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SYSTEMATIC REVIEWS

Ipsilateral femur and tibia fractures in pediatric patients: A systematic review

Jason B Anari, Alexander L Neuwirth, B David Horn, Keith D Baldwin

Jason B Anari, Alexander L Neuwirth, Department of Orthopaedic Surgery, University of Pennsylvania, Philadelphia, PA 19102, United States

B David Horn, Keith D Baldwin, Children's Hospital of Philadelphia, Philadelphia, PA 19103, United States

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Correspondence to: Keith D Baldwin, MD, MPH, MSPT, Children's Hospital of Philadelphia, 24th and Civic Center Boulevard, Philadelphia, PA 19103, United States. baldwink@email.chop.edu
Telephone: +1-856-4040653

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Abstract

AIM

To better understand how pediatric floating knee injuries are managed after the wide spread use of new orthopaedic technology.

METHODS

We searched EMBASE, COCHRANE and MEDLINE computerized literature databases from the earliest date available in the databases to February 2017 using the following search term including variants and pleural counterparts: Pediatric floating knee. All studies were thoroughly reviewed by multiple authors. Reference lists from all articles were scrutinized to identify any additional studies of interest. A final database of individual patients was assembled from the literature. Univariate and multivariate statistical tests were applied to the assembled database to assess differences in outcomes.

RESULTS

The English language literature contains series with a total of 97 pediatric patients who sustained floating knee injuries. Patients averaged 9.3 years of age and were mostly male (73). Approximately 25% of the fractures were open injuries, more tibia (27) than femur (10). Over 75% of the fractures of both the tibia and the femur involved the diaphysis. More than half (52) of the patients were treated non-operatively for both fractures. As a sequela of the injury 32 (33%) patients were left with a limb length discrepancy, 24 (25%) patients had lengthening of the injured limb at follow up, while 8 (8%) had shortening of the affected limb. Infection developed in 9 patients and 3 had premature physeal closure. Younger patients were more likely to be treated non-operatively ($P < 0.001$) and patients treated with operative intervention had statistically significant shorter hospital length of stays ($P = 0.001$).

CONCLUSION

Given the predominance of non-operative management

in published studies, the available literature is not clinically relevant since the popularization of internal fixation for pediatric long-bone fractures

Key words: Pediatrics; Femur; Tibia; Fracture; Floating knee

Core tip: Advances in orthopaedic technology and implants have dramatically changed the management of femur and tibia fractures in children, when treated in isolation. No current day study, however, has examined the effects of this advancement on the higher energy pediatric floating knee injury. This systematic review indicates a gap in the literature and the need for further investigation.

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INTRODUCTION

Isolated femur and tibia fractures are a frequent occurrence in the pediatric age group; these two diagnoses account for 2 of the 4 most frequent pediatric orthopaedic injuries requiring hospitalization[1]. In 1997 pediatric orthopaedic trauma accounted for 84000 in-patient hospital admissions, 43.2% of which was accounted for by tibia (21.5%) and femur (21.7%) fractures[2]. Although these two fractures occur often in the pediatric population their prevalence in the ipsilateral limb, resulting in a floating knee, is a rare event, generally resulting from a high energy mechanism[3]. Literature on ipsilateral tibia and femur fractures (floating knee) has primarily focused on the adult patient population leaving the optimal treatment of pediatric patients undefined.

Two unique classifications systems exist to describe these fracture patterns. Letts *et al*[3] in 1986 first grouped these fractures by region of fracture in the bone as well as whether the fracture was open or closed. The Letts-Vincent pediatric floating knee classification system is as follows: Type A-both fractures diaphyseal and closed; type B-both fractures closed with one diaphyseal and one metaphyseal fracture; type C-both fractures closed with one diaphyseal and epiphyseal fracture; type D-one fracture is open; and type E-both fractures are open[3]. The Bohn-Durbin classification system, published in 1991, is the other classification system for pediatric floating knee injuries. It has 3 types: Type 1-double shaft pattern; type 2-juxta-articular pattern; and type 3-epiphyseal component[4]. Neither classification system however provides therapeutic guidance or offers prognostic value.

Given the rare nature of the injury pattern, limited data exist in the literature. No published series includes more than 30 patients and no manuscript on pediatric floating knee injuries (excluding case reports) has been published in the English language literature in over a decade. Neither large prospective studies nor aggregate data reviews have been performed to further elucidate the best classification system or treatment algorithm for pediatric floating knee injuries. The objective of this study is to synthesize the literature and to identify factors associated with both good and poor outcomes of these complex pediatric injuries in order improve care of this high energy fracture pattern.

MATERIALS AND METHODS

We searched EMBASE, COCHRANE and MEDLINE computerized literature databases from the earliest possible date to February 2017 using the search term "pediatric floating knee". Reference lists from all articles were scrutinized to identify any additional studies of interest. All studies were thoroughly reviewed and included in the study if they met the following criteria: (1) written in English language; (2) had a level Ⅰ, Ⅱ, Ⅲ, Ⅳ, or Ⅴ study design classified by "Journal of Bone and Joint Surgery" criteria; (3) articles had patient information listed within article; and (4) patient age under 18 years old. Two authors performed the initial search (Jason B Anari, Alexander L Neuwirth) and three authors (Jason B Anari, Alexander L Neuwirth, Keith D Baldwin) independently reviewed the references of the qualifying papers and selected those studies that fit based on the aforementioned criteria. In the final phase of review, full text review, no disagreement occurred regarding which studies would be included. Univariate and multivariate statistical tests were applied to the assembled database to assess differences in outcomes.

When assessing for nonunion and malunion we applied the criteria previously described by Bohn and Durbin[4]. Malunion of the femur required the following criteria: 30° anterior, 15° valgus, 5° posterior or varus, or more than 2 cm of shortening. Malunion of the tibia is defined by angulation greater than 5° in any plane or more than 1 cm of shortening. Rotational nonunions were defined as more than 20° of external rotation or any internal rotation compared to the contralateral side. Nonunion was defined as the absence of bridging callus and persistent fracture lines beyond 4 mo.

Classification of the open fractures was based on the classification published by Gustilo *et al*[5] in 1984. Limb length discrepancies were diagnosed by clinical exam and measured on scanograms. Length of stay was determined by the number of days following admission until discharge to home, rehab, or another non-hospital facility. Infections included any fracture or wound requiring irrigation and debridement or treatment with antibiotics. Any additional operations performed on the

Table 1 Patient demographics and characteristics

Characteristics	*n* (%)
No. of patients	97
Age (yr)	9.3
Follow up (mo)	39.99
Open fracture	48
Tibia	27
Gustillo Anderson 1	5 (18.52)
Gustillo Anderson 2	11 (40.74)
Gustillo Anderson 3a	7 (25.92)
Gustillo Anderson 3b	2 (7.41)
Gustillo Anderson 3c	2 (7.41)
Femur	10
Gustillo Anderson 1	4 (40.00)
Gustillo Anderson 2	2 (20.00)
Gustillo Anderson 3a	2 (20.00)
Gustillo Anderson 3b	1 (10.00)
Gustillo Anderson 3c	1 (10.00)
Not specified	11
Fracture pattern	
Tibia	97
Diaphysis	75 (77.32)
Metaphysis	9 (9.28)
Epiphysis	13 (13.40)
Femur	97
Diaphysis	73 (75.26)
Metaphysis	15 (15.46)
Epiphysis	9 (9.28)
Management	
ORIF femur and non-operative tibia	14
ORIF tibia and non-operative femur	12
ORIF tibia and femur	19
Non-operative tibia and femur	52

ORIF: Open reduction internal fixation.

floating extremity were included under 2nd procedures.

We identified 5 articles from MEDLINE, 4 articles from EMBASE, all of which were duplicates, and zero articles from COCHRANE. Initially, articles were eliminated based on title relevance. Articles were then eliminated by abstract for failing to meet inclusion criteria. We finally reviewed the full text of the remaining 6 papers and 1 was eliminated for meeting exclusion criteria. References from the remaining 5 papers were evaluated and 1 additional study was identified that met inclusion criteria leaving us with 6 articles for the systematic review: Four case series and 2 case reports.

Data on 97 patients were then collected from the 6 articles that met inclusion criteria (Table 1). The average age of patients presenting with a floating knee injury was 9.3 years old. The male to female ratio was approximately 3:1. The majority of open fractures occurred in the tibia (27/48), with most injuries being Gustilo-Anderson grade 2. Seventy-five percent of the fractures for both the tibia (75/97) and the femur (73/97) occurred in the diaphysis. Over half (52/97) of the patients with floating knee injuries had both fractures definitively treated non-operatively with casting and/or traction. Average follow-up was 39.99 mo.

Table 2 Complications

Characteristics	*n* (%)
Limb length discrepancy	32
Overgrowth	24 (75.00)
Undergrowth	8 (25.00)
Non-union	7
Femur	3 (42.86)
Tibia	4 (57.14)
Mal-union	20
Femur	11 (55.00)
Tibia	9 (45.00)
Infection	9
2nd surgery	13
Premature physeal closure	3

Univariate *P* values were calculated on the basis of independent sample *t*-tests in cases of continuous variables, and Pearsons χ^2 and Fisher's exact tests were used to calculate differences in dichotomous or categorical outcomes. All statistics were calculated using SPSS version 20.0 (SPSS Inc, Chicago, IL).

RESULTS

In the assembled literature, 32 patients (33%) had limb length discrepancies at their final post-operative visit (Table 2). The majority of these were lengthening of the injured limb, presumably from overgrowth (24/32). Eight patients had shortening of the injured limb, most likely from healing in a shortened position, since only 3 patients with a floating knee experience premature physeal closure. Infection occurred in 9/97 patients. Thirteen patients required additional surgery after initial treatment of the floating knee injury. The two most prevalent additional procedures were osteotomy (4) for angulation or limb length discrepancy and revision fixation (4). Infections, which were mostly superficial pin track infections, also included deep space infections (more commonly involving the tibia than the femur). Femoral nonunion and malunion occurred in 3 and 11 patients, respectively. Tibial nonunion occurred in 4 patients, while malunion was present in 9.

Univariate analysis in Table 3 shows that younger children were more likely to be treated non-operatively than their adolescent counterparts ($P < 0.001$). Patients who were treated operatively for either their femur fracture, tibia fracture, or both had statistically significant shorter length of stays ($P = 0.001$). When evaluating length of stay in patients older or younger 10 years of age, this trend is accentuated. No association was noted between management of injury and resultant limb length discrepancy for either undergrowth or overgrowth.

DISCUSSION

Ipsilateral fractures of the tibia and femur in the pediatric patient are rare injuries. There is not a consensus

Table 3 Univariate analysis

Characteristics	mean	*P*
Age (yr)		< 0.001
ORIF femur and non-operative tibia	11.47	
ORIF tibia and non-operative femur	10.07	
ORIF tiba and femur	11.45	
Non-operative tibia and femur	7.7	
Length of stay (d)		0.001
ORIF femur and non-operative tibia	27.26	
ORIF tibia and non-operative femur	100.86	
ORIF tiba and femur	18	
Non-operative tibia and femur	37.35	
Limb length discrepancy overgrowth (mm)		0.372
ORIF femur and non-operative tibia	1.37	
ORIF tibia and non-operative femur	1.9	
ORIF tiba and femur	2.27	
Non-operative tibia and femur	2.81	
Limb length discrepancy undergrowth (mm)		0.514
ORIF femur and non-operative tibia	1.2	
ORIF tibia and non-operative femur	6	
ORIF tiba and femur	2.7	
Non-operative tibia and femur	2.75	

ORIF: Open reduction internal fixation.

regarding treatment of this fracture pattern in children and adolescents, and optimal treatment remains controversial. Historically, however, pediatric floating knee injuries have been treated non-operatively with traction and casting.

In 1975, Blake *et al*[6] reported one of the first case series on adult and pediatric patients with ipsilateral tibia and femur fractures. They noted the floating knee injury pattern to be associated with high-energy mechanisms of injury as well as to have a high rate of nonunion and malunion. Blake *et al*[6] treated most of the floating knee injuries with skeletal traction and casting, however they concluded that emerging techniques of osteosynthesis would alter the treatment options.

In 1986, Letts *et al*[3] reported on floating knee injuries in children. Over an 11-year period they treated 15 patients with ipsilateral tibia and femur fractures. Letts acknowledged the difficulty in treating this fracture pattern and recognized the complications associated with non-operative modalities such as casting and traction alone. Ultimately, Letts *et al*[3] concluded that at least one of the two fractures should be rigidly fixed when treating pediatric patients with floating knee injuries.

The largest collection of pediatric patients with ipsilateral tibia and femur fractures is Bohn *et al*[4]'s published case series from 1991. These authors were the first to suggest a treatment algorithm based on patient age, and they created their own classification system in an attempt to guide treatment by fracture type. For patients under 10 years of age they suggested a short leg cast for the tibia fracture and 90°-90° femoral-pin traction (with subsequent conversion to a hip spica cast at 4 wk) for the femur. In adolescent patients they recommended operative treatment of the femur fracture and non-operative treatment of the tibia fracture. The authors additionally identified general indications for operative treatment for each fracture. Severe head trauma, adolescent patient, severe soft tissue injury and inability to maintain reduction were indications for surgical treatment of the femur while severe soft tissue injury and inability to maintain reduction were indications for the tibia[4]. Importantly, given the risk of limb length discrepancy and deformity, the concept of longitudinal follow up until skeletal maturity was raised by Bohn and Durbin in their article

In 2000, Yue *et al*[7] reported another large case series of pediatric patients with floating knee injuries. The authors claimed that the rate of limb deformity and limb length discrepancy were decreased when fracture patterns were treated with operative intervention[7]. They recommended that all patients with floating knee injuries, regardless of age, be treated with operative fixation of the femoral fracture. The most recently published case series from Arslan *et al*[8] in 2003 reiterates the importance of operative fixation for patients with floating knee injuries independent of age. The authors additionally comment on the inadequacy of the Bohn and Durbin as well as the Letts classification systems in directing treatment plans for patients with floating knee injuries.

Ipsilateral fractures of the tibia and femur are rare but severe injuries in children and adolescents. They often result from a high-energy mechanism of injury. The literature currently available to the practicing orthopaedic surgeon is of limited value given the historic nature of the studies and available treatment strategies at the time of investigation. The articles reviewed, however, do demonstrate a high complication rate in the treatment of these injuries. The advent of newer techniques for treating long bone fractures in children and adolescents (such as flexible elastic nailing and submuscular plating) allow for surgeons to achieve relative stability in diaphyseal long bone fractures through minimally invasive approaches. In addition there are multiple techniques now available for reduction and stabilization of pediatric physeal and juxta-articular fractures. Long bone injuries in children and adolescents are now less frequently treated with traction and casting in the United States. Surgical fixation of isolated length-stable pediatric tibia and femur fractures allows for quicker mobilization, discharge from in-patient care, and return to school as well as activities of daily living (Figure 1)[9].

This study has limitations, which were largely due to the weakness of member studies. The studies were all uncontrolled, and many were small heterogeneous case series. This type of literature severely limits the conclusions one can draw. Many modern techniques, which are available today, were not evaluated in many of the member studies. However, our study has value in that it identifies the gap in the literature, and synthesizes the available outcomes so that the pediatric

Figure 1 A floating knee injury in a pediatric patient. A: AP of the right proximal femur showing an oblique diaphyseal fracture with a butterfly fragment; B: AP of the midshaft right femur confirming the oblique diaphsyeal fracture; C: AP of the right tibia showing an oblique diaphyseal fracture; D: Lateral of the right tibia confirming the oblique diaphyseal fracture (E) AP and (F) lateral of the right femur and (G) AP and (H) lateral of the right tibia at 12 wk with osseous union of both diaphyseal fractures.

orthopedic surgeon can counsel the patient with this rare injury.

The available literature on this uncommon injury is sorely lacking. The series available for review are comprised of heterogeneous treatments, which are largely non-operative. Many school-age children with long bone fractures are now treated with internal fixation that provides relative or absolute stability of theses fractures. New studies are needed to see if this approach is beneficial for pediatric floating knee injuries. A study evaluating current technology with consistent use of a single classification system that helps direct treatment will better elucidate how Pediatric Orthopaedic surgeons should manage this highly complex and often severe pediatric injury.

COMMENTS

Background

Historically pediatric patients who had injuries of both the femur and tibia were treated in traction and casting for weeks in the hospital.

Research frontiers

Open reduction and internal fixation has become more commonplace for pediatric long-bone fracture management given the advancement in orthopaedic technology.

Innovations and breakthroughs

Flexible nails for the femur and the tibia as well as adolescent intramedullary rods have changed the management of pediatric long bone fractures in isolation. No one is yet to comment on this technology in the setting of the more severe floating knee injury in pediatric patients.

Application

Mobilizing patients soon leads to improved patient satisfaction, shorter hospital stays, less costly time away from work, and overall better outcomes. Using this technology to get children back home and to school sooner and parents to work is beneficial to the hospital, the healthcare system, the patient, and the parents.

Terminology

Floating knee-injuries to both the femur and tibia resulting in the knee joint not being connected to either long bone.

Peer-review

Well-organized paper.

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