventions, populations, study methods and outcomes of significance to the review question and specific objectives.

Data synthesis

Quantitative papers, where possible, will be pooled in statistical meta-analysis using the JBI-MAStARI software. All results were subjected to double data entry to minimize the risk of error during the data entry. Where appropriate, Relative Risks and/or Odds Ratios and their associated 95% confidence interval will be calculated for analysis of categorical data. For continuous data that were collected using the same scale, the weighted mean differences (WMD) will be calculated; for data collected using different scales, the standardized mean differences (SMD) will be calculated. Heterogeneity will be assessed using standard Chi square test and if found will be investigated prior to any further analysis. Where appropriate, meta-analysis will be conducted using JBI MAStARI. Where statistical pooling is not possible, the findings are presented in narrative form.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

The authors would like to acknowledge Dr William Cundy, Associate Professor Eduardo Aromataris and Dr Catalin Tufanaru for their expert advice and suggestions regarding inclusion criteria, outcome measures and in the refinement of this protocol. Further acknowledgement to Maureen Bell for her input and feedback regarding the search strategy.

Appendix II: JBI-MAStARI appraisal instruments

JBI Critical Appraisal Checklist for Descriptive / Case Series

Reviewer _ Date _

Author _ Year _ _ _ _ _ _ _ Record Number _ _ _ _ _ _ _

	Yes	No	Unclear	Not Applicable
1. Was study based on a random or pseudo-random sample?	☐	☐	☐	☐
2. Were the criteria for inclusion in the sample clearly defined?	☐	☐	☐	☐
3. Were confounding factors identified and strategies to deal with them stated?	☐	☐	☐	☐
4. Were outcomes assessed using objective criteria?	☐	☐	☐	☐
5. If comparisons are being made, was there sufficient descriptions of the groups?	☐	☐	☐	☐
6. Was follow up carried out over a sufficient time period?	☐	☐	☐	☐
7. Were the outcomes of people who withdrew described and included in the analysis?	☐	☐	☐	☐
8. Were outcomes measured in a reliable way?	☐	☐	☐	☐
9. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

Comments (Including reason for exclusion)

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____

____

Appendix III: JBI-MAStARI tool for data extraction

JBI Data Extraction Form for Experimental / Observational Studies

Reviewer ______________________ Date ______________________

Author ______________________ Year ______________________

Journal ______________________ Record Number ______________________

Study Method

RCT ☐ Quasi-RCT ☐ Longitudinal ☐

Retrospective ☐ Observational ☐ Other ☐

Participants

Setting ______________________

Population ______________________

Sample size

Group A ______________ Group B ______________

Interventions

Intervention A ______________________

Intervention B ______________________

Authors Conclusions: ______________________

Reviewers Conclusions: ______________________

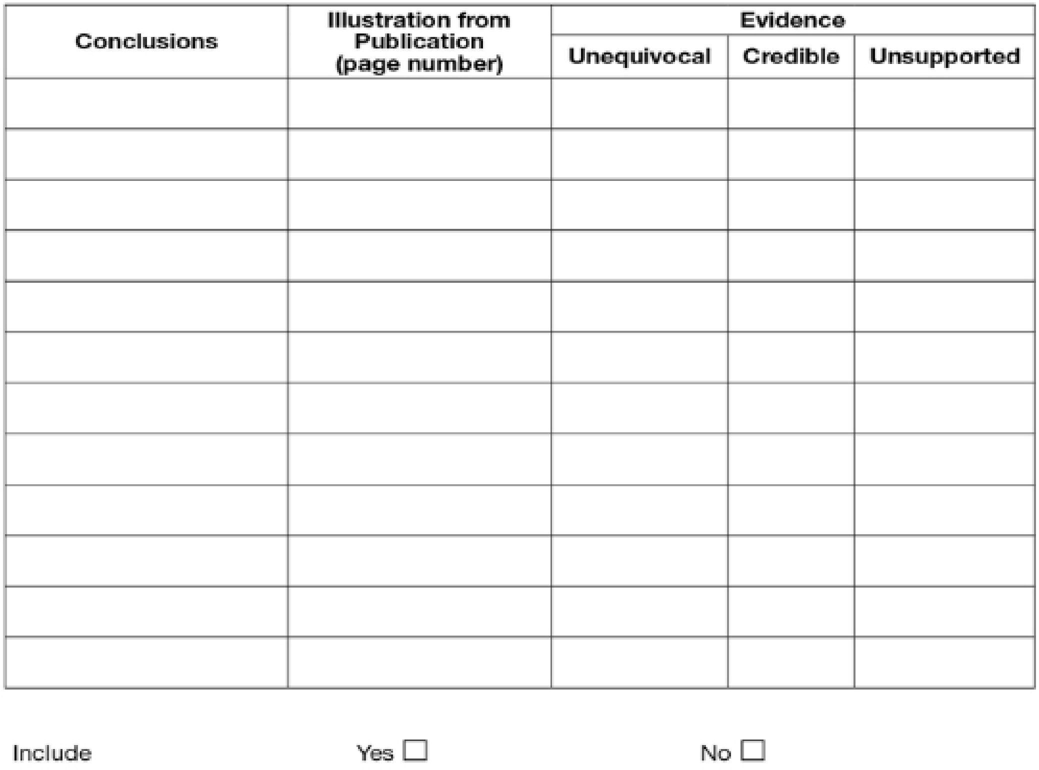
Study results

Dichotomous data

Outcome	Intervention ( ) number / total number	Intervention ( ) number / total number

Continuous data

Outcome	Intervention ( ) number / total number	Intervention ( ) number / total number



Conclusions	Illustration from Publication (page number)	Evidence		
		Unequivocal	Credible	Unsupported

Include Yes ☐ No ☐

Appendix IV: Standardized data extraction proforma

Study	
Year published	
Country	
Institution	
Years studied	
How patients selected	
Methods	
No. of patients initially	
No. of patients studied	
Sex	
Age range	
Average age at injury	
Aetiology of injuries	
SH I	
SH II	
SH III	
SH IV	
SH V	
SH VI	
Open fractures	
Neurovascular injuries	
Grading of displacement	
Conservative treatments:	
Surgical treatments	
Follow-up	
Outcomes measured	
Grading of complications	
Statistical analysis	
Results	
Further notes/ Classifications	

Appendix V: Studies excluded after full-text review

(Endnote 23/08/2014), updated January 2018 (45)

Albert, M. J., & Drvaric, D. M. (1995). Reduction and operative fixation of Salter-Harris Type II fractures of the distal femur. Operative Techniques in Orthopaedics, 5(2), 145-149.

Reason for exclusion: Not a study. A review paper.

Annan, I. H., & Moran, M. (2006). (i) Indications for internal fixation of fractures in children. Current Orthopaedics, 20(4), 241-255.

Reason for exclusion: Not a study. A review paper.

Basener, C. J., Mehlman, C. T., & DiPasquale, T. G. (2009). Growth disturbance after distal femoral growth plate fractures in children: A meta-analysis. J Orthop Trauma, 23(9), 663-667.

Reason for exclusion: Systematic review with different outcome measures.

Battiato, C. (2011). Dynamic internal fixator. Journal of Orthopaedics and Traumatology, 12, S91.

Reason for exclusion: No cases of distal femoral physeal fractures described.

Battiato, C., & Sartorello, E. (2013). DIF (dynamic internal fixator). Journal of Orthopaedics and Traumatology, 14(1), S66.

Reason for exclusion: No cases of distal femoral physeal fractures described.

Bhat, B. V., Kumar, A., & Oumachigui, A. (1994). Bone injuries during delivery. Indian J Pediatr, 61(4), 401-405.

Reason for exclusion: Less than four cases of distal femoral physeal fractures described.

Blasier, R. D. (2009). Surgical Technique for Adolescent Femur Fractures: The Trochanteric Entry Intramedullary Nail. Operative Techniques in Orthopaedics, 19(1), 24-30.

Reason for exclusion: Femoral shaft fractures only. No cases of distal femoral physeal fractures described.

Boero, S., Carbone, M., & Stella, G. (2000). The treatment of the outcomes of the physeal fractures of lower limbs. Minerva Ortopedica e Traumatologica, 51(3), 121-126.

Reason for exclusion: Full text requested but not available.

Brock, G. T. (2001). Pediatric musculoskeletal trauma. Current Opinion in Orthopaedics, 12(6), 462-469.

Reason for exclusion: Literature review only.

Brousil, J., & Hunter, J. B. (2013). Femoral fractures in children. Curr Opin Pediatr, 25(1), 52-57.

Reason for exclusion: Not a study. A review paper.

Buford Jr, D., Christensen, K., & Weatherall, P. (1998). Intramedullary nailing of femoral fractures in adolescents. Clin Orthop Relat Res(350), 85-89.

Reason for exclusion: Femoral shaft fractures only. No cases of distal femoral physeal fractures described.

Burnette, J. B., Ebramzadeh, E., Lee, J. L., Galanti, S., & Hoffer, M. M. (2004). Incidence of inpatient surgeries in children and young adults with childhood orthopaedic diagnoses. Journal of Pediatric Orthopaedics, 24(6), 738-741.

Reason for exclusion: Not a study. A review paper.

Butcher, C. C., & Hoffman, E. B. (2005). Supracondylar fractures of the femur in children: Closed reduction and percutaneous pinning of displaced fractures. Journal of Pediatric Orthopaedics, 25(2), 145-148.

Reason for exclusion: Distal femoral shaft fractures only. No cases of distal femoral physeal fractures specifically described.

Bylander, B., Hagglund, G., & Selvik, G. (1993). Dynamics of growth retardation after epiphysiodesis: A Roentgen stereophotogrammetric analysis. Orthopedics, 16(6), 710-712.

Reason for exclusion: Full text requested but not available.

Carty, H. M. L. (1993). Fractures caused by child abuse. Journal of Bone and Joint Surgery - Series B, 75(6), 849-857.

Reason for exclusion: Not a study. A review paper.

Cieslik, P., Piekarczyk, P., & Marczynski, W. (2007). Results of retrograde intramedullary nailing for distal femoral fractures--own experience. Ortop Traumatol Rehabil, 9(6), 612-617.

Reason for exclusion: Full text requested but not available.

Cohn, S. L., Sotta, R. P., & Bergfeld, J. A. (1990). Fractures about the knee in sports. Clin Sports Med, 9(1), vi-vii+121-139.

Reason for exclusion: Full-text requested but not available.

Davids, J. R. (1994). Rotational deformity and remodeling after fracture of the femur in children. Clin Orthop Relat Res.

Reason for exclusion: Less than four distal femur patients only reviewed post treatment.

Decoster, L. C., & Vailas, J. C. (1995). Fracture through the distal femoral epiphysis. J Athl Train.

Reason for exclusion: Full text requested but not available.

Dodwell, E. R., & Kelley, S. P. (2011). Physeal fractures: Basic science, assessment and acute management. Orthopaedics and Trauma, 25(5), 377-391.

Reason for exclusion: Not a study. A review paper.

Edwards, P. H., Jr., & Grana, W. A. (1995). Physeal Fractures About the Knee. J Am Acad Orthop Surg, 3(2), 63-69.

Reason for exclusion: Full text requested but not available.

Esenyel, C. Z., Ozturk, K., Adanir, O., Aksoy, B., Esenyel, M., & Kara, A. N. (2007). Skin traction in hip spica casting for femoral fractures in children. Journal of Orthopaedic Science, 12(4), 327-333.

Reason for exclusion: Femoral shaft fractures only. No cases of distal femoral physeal fractures described.

Etchebehere, E. C. S. C., Caron, M., Pereira, J. A., Lima, M. C. L., Santos, A. O., Ramos, C. D., . . . Camargo, E. E. (2001). Activation of the growth plates on three-phase bone scintigraphy: The explanation for the overgrowth of fracture femurs. Eur J Nucl Med, 28(1), 72-80.

Reason for exclusion: Femoral fractures but no cases of distal femoral physeal fractures.

Foster, B. K., John, B., & Hasler, C. (2000). Free fat interpositional graft in acute physeal injuries: The anticipatory Langenskiold procedure. Journal of Pediatric Orthopaedics, 20(3), 282-285.

Reason for exclusion: Less than four cases of distal femoral physeal fractures described.

Gabriel, K. R., Crawford, A. H., Roy, D. R., True, M. S., & Sauntry, S. (1994). Percutaneous epiphyseodesis. Journal of Pediatric Orthopaedics, 14(3), 358-362.

Reason for exclusion: Outcomes considered after initial treatment carried out.

Gilbert, S. R., MacLennan, P. A., Backstrom, I., Creek, A., & Sawyer, J. (2014). Altered lower extremity fracture characteristics in obese pediatric trauma patients. J Orthop Trauma.

Reason for exclusion: Lacking descriptions of treatments.

Hasler, C. C. (2010). Fractures of the knee and tibia Children's Orthopaedics and Fractures: Third Edition (pp. 775-792).

Reason for exclusion: Full text requested but not available.

Kanlic, E., & Cruz, M. (2007). Current concepts in pediatric femur fracture treatment. Orthopedics, 30(12), 1015-1019.

Reason for exclusion: Full text requested but not available.

Kelly, B., Heyworth, B., Yen, Y. M., & Hedequist, D. (2013). Adverse sequelae due to plate retention following submuscular plating for pediatric femur fractures. J Orthop Trauma, 27(12), 726-729.

Reason for exclusion: Femoral fractures but no cases of distal femoral physeal fractures.

Kennon, J. C., Ganey, T. M., Gaston, R. G., & Ogden, J. A. (2013). Continued growth after limited physeal bridging. Journal of Pediatric Orthopaedics, 33(8), 857-861.

Reason for exclusion: Patients identified and reviewed following detection of a bridge.

Kucukkaya, M., Karakoyun, O., Armagan, R., & Kuzgun, U. (2009). [Correction of complex lower extremity deformities with the use of the Ilizarov-Taylor spatial frame]. Acta Orthop Traumatol Turc, 43(1), 1-6.

Reason for exclusion: Patients reviewed following detection of a deformity.

Lin, D., Lian, K., Hong, J., Ding, Z., & Zhai, W. (2012). Pediatric physeal slide-traction plate fixation for comminuted distal femur fractures in children. Journal of Pediatric Orthopaedics, 32(7), 682-686.

Reason for exclusion: Injuries not comparable to population of interest.

Liu, B. J., & Dong, W. T. (2011). Miniaturized metacarpus steel plate for treatment of epiphysis injury. Zhongguo Gu Shang, 24(2), 170-172.

Reason for exclusion: Full text requested but not available.

Mann, D. C., & Rajmaira, S. (1990). Distribution of physeal and nonphyseal fractures in 2,650 long-bone fractures in children aged 0-16 years. Journal of Pediatric Orthopaedics, 10(6), 713-716.

Reason for exclusion: No treatments for distal femoral physeal fractures described.

Moran, M., & Macnicol, M. F. (2006). (ii) Paediatric epiphyseal fractures around the knee. Current Orthopaedics, 20(4), 256-265.

Reason for exclusion: Not a study. A review paper.

Newman, J. H. (1990). Supracondylar fractures of the femur. Injury, 21(5), 280-282.

Reason for exclusion: Not a study. A review paper.

PakuŁA, G., & SŁOwiŃSki, J. (2013). Biomechanics of distal femoral fracture fixed with an angular stable LISS plate. Acta Bioen Biomech. 2013;15(4):57-65

Reason for exclusion: Full text requested but not available.

Park, H., Kim, H. W., Park, H. W., & Lee, K. S. (2011). Limb angular deformity correction using Dyna-ATC: Surgical technique, calculation method, and clinical outcome. Yonsei Med J, 52(5), 818-830.

Reason for exclusion: Patients reviewed following detection of a deformity.

Roberts, J. M. (1990). Operative treatment of fractures about the knee. Orthopedic Clinics of North America, 21(2), 365-379.

Reason for exclusion: Full text requested but not available.

Simonian, P. T., Routt, M. L. C., & Harrington, R. M. (1994). Extramedullary skeletal traction for intramedullary femoral nailing. J Orthop Trauma. 1994 Oct;8(5):409-13

Reason for exclusion: Cadaveric study.

Sloboda, J. F., Benfanti, P. L., McGuigan, J. J., & Arrington, E. D. (2007). Distal femoral physeal fractures and peroneal nerve palsy: outcome and review of the literature. Am J Orthop (Belle Mead NJ), 36(3), E43-45.

Reason for exclusion: Full text requested but not available.

Stanitski, C. L. (1998). Epiphyseal fractures about the knee. Operative Techniques in Sports Medicine, 6(4), 234-242.

Reason for exclusion: Not a study. A review paper.

Wall, E. J., & May, M. M. (2012). Growth plate fractures of the distal femur. Journal of Pediatric Orthopaedics, 32(SUPPL. 1), S40-S46.

Reason for exclusion: Not a study. A review paper.

Yue, J. J., Churchill, R. S., Cooperman, D. R., Yasko, A. W., Wilber, J. H., & Thompson, G. H. (2000). The floating knee in the pediatric patient. Nonoperative versus operative stabilization. Clin Orthop Relat Res(376), 124-136.

Reason for exclusion: Less than four cases of distal femoral physeal fractures described.

Zionts, L. E. (2002). Fractures around the knee in children. J Am Acad Orthop Surg, 10(5), 345-355.

Reason for exclusion: Full text requested but not available.

Appendix VI: Outcomes of interest

Study	Overall no. of complications	Total no. of surgical patients	Surgical complications	Total no. of conservative patients	Conservative complications	Growth arrest	Non-clinically significant growth arrest (radiological)	Leg length discrepancy (15mm or more)	Angular deformity
Arkader A., Warner W., Horn, D., Shaw R., Wells L., 2007 (21)	29	37	20	36	9	20	7	9	8
Buess-Watson E., Exner G., Illo O., 1994(47)	12	-	-	-	-	12	-	3	4
Caterini R., Farsetti P., d'Arrigo C., Ippolito E., 1991(48)	5	1	1	6	4		-	-	-
Edmunds I., Nade S., 1993(15)	10	13	4	10	6	9	-	4	7
Eid A., Hafez M., 2002 (16)	53	61	25	90	28		28	21	77
Garrett B., Hoffman E., Carrara H., 2011(29)	12	44	9	11	3	12	-	-	-
Graham J., Gross R., 1990(17)	9	0	0	10	9	9	-	-	-
Havranek P., Pesl T., 2010(36)	-	-	-	-	-	-	-	-	-
Ilharreborde B., Raquillet C., Morel E., Fitoussi F., Bensahel H., Penneçot G., Mazda K., 2006(49)	14	16	-	4	-	13	-	5	13
Kritsaneepaiboon S., Shah R., Murray M., Kleinman P., 2009(50)	1	0	0	6	1	0	-	1	-
Krueger-Franke M., Siebert C., Pfoerringer W., 1992(51)	3	5	-	5		3	-	1	2
Lippert W., Owens R., Wall E., 2010(52)	4	11	3	3	1	2	-	2	0
Partio E., Tuompo P., HIrvensalo E., Böstman O., Rokkanen P., 1997(53)	8	9	8	-	-	1	-	2	2
Plánka L., Skvaril J., Stary D., Jochymek J., Gál P., 2008 (28)	6	20	6	11	0	6	-	2	4
Thomson J., Stricker S., Williams M., 1995(19)	21	16	12	14	9	-	2	5	5
Total	**187**	**233**	**88**	**206**	**70**	**87**	**37**	**55**	**122**

- Result not available

NB: Surgical plus conservative complications are not equal to the total number of complications due to the way studies grouped and reported their data

Appendix VII: Characteristics of included studies

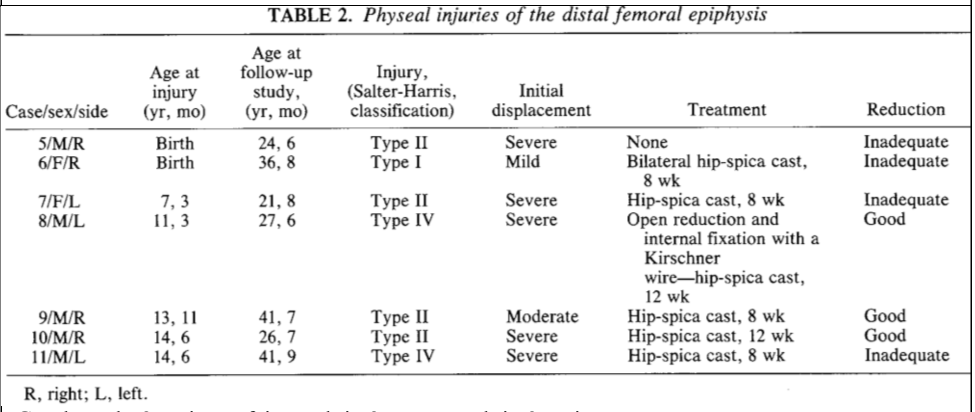
Study	Arkader A., Warner W., Horn, D., Shaw R., Wells L., 2007 (21)
Year published	2007
Country	USA
Institution	2 large level 1 paediatric centres
Years studied	‘Past 10 years'
How patients selected	From database, identified all skeletally immature patients sustained distal femoral physeal fracture at the two institutions
Methods	Retrospectively reviewed medical charts and images
No. of patients initially	83
No. of patients studied	73
Sex	67 male, 16 female (patients initially)
Age range	5 months to 17 years
Average age at injury	10 years
Aetiology of injuries	Motor vehicle accidents (including pedestrian vs. motor vehicle) Sports related [most common (American) football]
SH I	18
SH II	43
SH III	4
SH IV	7
SH V	1
SH VI	0
Open fractures	2 open fractures (both SH IV and grade 4)
Neurovascular injuries	Not mentioned
Grading of displacement	Grade 1: < 1/3 of bone width Grade 2: 1/3 to 2/3 of bone width Grade 3: >2/3 of bone width Grade 4: comminuted fractures
Surgical treatments	20 closed reduction with percutaneous crossed Steinman pins 13 had cannulated screws (Thurston-Holland fragment or epiphyseal frag in SH III or IV) 3 had multiple pin fixation (either percutaneous or during debridement of open injury) 1 external fixation for an open fracture
Conservative treatments	33 in long leg cast (for times supplemented by a pelvic band) 2 with posterior splint (non-displaced fractures) 1 in cylinder cast (non-displaced fracture)
Follow-up	Minimum 18 mo, average 24 months (18-84 months)
Outcomes measured	Complications (29) 1. Growth arrest in 20 [silent bony bridge formation (no LLD/ angular deformity in 7), LLD in 9, angular deformity in 8 - 11 needed surgical correction (8 had LLD >2cm,) 2. Loss of reduction in 3 3. Superficial infection over Steinman pins in 3 (11 patients had more than one complication)
Grading of complications	Minor complication: No further surgical treatment was needed Major complication: Surgery required
Statistical analysis	Cochran-Armitage trend test to determine relationship pattern of - fracture SH class vs. incidence of complications and final outcome - direction of displacement and outcome Fisher exact test to determine correlation of - degree of displacement and outcome - comparison of outcome among different methods of the chosen treatment X^2 to compare outcome according to conservative or surgical treatment Multivariate model to evaluate significant prognostic factors

Results	Age and mechanism of injury have no significant relationship to the incidence of complications SH classification correlated with the incidence of complications (p<0.03). Complication rates were - SH I 29.4% - SH II 33.3% - SH III 50% - SH IV 85.7% - SH V 100% Significant association between presence of displacement and the incidence of complications Overall complication rate 40% (29/73) 48.8% complication rate complication rate for displaced fractures (amount and direction did not make a difference) 26.6% complication rate complication rate for undisplaced fractures Conservative group had 25% incidence of complications Surgical group had 54% incidence of complications – likely due to selection bias. This was higher when the physis was crossed by hardware but P.06 for this
Notes/ Classifications	Exclusion criteria - Major clinical conditions [spina bifida (3), arthrogryposis (1)] - Not enough follow up at time of review (6) There were 2 open fractures Discrepancy between number of patients in SH II and IV reported in body of results and table

Study	Buess-Watson E., Exner G., Illo O., 1994(47)
Year published	1994
Country	Switzerland
Institution	Zurich Children's' University Hospital
Years studied	1971-1990
How patients selected	Statistics at Zurich Children's' University Hospital reviewed Inclusion criteria - Fractures of distal femur, proximal tibia or tibial eminence, epiphysis open at time of injury; growth completed at follow-up
Methods	Reviewed for the 20-year period between 1971 and 1990 in search of fractures about the knee. Patella fractures excluded (not relevant to this study). Pathological fractures excluded. 15 interviewed by telephone (11 of these had no problem with their knee) 10 lost to migration Follow up at Orthopaedic University Clinic Balgrist included questioning and detailed physical status by the same examiner (E.B.), standard XRs of both knees in two planes as well as stress views if indicated.
No. of patients initially (ALL)	68
No. of patients studied	14 distal femur from 43 available for f/u examination
Sex (ALL)	28 male, 15 female
Age range (ALL)	1-16 years
Average age at injury	(Age at injury of 11, 9 mentioned for distal femur [ranges given 6,3 to 14,9]).
Aetiology of injuries (DF)	B/w 50 and 75% (approx. 58%): high energy traumas at wintersports Approx. 28% is bicycle Approx. 14% is athletics/pedestrians/falls
SH I	1
SH II	9
SH III	4
SH IV	0
SH V	0
SH VI	0
Open fractures	Not mentioned

Neurovascular injuries	Not mentioned
Grading of displacement	Not stated
Surgical treatments	7 had open reduction internal fixation 1 had closed reduction percutaneous pinning
Conservative treatments	3 had cast immobilization 3 had cast immobilization after closed reduction
Follow-up	Clinical and radiological examination after an average period of 13 years post trauma
Outcomes measured	Asymmetric growth arrest/axis deviation, LLD, (re)operation, stability
Grading of complications	See results
Statistical analysis	No clear methods listed
Results	5 of 14 patients needed corrective surgical procedures - 4 patients had asymmetrical growth arrest on the lateral side which lead to rapidly increasing valgisation needing correction o Although open wedge osteotomies used, at follow-up, 3 patients had leg length discrepancy of more than 2.5cm - 1 patient had leg length discrepancy of 3cm without axis deviation - 4 out of 5 of these patients had a SH II injury. Operative primary treatment (ORIF) did not avoid this - 4 out of 5 of these patients had been treated primarily with an ORIF - Age at trauma did not seem to be a decisive factor For the remaining 9 patients without secondary procedures - 5 had a minor axis deviation of 5 to 7 degrees at XRs and/or a leg length discrepancy with shortening of 1.5 to 2.5cm - 2 patients after reduction under general anaesthesia had a lengthening of 1cm - Evident posterior instability was found in one patient Age at trauma did not seem to be a factor in minor axis deviations and/or shortening at follow-up SH II, traditionally felt to have a good prognosis, led to frequent growth disturbances at the distal femur. ORIF did not avoid this. Authors agree prognostic value of SH in this fracture is questionable
Notes/ classifications	-

Study	Caterini R., Farsetti P., d'Arrigo C., Ippolito E., 1991(48)
Year published	1991
Country	Italy
Institution	Department of Orthopaedic Surgery of the University of Rome "La Spapienza"
Years studied	1944-1976
How patients selected	(34) Patients treated from 1944 to 1976 at above institution with physeal injuries of the hip or knee -> 22 patients located at their new address invited to the Hospital for clinical and radiographic assessment. 16 attended the hospital
Methods	Retrospective case review with clinical and radiographic follow-up
No. of patients initially	34
No. of patients studied	7 distal femoral epiphysis (of 16 lower limb)
Sex	5 male, 2 female
Age range	16 days to 15 years and 3 months (all lower limb but can calculate from data)
Average age at injury	8 years 6 months (all lower limb but can calculate from data)
Aetiology of injuries	2/7 obstetric injuries, otherwise not mentioned
SH I	1
SH II	4

<table>
<tr><td>SH III</td><td>0</td></tr>
<tr><td>SH IV</td><td>2</td></tr>
<tr><td>SH V</td><td>0</td></tr>
<tr><td>SH VI</td><td>0</td></tr>
<tr><td>Open fractures</td><td>Nil mentioned</td></tr>
<tr><td>Neurovascular injuries</td><td>Nil mentioned</td></tr>
<tr><td>Grading of displacement</td><td>Mild: gap present between fragments <1mm
Moderate: gap 1-2mm
Severe: gap >2mm</td></tr>
<tr><td>Surgical treatments</td><td>Open reduction internal fixation with K wire + hip spica cast</td></tr>
<tr><td>Conservative treatments</td><td>None (no treatment)
Bilateral hip spica cast for 8 weeks
Hip spica cast 8 weeks or 12 weeks</td></tr>
<tr><td>Follow-up</td><td>21 years 8 months to 42 years 10 months (average 23 years 8 months); see data table for specifics</td></tr>
<tr><td>Outcomes measured</td><td>Symptoms, Physical examination findings, XR examination of complications</td></tr>
<tr><td>Grading of complications/ result</td><td>Good result: Patient did not report any subjective symptom. Physical examination did not show any difference between the normal and unaffected side, while at the x-ray examination no leg length discrepancies or axial deviation or osteoarthritis was present
Fair result: Patient complained of some occasional pain, and at the physical examination there was a 10 degree limitation in the joint. The x-ray examination revealed a leg length discrepancy of up to 2.5cm and/or an axial deviation of up to 5 degrees without signs of osteoarthritis
Poor result: The patient complained of frequent episodes of pain, mainly after prolonged ambulation or standing, and at the physical examination there was a 10 degree limitation in the joint. The x-ray examination showed a leg length discrepancy or more than 2.5cm and/or axial deviation of more than 5 degrees, and/or signs of osteoarthritis</td></tr>
<tr><td>Statistical analysis</td><td>No specific EBM tools used. Individual results observed and described</td></tr>
<tr><td>Results</td><td>
TABLE 2. <i>Physeal injuries of the distal femoral epiphysis</i>
<table>
<tr><th>Case/sex/side</th><th>Age at injury (yr, mo)</th><th>Age at follow-up study, (yr, mo)</th><th>Injury, (Salter-Harris, classification)</th><th>Initial displacement</th><th>Treatment</th><th>Reduction</th></tr>
<tr><td>5/M/R</td><td>Birth</td><td>24, 6</td><td>Type II</td><td>Severe</td><td>None</td><td>Inadequate</td></tr>
<tr><td>6/F/R</td><td>Birth</td><td>36, 8</td><td>Type I</td><td>Mild</td><td>Bilateral hip-spica cast, 8 wk</td><td>Inadequate</td></tr>
<tr><td>7/F/L</td><td>7, 3</td><td>21, 8</td><td>Type II</td><td>Severe</td><td>Hip-spica cast, 8 wk</td><td>Inadequate</td></tr>
<tr><td>8/M/L</td><td>11, 3</td><td>27, 6</td><td>Type IV</td><td>Severe</td><td>Open reduction and internal fixation with a Kirschner wire—hip-spica cast, 12 wk</td><td>Good</td></tr>
<tr><td>9/M/R</td><td>13, 11</td><td>41, 7</td><td>Type II</td><td>Moderate</td><td>Hip-spica cast, 8 wk</td><td>Good</td></tr>
<tr><td>10/M/R</td><td>14, 6</td><td>26, 7</td><td>Type II</td><td>Severe</td><td>Hip-spica cast, 12 wk</td><td>Good</td></tr>
<tr><td>11/M/L</td><td>14, 6</td><td>41, 9</td><td>Type IV</td><td>Severe</td><td>Hip-spica cast, 8 wk</td><td>Inadequate</td></tr>
</table>
R, right; L, left.
Good result: 2 patients, fair result in 2, poor result in 3 patients

Final result in distal femoral physeal injuries closely related to SH type
Results unpredictable in obstetric lesions as good short term results may deteriorate during skeletal growth</td></tr>
<tr><td>Notes/ classifications</td><td>Reduction graded as inadequate or good.</td></tr>
</table>

Study	Edmunds I., Nade S., 1993(15)
Year published	1993
Country	Australia
Institution	Westmead Hospital, Sydney, Australia
Years studied	1978-1991
How patients selected	Retrospective study of fractures involving the growth plate and epiphysis of the distal femur out of all fractures during this time (0.16% of the 20219 fractures admitted to Westmead Hospital during this period)

Methods	Attendance for clinical review or adequate documentation in medical records for minimum 1 year post injury See outcomes measured below
No. of patients initially	33
No. of patients studied	23
Sex	23 males, 10 females
Age range	4-18 years
Average age at injury	12
Aetiology of injuries	Motor vehicle vs. pedestrian or cyclist: 13 Fall: 8 Motorcycle accident: 6 Motor vehicle accident: 3 Sporting accident: 3
SH I	0
SH II	16
SH III	4
SH IV	2
SH V	1
SH VI	0
Open fractures	2
Neurovascular injuries	0
Grading of displacement	Direction of displacement: medial most common, then lateral. Anterior and posterior displacement uncommon 4 patients had minimally displaced fractures
Surgical treatments	Closed reduction and percutaneous fixation with wires or screws Closed reduction and traction (these were generally comminuted and severely displaced) Open reduction and internal fixation (fixation with K wires, AO screws, Herbert screws)
Conservative treatments	Robert Jones bandage only Plaster of Paris only Closed reduction and Robert Jones Closed reduction and cast
Follow-up	Minimum 1 year post injury - 4.8 years average follow-up 23 patients available to attend for clinical review or adequate documentation
Outcomes measured	LLD, Angular deformity, limitation in ROM, osteomyelitis, lost position, further treatment required
Grading of complications	Poor outcome defined as • Leg length discrepancy of 2cm or more • Angular deformity sufficient to cause a physical or cosmetic handicap • Limitation in range of movement by more than 20 degrees • Or osteomyelitis
Statistical analysis	No specific EBM tools used
Results	** See also the graphs for better comparison of treatments 10 of 23 patients had poor results • 5 patients had valgus deformities of which 2 limbs were also short (no further description) • 2 had varus deformities • 2 had shortening without angular deformity • 1 developed osteomyelitis post CR and percuatneous K wires o Had 2 debridements and then cured • Significant limitation in range of movement in the knee occurred in only one patient who had an ipsilateral femoral shaft fracture with quadriceps adhesions requiring quadricepsplasty (thus not considered to be a poor result) • 3 patients with significant deformity elected not to have corrective surgery • 7 remaining patients had total of o 5 osteotomies o 2 contralateral epiphysiodesis o 1 epiphysiolysis

	Initial versus final treatment Robert Jones bandage only 2 initial/2 final Plaster of Paris only 2/2 Closed reduction and Robert Jones 2/1 (Position lost in one. A second CR and cast also failed so proceeded to ORIF) Closed reduction and toe-to-groin cast 9/5 (5 lost position. One had a second manipulation and cast but displaced again, position accepted and remodeling occurred. 4 other patients had another manipulative CR and percutaneous fixation) Closed reduction and percutaneous fixation with wires or screws 4/8 Closed reduction and traction 4/4 Open reduction and internal fixation 10/11Poor results by SH classification SH I 0 SHII 6/16 SH III 2/4 SH IV 1/2 Poor results by treatment method (final treatment) Nil 2/3 CRPOP 2/4 CRT (traction) 2/3 CRIF 3/5 ORIF 1/8 Poor results by treatment method in the SH II fractures CRPOP 1/3 CRT 1/2 CRIF 3/5 ORIF 1/6 The 10 patients lost to follow-up before 1 year had no complications when last seen
Notes/ classifications	-

Study	Eid A., Hafez M., 2002 (16)
Year published	2002
Country	Egypt
Institution	University of Alexandria Hospitals, Alexandria, Egypt
Years studied	1980-1996
How patients selected	A retrospective review was carried out of 151 patients with traumatic injuries of the distal femoral physis. Not clear how patients were selected. Exclusion criteria: associated neurologic abnormalities, muscular dystrophy, metabolic bone disease, congenital abnormality of the skeleton, inflammatory joint disease
Methods	All patients reviewed personally by the two authors. Notes and radiographs were reviewed to ascertain the • Mechanism of injury • Presence of associated injuries • Type of epiphyseal plate injury • Degree of displacement • Line of treatment • Subsequent follow-up • Complications if any At the clinical interview, subjective complaints were recorded. Patients were assessed for gait, lower limb deformity, range of movements in the knee, ligamentous laxity, thigh atrophy and limb length discrepancy, adjustment was made if there was any angular deformity. All patients had up to date radiographic examination that included anterior-posterior and lateral views of both knees standing. Radiographs were assessed for the presence of premature growth arrest or angular deformities both in coronal and sagittal planes. Radiographs with scale markers were used to assess limb length discrepancy.
No. of patients initially	151

No. of patients studied	151
Sex	129 male, 22 female
Age range	10 months to 16 years. 11 injuries in children under the age of 2 years 49 injuries in children 2 to less than 11 years 91 patients 11 years or older
Average age at injury	12.3 years
Aetiology of injuries	Sports-related activities: 90 Road traffic accidents: 34 Various falls: 27
SH I	39
SH II	65
SH III	19
SHIV	22
SH V	6
SH VI	0
Open fractures	4 patients
Neurovascular injuries	Peroneal nerve palsy in 11 Vascular impairment in 4
Grading of displacement	Medial displacement: 52 injuries Lateral displacement: 49 injuries Posterior displacement: 26 injuries Anterior displacement: 18 injuries Stress films were used to diagnose coronal displacement in 13 patients
Surgical treatments	Open reduction internal fixation: 59 patients (34 as primary treatment, 25 who failed to improve after an attempt of remanipulation) Fixation was with either • 2 K wires (37 patients) • cancellous screws that dis not cross the physis (22 patients) In all cases, a long leg cast was applied for 6-8 weeks following internal fixation
Conservative treatments	Only 145 patients had early treatment as those with type V injuries were not diagnosed in the first instance Closed treatment initially successful in 111 patients Immobilized in long leg cast: 25 undisplaced injuries Closed reduction and long leg cast: 57 Closed reduction and hip spica: 29 Indications for long leg cast or spica were unclear from the patient's records
Follow-up	2-19 years: Until complete fusion of the distal femoral growth plate. How was this determined?
Outcomes measured	Subjective complaints Gait Lower limb deformity Range of movements in the knee Ligamentous laxity Thigh atrophy Limb length discrepancy clinically Angular deformity clinically Premature growth arrest or angular deformities on XR Limb length discrepancy on XR
Grading of complications	Poor outcome considered as • Symptoms restricting full activity • Loss of more than 20 degrees of the last degrees of flexion • Extension lag of 10 degrees or more • Varus, valgus or flexion deformity of 10 degrees or more compared to the normal side • OR leg length discrepancy more than 1.5cm For patients managed with closed treatment, up to 2mm residual displacement was considered satisfactory
Statistical analysis	Chi square test used for statistical analysis
Results	

30/82 cases immobilized in a long leg cast had redisplayed in the first 2 weeks
3/29 cases immobilized in a hip spica had re-displaced (in the first 2 weeks)
Remanipulation was attempted in all re-displaced injuries but was only successful in only 8 cases

All 11 peroneal nerve palsies that were noticed before treatment recovered spontaneously, following reduction, over a period of 2-3 months

The 4 patients with vascular impairment showed spasm of the popliteal artery on arteriography
- 2 patients recovered completely on medical treatment
- 2 patients had Volkmann's ischaemic contracture that left them with marked disability
    - these 2 patients showed shortening of 10 and 11cm; nearly one third of the shortening was in the tibia (in all other patients, shortening was in the femur only)

Compartment syndrome seen in 2 patients that was severe. This resulted in significant muscle wasting and limb length discrepancy. Failure of early recognition led to severe functional loss

Satisfactory results in 98 cases, 53 had poor results. See table below regarding which SH fared better/ worse

Shortening and premature arrest of growth
- Shortening ranged from 0.5 to 11cm
- Present in 58 patients (see table for SH breakdown)
- Patients in the juvenile age group suffered the most shortening (and this was statistically significant)

Premature growth arrest was evidenced radiologically in a total of 28 cases (again see table)

Angular deformity
- Suffered by 77 patients
- 5-30 degrees in 21 patients
- 5-15 degrees valgus in 14
- 20 degrees recurvatum in 2
- 10-25 degrees flexion deformity in 19
- varus or valgus associated with flexion deformity in 21
- Again, patients in the juvenile age group suffered the most deformities (and this was statistically significant)

Loss of knee joint motion
- Loss of the last degrees of flexion ranged from 10 to 40 degrees and extension lag between 5 and 20 degrees were detected in 43 patients
- This could not be related to the type of injury or treatment
- None of the open injuries regained full knee movement

Ligamentous laxity
- Ligamentous laxity clinically evident in 21 patients
    - MCL in 4
    - LCL in 6
    - ACL in 11
- Ligamentous laxity was sufficient to produce symptoms of instability in 12 patients

Thigh atrophy
- Thigh atrophy of varying degrees was encountered in 42 patients
- The most wasting was seen in the 2 patients who had Volkmann's ischaemic contracture
- The 4 patients with open injuries had considerable wasting of the quadriceps
- Muscle wasting was not related to the type of injury or treatment

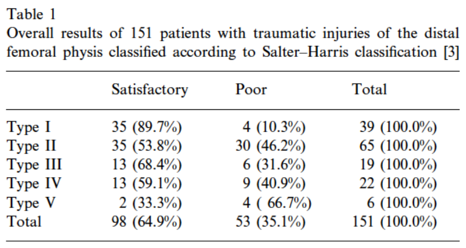


Table 1
Overall results of 151 patients with traumatic injuries of the distal femoral physis classified according to Salter–Harris classification [3]

	Satisfactory	Poor	Total
Type I	35 (89.7%)	4 (10.3%)	39 (100.0%)
Type II	35 (53.8%)	30 (46.2%)	65 (100.0%)
Type III	13 (68.4%)	6 (31.6%)	19 (100.0%)
Type IV	13 (59.1%)	9 (40.9%)	22 (100.0%)
Type V	2 (33.3%)	4 (66.7%)	6 (100.0%)
Total	98 (64.9%)	53 (35.1%)	151 (100.0%)

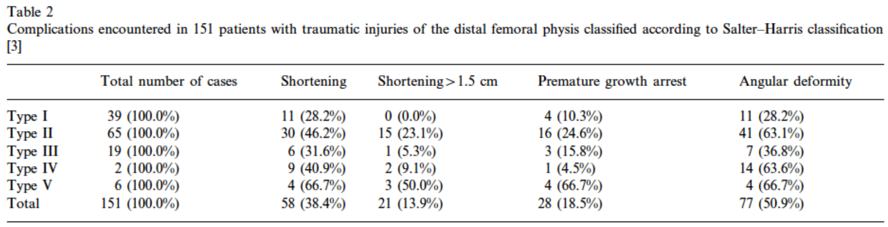


Table 2
Complications encountered in 151 patients with traumatic injuries of the distal femoral physis classified according to Salter–Harris classification [3]

	Total number of cases	Shortening	Shortening > 1.5 cm	Premature growth arrest	Angular deformity
Type I	39 (100.0%)	11 (28.2%)	0 (0.0%)	4 (10.3%)	11 (28.2%)
Type II	65 (100.0%)	30 (46.2%)	15 (23.1%)	16 (24.6%)	41 (63.1%)
Type III	19 (100.0%)	6 (31.6%)	1 (5.3%)	3 (15.8%)	7 (36.8%)
Type IV	2 (100.0%)	9 (40.9%)	2 (9.1%)	1 (4.5%)	14 (63.6%)
Type V	6 (100.0%)	4 (66.7%)	3 (50.0%)	4 (66.7%)	4 (66.7%)
Total	151 (100.0%)	58 (38.4%)	21 (13.9%)	28 (18.5%)	77 (50.9%)

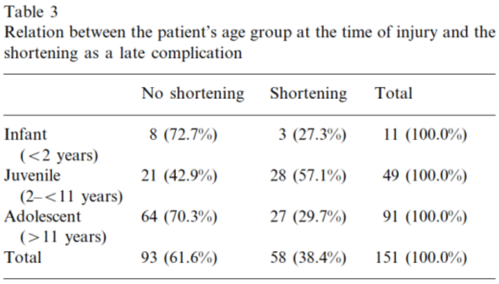


Table 3
Relation between the patient's age group at the time of injury and the shortening as a late complication

	No shortening	Shortening	Total
Infant (<2 years)	8 (72.7%)	3 (27.3%)	11 (100.0%)
Juvenile (2–<11 years)	21 (42.9%)	28 (57.1%)	49 (100.0%)
Adolescent (>11 years)	64 (70.3%)	27 (29.7%)	91 (100.0%)
Total	93 (61.6%)	58 (38.4%)	151 (100.0%)

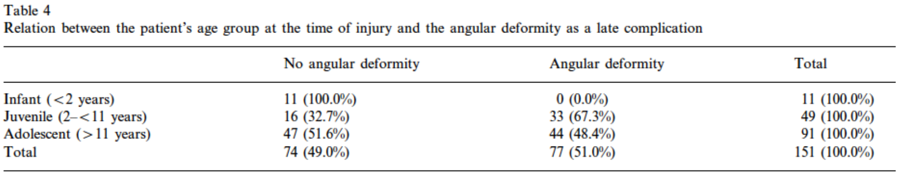
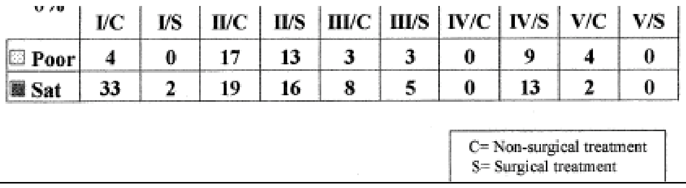


Table 4
Relation between the patient's age group at the time of injury and the angular deformity as a late complication

	No angular deformity	Angular deformity	Total
Infant (<2 years)	11 (100.0%)	0 (0.0%)	11 (100.0%)
Juvenile (2–<11 years)	16 (32.7%)	33 (67.3%)	49 (100.0%)
Adolescent (>11 years)	47 (51.6%)	44 (48.4%)	91 (100.0%)
Total	74 (49.0%)	77 (51.0%)	151 (100.0%)



	I/C	I/S	II/C	II/S	III/C	III/S	IV/C	IV/S	V/C	V/S
▨ Poor	4	0	17	13	3	3	0	9	4	0
■ Sat	33	2	19	16	8	5	0	13	2	0

C= Non-surgical treatment
S= Surgical treatment

Notes/ classifications	-

Study	Garrett B., Hoffman E., Carrara H., 2011(29)
Year published	2011
Country	South Africa
Institution	Authors from the Red Cross Children's Hospital, Maitland Cottage Paediatric Hospital and the Department of Orthopaedics, University of Cape Town, South Africa. Seems patients from 2 above hospitals.
Years studied	1994 to 2007
How patients selected	Patients who had sustained displaced distal femoral physeal fractures. Only displaced fractures requiring reduction were included in the study.
Methods	Clinical records, operation notes and radiographs reviewed of 55 patients. Patients were followed up at 6 monthly intervals for 2 years Leg length and mechanical alignment were assessed clinically Anteroposterior and lateral radiographs of the knee were taken in order to assess growth plate and growth arrest lines Early detection of growth arrest was made according to the configuration of the Harris growth arrest lines. Physeal bar formation was confirmed and plotted with biplanar tomography in the early part of the study and/or MRI in the latter part which is currently the gold standard 31 patients were recalled after skeletal maturity and assessed radiologically for the mechanical axis and clinically for leg length • Of these 31, 3 who had defaulted routine post–operative follow-up had a leg length discrepancy and deformity due to formation of a physeal bar 9 of the 12 patients that developed a bar were radiologically evident within 1 year The remaining 15 who were not skeletally mature at the time of the study and who had not developed obvious physeal bars were followed up for a minimum of 2 years
No. of patients initially	55
No. of patients studied	40 patients were assessed clinically and radiologically after skeletal maturity or at the time of formation of a bar The remaining 15 patients were followed up for a minimum of 2 years

Sex	Not recorded
Age range	3 to 13 years 31 were juveniles (<11 years) 24 were adolescents 11 years and older
Average age at injury	10 years (median)
Aetiology of injuries	High energy • Motor vehicle accident, including those involving a pedestrian or cyclist: 33 • Crush injuries: 3 Low energy • Falls: 13 • Sports-related: 6
SH I	4
SH II	46
SH III	2
SH IV	3
SH V	0
SH VI	0
Open fractures	Nil stated
Neurovascular injuries	Nil stated
Grading of displacement	50 fractures were extra-articular • 21 displaced medially • 9 displaced laterally • 19 displaced anteriorly • 1 displaced posteriorly
Surgical treatments	Open reduction: 6 patients • In 4/5 intra-articular SH III and SH IV fractures • 2 Type II fractures with interposed periosteum In 40 patients (includes both closed and ORIF), reduction was maintained with 2 smooth percutaneous K wires or Steinmann pins (1.8 to 3.2mm) crossing the physis and an above-knee plaster cast in full extension 4 had fixation with screws (3/5 of the intra-articular fractures and one SH II via the metaphyseal fragment) The cast and pins were removed after 6 weeks and the knee was mobilized 9 of the 12 patients who developed physeal bars were radiologically evident within one year
Conservative treatments	Closed reduction: 49 patients • 11 patients were treated with cast only
Follow-up	Minimum 2 years (15 patients). 40 other patients assessed clinically and radiologically until skeletal maturity or physeal bar formation
Outcomes measured	Physeal bar formation
Grading of complications	-
Statistical analysis	STATA version 11 was used for statistical analysis. Fisher's exact test used for frequencies <5 Non-parametric test by Cuzick (an extension of Wilcoxon's rank-sum test)
Results	Incidence of physeal bar formation was associated with high energy injuries and increasing severity of fracture by Salter Harris Classification, not age, method of treatment, direction of displacement

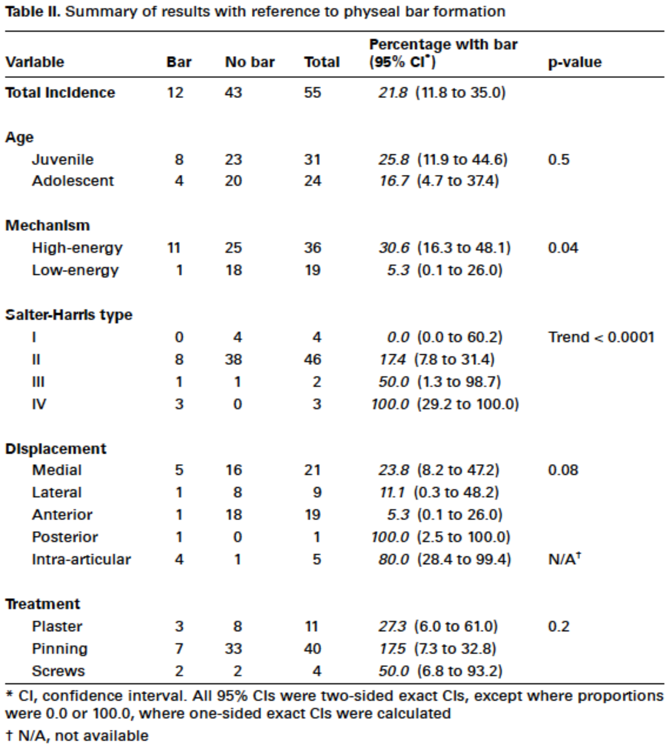
	 Formation of a physeal bar occurred in 12 (21.8%) patients with the rate rising to 30.6% in patients with high-energy injuries compared with 5.3% in those with low energy injuries Significant trend for physeal arrest according to increasing severity using the Salter-Harris classification system Percutaneous smooth pins across the physis were not statistically associated with growth arrest
Notes/ classifications	-

Table II. Summary of results with reference to physeal bar formation

Variable	Bar	No bar	Total	Percentage with bar (95% CI*)	p-value
Total incidence	12	43	55	*21.8* (11.8 to 35.0)	
Age					
Juvenile	8	23	31	*25.8* (11.9 to 44.6)	0.5
Adolescent	4	20	24	*16.7* (4.7 to 37.4)	
Mechanism					
High-energy	11	25	36	*30.6* (16.3 to 48.1)	0.04
Low-energy	1	18	19	*5.3* (0.1 to 26.0)	
Salter-Harris type					
I	0	4	4	*0.0* (0.0 to 60.2)	Trend < 0.0001
II	8	38	46	*17.4* (7.8 to 31.4)	
III	1	1	2	*50.0* (1.3 to 98.7)	
IV	3	0	3	*100.0* (29.2 to 100.0)	
Displacement					
Medial	5	16	21	*23.8* (8.2 to 47.2)	0.08
Lateral	1	8	9	*11.1* (0.3 to 48.2)	
Anterior	1	18	19	*5.3* (0.1 to 26.0)	
Posterior	1	0	1	*100.0* (2.5 to 100.0)	
Intra-articular	4	1	5	*80.0* (28.4 to 99.4)	N/A†
Treatment					
Plaster	3	8	11	*27.3* (6.0 to 61.0)	0.2
Pinning	7	33	40	*17.5* (7.3 to 32.8)	
Screws	2	2	4	*50.0* (6.8 to 93.2)	

* CI, confidence interval. All 95% CIs were two-sided exact CIs, except where proportions were 0.0 or 100.0, where one-sided exact CIs were calculated

† N/A, not available

Study	Graham J., Gross R., 1990(17)
Year published	1990
Country	USA
Institution	The authors' institution and affiliated hospitals – Department of Orthopaedic Surgery, Medial University of South Carolina, Charleston
Years studied	1977 to 1987
How patients selected	There were 10 patients treated at the authors' institution and affiliated hospitals with fractures of the distal femoral physis
Methods	A retrospective review was performed
No of patients initially	10
No of patients studied	10
Sex	9 males, 1 female
Age range	Nil given
Average age at injury	13 years
Aetiology of injuries	(American) football: 6 Other sports: 3 Auto-pedestrian accident: 1
SH I	2
SH II	7
SH III	0
SH IV	1
SH V	0

SH VI	0
Open fractures	0
Neurovascular injuries	1 – peroneal nerve palsy after auto-pedestrian accident
Grading of displacement	Not included in study; only discussion of other papers
Surgical treatments	Nil
Conservative treatments	Closed management in all cases • Traction alone • Traction and casting (with a spica or long leg cast) • Casting alone
Follow-up	Nil given except suggestion
Outcomes measured	Loss of reduction, asymmetric growth arrest within 6 months, manifesting as angular deformity, shortening, flexion deformity
Grading of complications	Asymmetric growth arrest manifesting as stated below
Statistical analysis	Nil specific EBM tools
Results	Seven Fractures lost position/reduction - 5 within 2 weeks after injury - 2 patients from 2-6 weeks post reduction Nine patients developed subsequent asymmetric growth arrest within 6 months post injury, manifesting as - Angular deformity greater than or equal to 5 degrees of varus or valgus as compared to the contralateral leg - Shortening of greater than 2.5cm - Flexion deformities of greater than or equal to 20 degrees - 3 of these patients required subsequent osteotomy or contralateral epiphyseodesis for correction
Notes/ classifications	Suggested this review of closed treatment yielded a high rate of unacceptable results Suggested • Anatomic reduction with more liberal use of open reduction internal fixation or closed percutaneous pinning in order to maintain reduction • Well moulded, well fitting cast • Weekly follow-up evaluations for 4-6 weeks to ensure maintenance of reduction • Total follow-up terms of at least one year with longer terms with young children to rule out growth disturbance

Study	Havranek P., Pesl T., 2010(36)
Year published	2010
Country	Czech Republic
Institution	3rd Faculty of Medicine, Charles' University and Thomayer's Teaching Hospital, Prague
Years studied	1987 to 2006
How patients selected	Patients with a type 6 injury treated at the hospital and present growth plates - only included patients with a clear avulsion of an epiphyseal and/or metaphyseal perichondrial osseous fragment
Methods	Retrospective study from 1987 to 2006. 29878 children were treated for acute skeletal injury – 36 of these treated for type 6 physeal injury Diagnosis of type 6 injury was based on X Ray images Only included • children with present growth plates • patients with a clear avulsion of an epiphyseal and/or metaphyseal perichondrial osseous fragment Recorded affected physis, aetiology, mechanism of injury, age, sex, method of treatment, outcome
No. of patients initially	8 distal femur from 36 Type 6 injuries
No. of patients studied	8 distal femur from 36 Type 6 injuries

Sex	21 boys and 15 girls (all type 6 injuries)
Age range	4-16 years
Average age at injury	11.6 years (mean) (all type 6 injuries)
Aetiology of injuries	Majority due to indirect forces (29 children) i.e. ligamentous avulsions of the perichondrial ring (all type 6 injuries) Athletic sports Soccer Gymnastics Stumbling/fall from height Traffic injuries Gunshot wounds
SH I	0
SH II	0
SH III	0
SH IV	0
SH V	0
SH VI	8
Open fractures	3 of 36 open scalping injuries distal tibial, distal humeral, distal fibular(all type 6 injuries) but none were distal femoral. These were scraping of the joint by car or bike wheel on road surface 2 were gunshot injuries – one metallic splinter from Petard explosion, the other from an airgun (langenskiold NOT ANTICIPATORY procedure performed in 2nd patient. Injury was of pharynx). Both of these patients had a partial growth arrest (bony bridge)
Neurovascular injuries	-
Grading of displacement	Minimal displacement in 28 cases.
Surgical treatments	Total Type VI injuries ('Surgery in 3 open scalping injuries – repeated debridement and subsequent skin grafting with anticipatory Langenskiold procedure using free fat interposition, osteosynthesis in 1 type 6 as large scale displacement of a perichondrial fragment (K wires for this lateral distal humerus fracture), osteosynthesis of a type 3 and a 4 injury (combined injuries both in distal tibia), splinter removal in 2 gunshot wounds - one projectile needed removal in one langenskiold NOT STATED ANTICIPATORY procedure performed in 2nd patient. Injury was of pharynx). Both of these patients had a partial growth arrest (bony bridge)")
Conservative treatments	Total Type VI injuries (28 cases 'non operative) Most injuries consisted of only minimal displacement and could be treated conservatively with immobilization
Follow-up	At least 2-4 years, mostly until cessation of physeal growth
Outcomes measured	see 'Materials and Methods' 'Outcome' Partial growth arrest, leg length (not universally reported) OUTCOMES NOT PROPERLY STATED
Grading of complications	-
Statistical analysis	-
Results	Focused on factors such as incidence, location of injury, fracture displacement, open/closed injury, aetiology of injury RATHER THAN objective outcomes ➔ CONSIDER EXCLUDING FROM STUDY OR HAVING AS SEPARATE INCLUSION Did note that 2 patients with a SH VI caused by a gunshot had partial growth arrest treated in the second child with a Langenskiold Procedure In several adolescents with conservative treatment, the affected physis closed several months earlier but this did not affect leg length
Notes/ classifications	Open fractures with skin and soft tissue loss including abrasion of the whole perichondrial regions are most serious injury Recommend surgery to prevent bony bridge formation. In a displaced, fresh injury, simple resection of the metaphyseal fragment or an anticipatory **Langenskiöld** procedure with resection of all avulsed peripheral structures an fat interposition is the method of treatment to prevent bony bridge formation Majority of these fractures are in adolescents closed and minimally displaced or small fragments from indirect forces – conservative orthopaedic treatment and long term follow-up recommended

Study	Ilharreborde B., Raquillet C., Morel E., Fitoussi F., Bensahel H., Penneçot G., Mazda K., 2006(49)
Year published	2006
Country	France
Institution	Robert Debré Hospital Paris France
Years studied	1994-2003
How patients selected	All patients with SH II # DF physis at author's institution during above years
Methods	Retrospective review of all patients with Salter Harris II injuries of the distal femoral physis managed at the above institution between 1994 and 2003 Patients with obstetric injuries were excluded At latest follow-up, all patients had AP and lateral radiographs if the injured knee to look for limb length discrepancy and angular deformity. Angular deformity clinically significant if varus or valgus at least 5 degrees more than the uninjured side Looked at type of injury, adequacy of reduction, stability or loss of reduction during treatment period, evidence of premature closure of the physeal plate
No. of patients initially	20
No. of patients studied	20
Sex	16 boys, 4 girls
Age range	8-15 years 10 fractures in juvenile age period (8 years to 10 years and 11 months) 10 fractures occurred in the adolescent age range (11 years or older)
Average age at injury	11 years (mean)
Aetiology of injuries	Always high energy trauma 13 were struck by cars whilst walking or bicycling 4 sports related (ski, soccer, judo) 3 from a fall
SH I	0
SH II	20
SH III	0
SH IV	0
SH V	0
SH VI	0
Open fractures	1 (Gustilo 3B)
Neurovascular injuries	0
Grading of displacement	(Initial) Type 1: less than 2mm Type 2: more than 2mm with contact between the 2 fragments Type 3: No contact between the 2 fragments Also graded as to the presence (B) or absence (A) of comminution Metaphyseal fragment was laterally displaced in 8 cases and medially in 12 cases
Surgical treatments	16 patients had open reduction internal fixation of the metaphyseal fragment by cortical screws followed by plaster-cast immobilization The open fracture required debridement followed by open reduction and osteosyntheis In all cases, full reduction was obtained
Conservative treatments	The 2 type one patients were treated conservatively with plaster cast immobilization without reduction All displaced fractures were reduced under general anesthesia 2 patients with type 2 fractures had closed reduction and plaster cast
Follow-up	18/12 to 11 years + 3/12 (average of 4 years and 2 months)
Outcomes measured	LLD, Angular deformity, limitation in ROM, epiphysiodesis, ligamentous laxity
Grading of	Varus or valgus was considered clinically significant if 5 degrees or more

complications	
Statistical analysis	-

Results

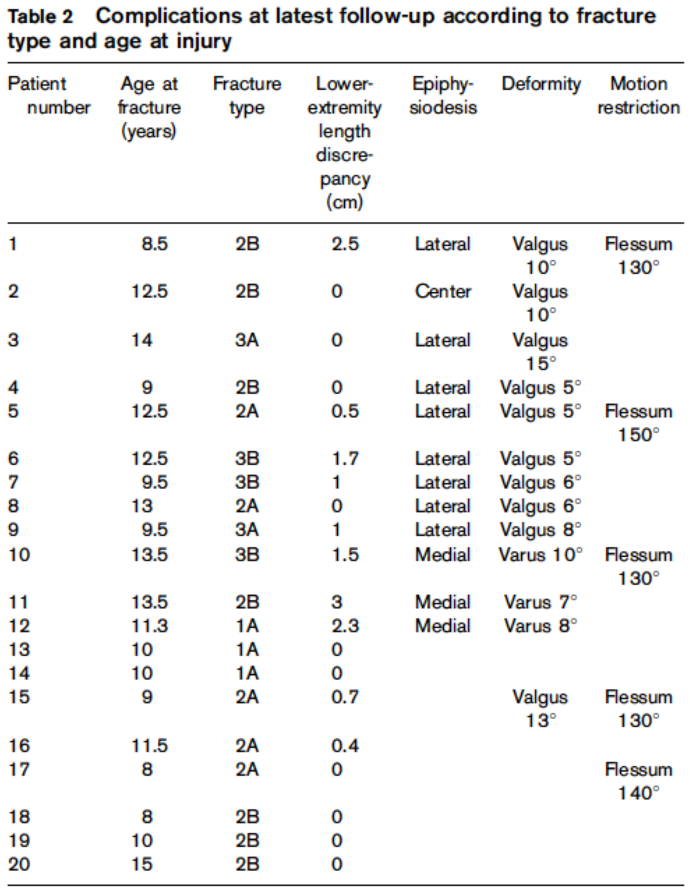


Table 2 Complications at latest follow-up according to fracture type and age at injury

Patient number	Age at fracture (years)	Fracture type	Lower-extremity length discrepancy (cm)	Epiphysiodesis	Deformity	Motion restriction
1	8.5	2B	2.5	Lateral	Valgus 10°	Flessum 130°
2	12.5	2B	0	Center	Valgus 10°	
3	14	3A	0	Lateral	Valgus 15°	
4	9	2B	0	Lateral	Valgus 5°	
5	12.5	2A	0.5	Lateral	Valgus 5°	Flessum 150°
6	12.5	3B	1.7	Lateral	Valgus 5°	
7	9.5	3B	1	Lateral	Valgus 6°	
8	13	2A	0	Lateral	Valgus 6°	
9	9.5	3A	1	Lateral	Valgus 8°	
10	13.5	3B	1.5	Medial	Varus 10°	Flessum 130°
11	13.5	2B	3	Medial	Varus 7°	
12	11.3	1A	2.3	Medial	Varus 8°	
13	10	1A	0			
14	10	1A	0			
15	9	2A	0.7		Valgus 13°	Flessum 130°
16	11.5	2A	0.4			
17	8	2A	0			Flessum 140°
18	8	2B	0			
19	10	2B	0			
20	15	2B	0			

**Type = displacement
** All are Salter Harris type II injuries

2 patients with type 1 injuries were treated conservatively, with no complication
2 patients with type 2 fractures had closed reductions and plaster cast immobilization and 16 had ORIF of metaphyseal fragment by cortical screws then immobilization

No loss of reduction for all 18 of the reduction group
No post-operative infection

14 patients had a complication due to either

- Eiphysiodesis
- Femoral overgrowth
- Associated loss of knee motion

No complication after initial type one injury
All patients with type 3 injuries suffered complications

Clinically significant angular deformity in 13 patients
12 patients had epiphyseodesis (7 of these type B fractures), significant LLD in 6 patients
1 patient with femoral over-lengthening (less than 1cm clinically)
3 had varus, 10 had valgus
No recurvatum or flexion deformity
5 had loss of knee joint ROM ranging from 10 to 30 degrees including one with an open fracture (in 4 of these cases it was associated with another complication)
Extension lag between 5 and 10 degrees in 3 patients
No ligamentous laxity was reported

14/20 patients were skeletally mature at latest follow-up
5 patients required surgery before being skeletally mature in an effort to correct a predictable discrepancy of more than 2.5cm (3 had contralateral epiphyseodesis and 2 treated with femoral lengthening)

No correlation between direction of initial displacement and location of the metaphyseal fragment and the subsequent progression of valgus or varus angulation was noted

Notes/ classifications	-

Study	Kritsaneepaiboon S., Shah R., Murray M., Kleinman P., 2009(50)
Year published	2009
Country	USA
Institution	Children's Hospital Boston
Years studied	2002 to 2008
How patients selected	SH II fractures of the distal femur, identified from knee MRI reports
Methods	Text search using the keywords "Salter-Harris fracture" or "physeal injury" in radiology reports for all paediatric patients who underwent knee MRI from Jan 2002 to Feb 2008 Exclusion criteria: examinations performed post-operatively or done remote to time of injury (11 excluded) 7 distal femur, 5 proximal tibia remained. Only looking at SHII and distal femur, thus SH IV of distal femur was excluded Imaging and clinical findings in distal femur analysed AP and (otherview) ** 1. To assess frequency of posterior periosteal disruption on MRI in radiologically occult or subtle SHI distal femur fractures of distal femur ** 2. To evaluate associated soft tissue findings that support a hyperextension mechanism of injury Radiographic studies reviewed and interpreted in consensus by board certified and a paediatric musculoskeletal radiologist
No. of patients initially	23
No. of patients studied	6
Sex	All boys
Age range	8 to 16 years
Average age at injury	12.5 years
Aetiology of injuries	Clear hyper-extension injury for 2, 4 had direct injury to the knee
SH I	0
SH II	6
SH III	0
SH IV	0
SH V	0
SH VI	0
Open fractures	Nil stated
Neurovascular injuries	Nil stated
Grading of displacement	Evaluation of Location of fracture Bone marrow oedema Physeal widening Posterior joint capsule disruption Trapped or disrupted posterior periosteum Abnormalities of the menisci Medial and lateral collateral ligament and other soft tissue abnormalities Size of joint effusion was noted and graded
Surgical treatments	-
Conservative treatments	HKB and physiotherapy Long leg cast (patient 5 only)
Follow-up	8 weeks to 18 months
Outcomes measured	Return to normal activities, LLD Radiographic: location of fracture and bone marrow oedema, physeal widening, posterior joint capsule disruption, trapped or disrupted posterior periosteal disruption, abnormalities of the

<table>
<tr><td></td><td>menisci, MCL, LCL complex and other soft tissue abnormalities. The size of the effusion was graded</td></tr>
<tr><td>Grading of complications</td><td>-</td></tr>
<tr><td>Statistical analysis</td><td>-</td></tr>
<tr><td>Results</td><td>5 out of 6 patients were able to return to normal activities without radiographic evidence of growth arrest (At 5-18 month follow-up)
- Among these, patient 2 had a leg length discrepancy with the fractured extremity 1cm longer than the unaffected side

Radiological findings below

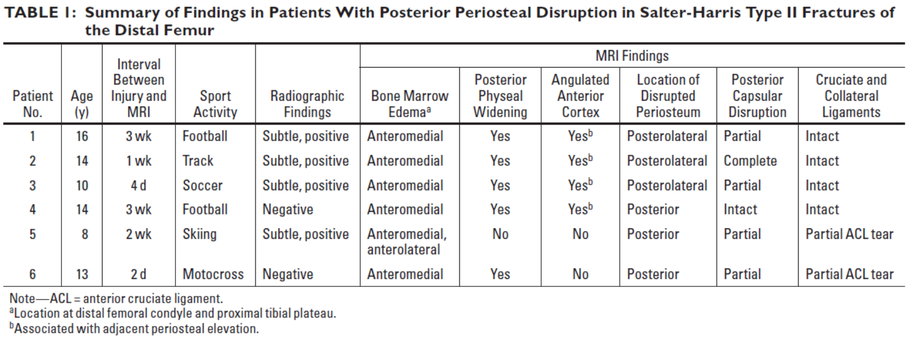



TABLE I: Summary of Findings in Patients With Posterior Periosteal Disruption in Salter-Harris Type II Fractures of the Distal Femur
<table>
<tr><th></th><th></th><th></th><th></th><th></th><th colspan="6">MRI Findings</th></tr>
<tr><th>Patient No.</th><th>Age (y)</th><th>Interval Between Injury and MRI</th><th>Sport Activity</th><th>Radiographic Findings</th><th>Bone Marrow Edema^a</th><th>Posterior Physeal Widening</th><th>Angulated Anterior Cortex</th><th>Location of Disrupted Periosteum</th><th>Posterior Capsular Disruption</th><th>Cruciate and Collateral Ligaments</th></tr>
<tr><td>1</td><td>16</td><td>3 wk</td><td>Football</td><td>Subtle, positive</td><td>Anteromedial</td><td>Yes</td><td>Yes^b</td><td>Posterolateral</td><td>Partial</td><td>Intact</td></tr>
<tr><td>2</td><td>14</td><td>1 wk</td><td>Track</td><td>Subtle, positive</td><td>Anteromedial</td><td>Yes</td><td>Yes^b</td><td>Posterolateral</td><td>Complete</td><td>Intact</td></tr>
<tr><td>3</td><td>10</td><td>4 d</td><td>Soccer</td><td>Subtle, positive</td><td>Anteromedial</td><td>Yes</td><td>Yes^b</td><td>Posterolateral</td><td>Partial</td><td>Intact</td></tr>
<tr><td>4</td><td>14</td><td>3 wk</td><td>Football</td><td>Negative</td><td>Anteromedial</td><td>Yes</td><td>Yes^b</td><td>Posterior</td><td>Intact</td><td>Intact</td></tr>
<tr><td>5</td><td>8</td><td>2 wk</td><td>Skiing</td><td>Subtle, positive</td><td>Anteromedial, anterolateral</td><td>No</td><td>No</td><td>Posterior</td><td>Partial</td><td>Partial ACL tear</td></tr>
<tr><td>6</td><td>13</td><td>2 d</td><td>Motocross</td><td>Negative</td><td>Anteromedial</td><td>Yes</td><td>No</td><td>Posterior</td><td>Partial</td><td>Partial ACL tear</td></tr>
</table>
Note—ACL = anterior cruciate ligament.
[a] Location at distal femoral condyle and proximal tibial plateau.
[b] Associated with adjacent periosteal elevation.</td></tr>
<tr><td>Notes/ classifications</td><td>Purpose of study to look at MRI findings to determine whether evidence of hyperextension mechanism</td></tr>
</table>

Study	Krueger-Franke M., Siebert C., Pfoerringer W., 1992(51)
Year published	1992
Country	Germany
Institution	Staatliche Orthopaedische Klinik Muenchen
Years studied	1968-1989
How patients selected	Treated at their Institution for sports-related epiphyseal injuries of the lower extremity
Methods	Report of patients treated at their hospital for sports related epiphyseal injuries of the lower extremity
No. of patients initially	10/85 = distal femur (before exclude lost to follow-up)
No. of patients studied	Number of DF follow-up not stated/49
Sex	60 boys, 25 girls
Age range	4-17 years (all lower limb patients) For DF 5-7 yo: 2 9-11 yo: 1 11-13 yo: 2 13-15 yo: 3 15-17 yo: 2 >17 yo: 0
Average age at injury	12.3 (male) and 12.9 years (female)
Aetiology of injuries	Soccer: 1 Skiing: 5 Gymnastics: 3 Other: 1
SH I	2
SH II	4
SH III	2
SH IV	2

SH V	0
SH VI	0
Open fractures	At least one of the ankle which resulted in osteomyelitis and destruction of the joint – had debridement and arthrodesis.
Neurovascular injuries	Nil stated
Grading of displacement	Not stated
Surgical treatments	5 distal femoral physeal fractures managed operatively
Conservative treatments	5 distal femoral physeal fractures managed conservatively
Follow-up	49 lower limb patients available for follow-up at the conclusion of their growth
Outcomes measured	Varus/ valgus deformity, rotational deformity, LLD
Grading of complications	-
Statistical analysis	
Results	Overall - 49/85 available for clinical and radiographic evaluation at the conclusion of their growth - 9 cases of growth deformity or complication of which 6 required corrective procedures 3 of the 4 SH II Distal femur injuries lead to a variety of deformities all requiring surgical correction - 15 degrees valgus deformity of the knee with a 1cm shortening - 20 degree rotational deformity - leg lengthening of 4cm Other region complications: 1 AVN femoral head, 2 more LLDs, 2 more axial deviations and the osteomyelitis
Notes/ classifications	-

Study	Lippert W., Owens R., Wall E., 2010(52)
Year published	2010
Country	USA
Institution	Cincinnati Children's Hospital
Years studied	1995 to 2006
How patients selected	All patients identified by search of Institution's computerised database
Methods	Retrospective Review. Fracture displacement on pain X Ray was compared with the fracture displacement on MRI or CT. Patient charts were reviewed for pertinent data such as sex, side of injury, age at injury, the mechanism of injury, associated injuries with the fracture, and the type of treatment executed. Also, all X Ray, MRI and or CT imaging studies reviewed and measured. Timing to CT/ MRI recorded. Follow-up data obtained from clinic notes including presence of growth disturbance, range of motion, pain, function, need for hardware removal and/or Follow-up limb length procedures such as epiphysiodesis
No. of patients initially	14
No. of patients studied	14
Sex	2 females, 12 males
Age range	7 years 8 months to 17 years 11 months
Average age at injury	13 years 11 months
Aetiology of injuries	Fall, fall down stairs, tombstone fell on leg, (American) football, fall from bicycle

SH I	0
SH II	0
SH III	14
SH IV	0
SH V	0
SH VI	0
Open fractures	Nil stated
Neurovascular injuries	Nil stated
Grading of displacement	Measured in mm. Initial fracture displacement on XR was compared with fracture displacement on MRI or CT scan
Surgical treatments	Closed reduction percutaneous pinning Open reduction internal fixation
Conservative treatments	Cast Knee immobilizer
Follow-up	2 to 47 months (average 21.5 months)
Outcomes measured	LLD/ growth disturbance, ROM deficit, pain, physical limitations
Grading of complications	No grading stated
Statistical analysis	Normality tests to determine appropriate statistical test, suggesting paired student t test. P value <0.05 used.

Results

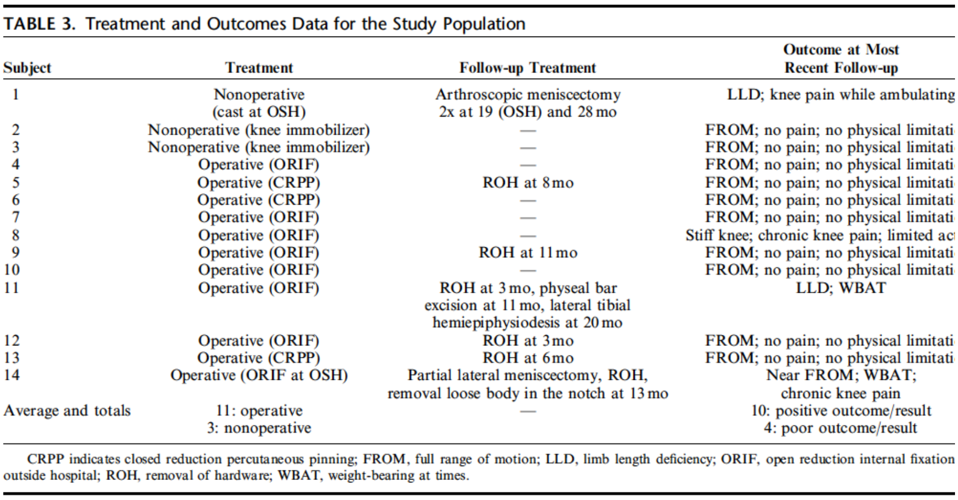


TABLE 3. Treatment and Outcomes Data for the Study Population

Subject	Treatment	Follow-up Treatment	Outcome at Most Recent Follow-up
1	Nonoperative (cast at OSH)	Arthroscopic meniscectomy 2x at 19 (OSH) and 28 mo	LLD; knee pain while ambulating
2	Nonoperative (knee immobilizer)	—	FROM; no pain; no physical limitati
3	Nonoperative (knee immobilizer)	—	FROM; no pain; no physical limitati
4	Operative (ORIF)	—	FROM; no pain; no physical limitati
5	Operative (CRPP)	ROH at 8 mo	FROM; no pain; no physical limitati
6	Operative (CRPP)	—	FROM; no pain; no physical limitati
7	Operative (ORIF)	—	FROM; no pain; no physical limitati
8	Operative (ORIF)	—	Stiff knee; chronic knee pain; limited ac
9	Operative (ORIF)	ROH at 11 mo	FROM; no pain; no physical limitati
10	Operative (ORIF)	—	FROM; no pain; no physical limitati
11	Operative (ORIF)	ROH at 3 mo, physeal bar excision at 11 mo, lateral tibial hemiepiphysiodesis at 20 mo	LLD; WBAT
12	Operative (ORIF)	ROH at 3 mo	FROM; no pain; no physical limitati
13	Operative (CRPP)	ROH at 6 mo	FROM; no pain; no physical limitati
14	Operative (ORIF at OSH)	Partial lateral meniscectomy, ROH, removal loose body in the notch at 13 mo	Near FROM; WBAT; chronic knee pain
Average and totals	11: operative 3: nonoperative	—	10: positive outcome/result 4: poor outcome/result

CRPP indicates closed reduction percutaneous pinning; FROM, full range of motion; LLD, limb length deficiency; ORIF, open reduction internal fixation outside hospital; ROH, removal of hardware; WBAT, weight-bearing at times.

Plain XRs significantly underestimated displacement of SH III fractures (compared to MR or CT). Treatment changed on 4 of patients due to addition of MR or CT findings (subjects 4,8,11,12) as displacement >2mm (criterion).

6 of 14 patients had fractures which appeared non displaced or missed initially on plain films

10/14 patients had no physical limitation and full knee motion at most recent Follow-up

Notes/ classifications	Recommend CT or MRI to be done for every SHIII of the distal femur

Study	Partio E., Tuompo P., HIrvensalo E., Böstman O., Rokkanen P., 1997(53)
Year published	1997
Country	Finland
Institution	Helsinki University Central Hospital
Years studied	1990-1994
How patients selected	Patients treated between July 1990 and May 1994 with a fracture of the distal epiphysis treated with totally absorbable, self-reinforced fixation devices

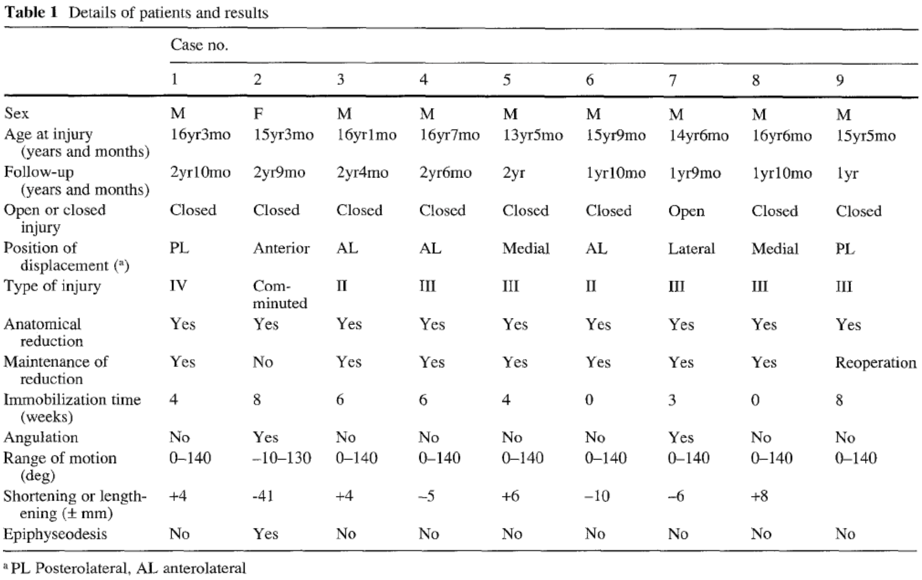
Methods	Retrospective review. Follow-up times were 3 weeks, 6 weeks, 3 months, 6 months, 1 year and at the end of the study. Clinical result e.g. movement of the knee joint, ligamentous laxity, muscle atrophy, and subjective complaints of daily living and sport activities was recorded. Plain radiographs of the fractured femur were taken throughout, and the end of the follow-up the length of both legs was measured radiographically in 8 patients
No. of patients initially	9
No. of patients studied	9
Sex	8 boys, 1 girl
Age range	13 to 16 years
Average age at injury	15 years 6 months
Aetiology of injuries	Motorbike accidents, ice hockey, fall whilst horse riding, fall from bicycle
SH I	0
SH II	2
SH III	5
SH IV	1
SH V	(1 comminuted)
SH VI	0
Open fractures	1
Neurovascular injuries	Nil stated
Grading of displacement	Position of displacement rather than measurement
Surgical treatments	Open reduction internal fixation then plaster cast applied for 4-8 weeks in seven patients whilst 2 wore a splint
Conservative treatments	Closed reduction tried initially in the two SH II fractures but then finally treated with ORIF as unacceptable reduction
Follow-up	1 year to 2 years 10 months (average 2 years 2 months). All but one became skeletally mature.
Outcomes measured	Maintenance of reduction, angulation, ROM, LLD, Epiphysiodesis, ligamentous laxity, muscle atrophy, comments on daily living
Grading of complications	-
Statistical analysis	-
Results	

Table 1 Details of patients and results

	Case no.								
	1	2	3	4	5	6	7	8	9
Sex	M	F	M	M	M	M	M	M	M
Age at injury (years and months)	16yr3mo	15yr3mo	16yr1mo	16yr7mo	13yr5mo	15yr9mo	14yr6mo	16yr6mo	15yr5mo
Follow-up (years and months)	2yr10mo	2yr9mo	2yr4mo	2yr6mo	2yr	1yr10mo	1yr9mo	1yr10mo	1yr
Open or closed injury	Closed	Closed	Closed	Closed	Closed	Closed	Open	Closed	Closed
Position of displacement ([a])	PL	Anterior	AL	AL	Medial	AL	Lateral	Medial	PL
Type of injury	IV	Comminuted	II	III	III	II	III	III	III
Anatomical reduction	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Maintenance of reduction	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Reoperation
Immobilization time (weeks)	4	8	6	6	4	0	3	0	8
Angulation	No	Yes	No	No	No	No	Yes	No	No
Range of motion (deg)	0–140	–10–130	0–140	0–140	0–140	0–140	0–140	0–140	0–140
Shortening or lengthening (± mm)	+4	-41	+4	–5	+6	–10	–6	+8	
Epiphyseodesis	No	Yes	No	No	No	No	No	No	No

[a] PL Posterolateral, AL anterolateral

	In 2/9, a clinically significant growth disturbance occurred. LLD 5mm on average One valgus deformity was noted Fixation failed in 2 patients – in one it failed during application of the plaster cast. This patient was then treated by traction for 4 weeks followed by plaster cast immobilization for another 4 weeks. In the other patient, they had PGA rod – and had reoperation on the 4th post operative day One patient had a DVT noted in the operated leg noted day 5 post op 8/9 patients gained full ROM. Case 2 had a premature growth arrest and valgus deformity of 18 degrees and slight ligamentous laxity. Case 7 had a lateral growth arrest Follow-up until mature both distal epiphyses in bilateral femurs in 8 cases Excluded patient managed with traction 3 grew 3-4cm and four patients grew 7-10cm in length during follow-up, showing breakages in the drill channel recorded radiographically (but proximal part clearly above and distal part clearly below the epiphysis)
Statistical analysis	-
Notes/ classifications	ORIF sees to be suitable for the fixation of distal femoral fractures in adolescents

Study	Plánka L., Skvaril J., Stary D., Jochymek J., Gál P., 2008 (28)
Year published	2008
Country	Czech Republic
Institution	Department of Paediatric Surgery, Orthopaedics and Traumatology Faculty Hospital, Brno, Czech Republic
Years studied	1997 to 2007
How patients selected	Physeal injury of the distal femur treated at Institution
Methods	Data obtained from the Hospital Information System AMIS H All patients underwent a control examination based on a uniform protocol Retrospective Formulated a set of patients • 0-19 years • diagnosis of SH I – VI • and the patient having undergone complex treatment at the department between 1/1/1997 and 31/12/2007 Then acquired medical records and obtained information on (after this, had 38 patients) • post injury and follow-up X-ray findings • treatment method • necessity and length of rehabilitation, occurrence of complications Month 3 post injury was last clinical examination of patients including movement examination of surrounding joints XRs at day 3, 10, 28, 32 and then during months 2 and 3 Spica cast removal after 5 weeks Metal extraction during month 3 post surgery
No. of patients initially	46
No. of patients studied	31
Sex	16 boys, 15 girls
Age range	2-16 years
Average age at injury	11.9 years
Aetiology of injuries	Mainly sports and traffic accidents. Postnatal ephyseolysis was not included as part of the set as considered a separate issue.
SH I	3
SH II	26
SH III	2

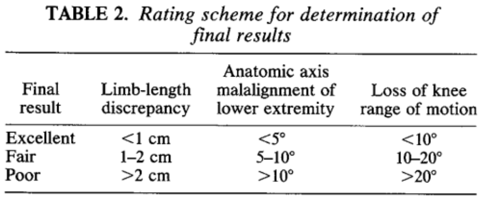
SH IV	0
SH V	0
SH VI	0
Open fractures	Nil stated
Neurovascular injuries	Nil stated
Grading of displacement	Termed 'dislocation'. Absolute term only.
Surgical treatments	Dislocated SH I and SH II - Repositioning, transfixion by K wires. Spica cast SH III, SH IV - Repositioning, transfixion by K wires. Spica cast In case of persistent fragment distraction following repositioning, 1-2 cannulated tension screws. Spica cast
Conservative treatments	Spica cast for non-dislocated fracture
Follow-up	Month 3 post injury was last clinical examination of patients including movement examination of surrounding joints
Outcomes measured	Angulation, shortening, development of porosis, limitation in hip and knee ROM, redislocation, re-surgery, damage to neurovascular plexus, complete healing of epiphysiolysis
Grading of complications	Successful treatment regarded as • Complete healing of epiphyseolysis without significant angulation (less than 5 degrees) • Difference in length less than 1cm compared to the unaffected femur and the absence of any other complications (according to Ogden) such as o Post-injury angulation o Shortening of femur o Development of porosis in distal femur o Limitation of knee and hip movement o Redislocation o Resurgery o Damage to neural vascular plexus
Statistical analysis	-
Results	Overall, 25 patients had healing without complications Conservative group (total 11 patients) involved non-dislocated fracture managed at outpatient department with spica cast - 0 complications Osteosynthesis with K wires (total 18 patients) - percutaneous transfixation by Kirschner wires was conducted following repositioning - 4 cases of clinically significant angulation - 2 cases of significant shortening (in one case in combination with angulation) Osteosynthesis with a cannulated 'tension' screw (total 2 patients) - Clinically significant angulation in one patient Open reduction was not necessary in any of the cases Concluded that this diagnostic and therapeutic procedure provides long term satisfactory results in 81% patients
Notes/ classifications	The operative treatment method combined a conservative approach making use of a spica cast with percutaneous mini-invasive osteosynthesis using Kirschner wires or cannulated screws, depending on the type of epiphyseolysis and the level of the dislocation • In case of fragment disocation and instability of epiphyseolysis, the department preference was osteosynthesis with Kirschner wires (after accurate repositioning, inserted transphyseally and percutaneously)

Study	Thomson J., Stricker S., Williams M., 1995(19)
Year published	1995
Country	USA
Institution	University of Miami/Jackson Memorial Centre
Years studied	1982 to 1991

<table>
<tr><td>How patients selected</td><td>Consecutive fractures of the distal femoral plate retrospectively reviewed</td></tr>
<tr><td>Methods</td><td>- 37 patients initially but complete records and sufficient follow-up
- thus 29 patients with 30 fractures

Inclusion criteria
- initial injury roentgenograms demonstrating a distal femoral epiphyseal plate fracture
- and minimum of 1 year follow-up with clinical and radiographic evaluation

Exclusion criteria
- open fractures
- unsubstantiated SH I fractures

Noted complications such as lower limb malalignment, limb length inequality, restricted knee joint motion, ligamentous instability</td></tr>
<tr><td>No. of patients initially</td><td>37</td></tr>
<tr><td>No. of patients studied</td><td>29 patients with 30 fractures</td></tr>
<tr><td>Sex</td><td>22 males (one had bilateral fractures), 7 females</td></tr>
<tr><td>Age range</td><td>6 months to 15 years old</td></tr>
<tr><td>Average age at injury</td><td>10.9 years (mean)</td></tr>
<tr><td>Aetiology of injuries</td><td>Nil recorded</td></tr>
<tr><td>SH I</td><td>0</td></tr>
<tr><td>SH II</td><td>24</td></tr>
<tr><td>SH III</td><td>2</td></tr>
<tr><td>SH IV</td><td>4</td></tr>
<tr><td>SH V</td><td>0</td></tr>
<tr><td>SH VI</td><td>0</td></tr>
<tr><td>Open fractures</td><td>Excluded</td></tr>
<tr><td>Neurovascular injuries</td><td>None of the patients had a neurovascular injury. Associated injuries: one closed contralateral midshaft femoral fracture, one distal radius fracture, two ipsilateral anterior cruciate tears, one liver laceration</td></tr>
<tr><td>Grading of displacement</td><td>Group 1 (non-displaced): displacement <2mm
- 7 fractures
Group 2: displacement <50% of the transverse diameter of the distal femoral metaphysis on either anteroposterior or lateral roentgenogram
- 10 fractures
Group 3: > 50% initial fracture displacement
- 13 fractures</td></tr>
<tr><td>Surgical treatments</td><td>The remainder of reductions were performed under general anesthesia by various orthopaedic surgeons
15 fractures were internally fixed with screw or pin fixation (at surgeons discretion)
All patients were treated with early attempts at closed or open reduction</td></tr>
<tr><td>Conservative treatments</td><td>No patients were treated with traction
Four patients had reductions in ER
Closed reduction in theatre</td></tr>
<tr><td>Follow-up</td><td>1-8 years</td></tr>
<tr><td>Outcomes measured</td><td>LLD, Malalignment, loss of ROM, loss of reduction, further bony surgery</td></tr>
<tr><td>Grading of complications</td><td>
TABLE 2. <i>Rating scheme for determination of final results</i>
<table>
<tr><th>Final result</th><th>Limb-length discrepancy</th><th>Anatomic axis malalignment of lower extremity</th><th>Loss of knee range of motion</th></tr>
<tr><td>Excellent</td><td><1 cm</td><td><5°</td><td><10°</td></tr>
<tr><td>Fair</td><td>1–2 cm</td><td>5–10°</td><td>10–20°</td></tr>
<tr><td>Poor</td><td>>2 cm</td><td>>10°</td><td>>20°</td></tr>
</table></td></tr>
<tr><td>Statistical analysis</td><td>Fisher’s exact test to compare the outcomes amongst treatment groups</td></tr>
<tr><td>Results</td><td></td></tr>
</table>

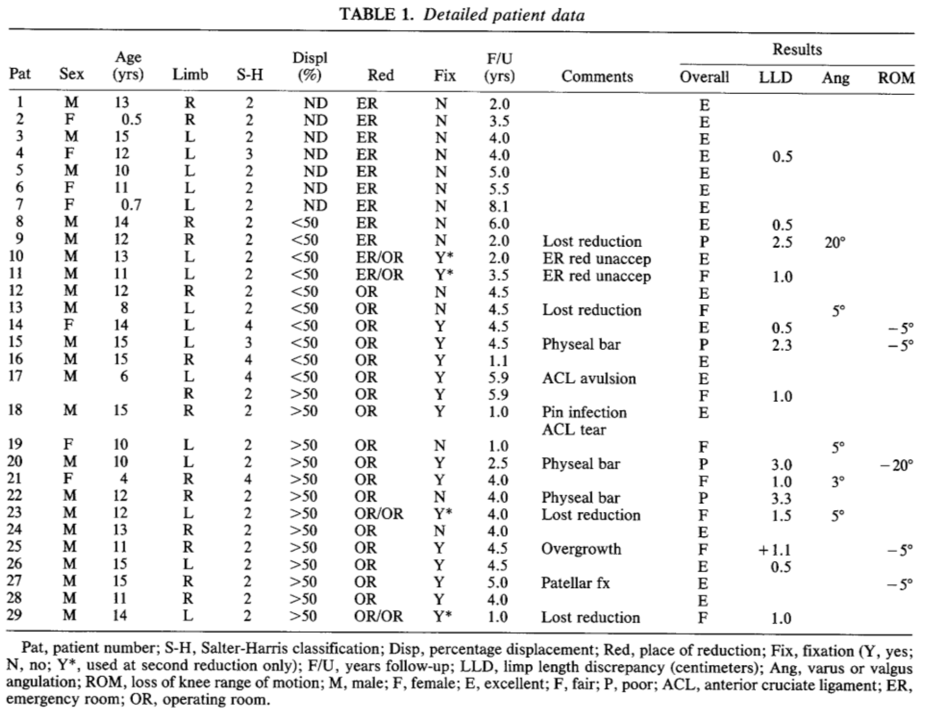


TABLE 1. *Detailed patient data*

Pat	Sex	Age (yrs)	Limb	S-H	Displ (%)	Red	Fix	F/U (yrs)	Comments	Results			
										Overall	LLD	Ang	ROM
1	M	13	R	2	ND	ER	N	2.0		E			
2	F	0.5	R	2	ND	ER	N	3.5		E			
3	M	15	L	2	ND	ER	N	4.0		E			
4	F	12	L	3	ND	ER	N	4.0		E	0.5		
5	M	10	L	2	ND	ER	N	5.0		E			
6	F	11	L	2	ND	ER	N	5.5		E			
7	F	0.7	L	2	ND	ER	N	8.1		E			
8	M	14	R	2	<50	ER	N	6.0		E	0.5		
9	M	12	R	2	<50	ER	N	2.0	Lost reduction	P	2.5	20°	
10	M	13	L	2	<50	ER/OR	Y*	2.0	ER red unaccep	E			
11	M	11	L	2	<50	ER/OR	Y*	3.5	ER red unaccep	F	1.0		
12	M	12	R	2	<50	OR	N	4.5		E			
13	M	8	L	2	<50	OR	N	4.5	Lost reduction	F		5°	
14	F	14	L	4	<50	OR	Y	4.5		E	0.5		−5°
15	M	15	L	3	<50	OR	Y	4.5	Physeal bar	P	2.3		−5°
16	M	15	R	4	<50	OR	Y	1.1		E			
17	M	6	L	4	<50	OR	Y	5.9	ACL avulsion	E			
			R	2	>50	OR	Y	5.9		F	1.0		
18	M	15	R	2	>50	OR	Y	1.0	Pin infection ACL tear	E			
19	F	10	L	2	>50	OR	N	1.0		F		5°	
20	M	10	L	2	>50	OR	Y	2.5	Physeal bar	P	3.0		−20°
21	F	4	R	4	>50	OR	Y	4.0		F	1.0	3°	
22	M	12	R	2	>50	OR	N	4.0	Physeal bar	P	3.3		
23	M	12	L	2	>50	OR/OR	Y*	4.0	Lost reduction	F	1.5	5°	
24	M	13	R	2	>50	OR	N	4.0		E			
25	M	11	R	2	>50	OR	Y	4.5	Overgrowth	F	+1.1		−5°
26	M	15	L	2	>50	OR	Y	4.5		E	0.5		
27	M	15	R	2	>50	OR	Y	5.0	Patellar fx	E			−5°
28	M	11	R	2	>50	OR	Y	4.0		E			
29	M	14	L	2	>50	OR/OR	Y*	1.0	Lost reduction	F	1.0		

Pat, patient number; S-H, Salter-Harris classification; Disp, percentage displacement; Red, place of reduction; Fix, fixation (Y, yes; N, no; Y*, used at second reduction only); F/U, years follow-up; LLD, limp length discrepancy (centimeters); Ang, varus or valgus angulation; ROM, loss of knee range of motion; M, male; F, female; E, excellent; F, fair; P, poor; ACL, anterior cruciate ligament; ER, emergency room; OR, operating room.

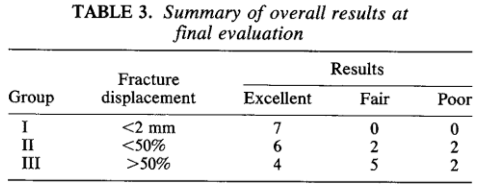


TABLE 3. *Summary of overall results at final evaluation*

Group	Fracture displacement	Results		
		Excellent	Fair	Poor
I	<2 mm	7	0	0
II	<50%	6	2	2
III	>50%	4	5	2

location of reduction

- 2/4 reductions performed in ER were unacceptable and a third reduction was lost in the cast
    - 75% failure rate
    - the 2 failed reductions were then repeated under GA
- 3/19 of OR reductions under GA lost reduction
    - 2 of these were treated with repeat closed reduction under general anaesthesia augmented by Steinmann pin fixation ultimately yielding a fair result
    - The third lost reduction was not recognised until 12 days post-reduction
        - Repeat manipulation not attempted due to concern of iatrogenic physeal injury
        - Patient had a fair result

No fractures with internal fixation displaced. 43% of fractures reduced without fixation displaced during cast treatment

Complications more frequent in displaced than non-displaced fractures

Unable to demonstrate whether ER reduction better than OR in terms of physeal arrest but OR more likely to remain anatomic

Deep pin tract infection from subcutaneous fixation pin

Patella fracture from fall during physio – required ORIF TBW

Notes/ classifications

A patient temporarily lost to follow-up developed quads adhesions as was in spica for 11/52. Then this patient fell during physio sustaining displaced patella fracture which was fixed. His final result was excellent. Another patient treated I hip spica cast developed a transient peroneal nerve palsy and a full thickness pressure ulceration that required SSG

Only 2 patients had bony reconstructive procedures

- One patient had physeal bar resection
- One had epiphysiodesis with distal femoral osteotomy