Reprinted from

VOL 20, NO 1 **JANUARY 2002**

The American Journal of Emergency Medicine

Orthopedic Pitfalls in the ED: Pediatric Growth Plate Injuries

ANDREW D. PERRON, MD, MARK D. MILLER, MD, AND WILLIAM J. BRADY, MD

W.B. SAUNDERS

Orthopedic Pitfalls in the ED: Pediatric Growth Plate Injuries

ANDREW D. PERRON, MD, MARK D. MILLER, MD, AND WILLIAM J. BRADY, MD

Musculoskeletal injuries are frequently the reason children and adolescents seek care in the emergency department. In the skeletally immature patient, injury to the open growth plate can occur. When missed or mismanaged, these injuries can result in growth plate arrest. The emergency physician needs to remain vigilant for these injuries. This review article examines the clinical presentation, diagnostic techniques, and management options applicable to the emergency physician. (Am J Emerg Med 2002;20:50-54. Copyright © 2002 by W.B. Saunders Company)

The emergency physician sees a wide range of musculoskeletal injuries in the pediatric and adolescent population. The most significant difference between the immature skeleton in this population and the mature adult human skeletal system is the presence of a physis or growth plate. Composed of proliferating cartilage cells between the metaphysis and epiphysis of growing bones, this area lacks inherant mechanical strength, and is therefore more susceptible to trauma than the surrounding ossified bone. Injuries to the physis can occur at any age before physeal closure, but are most common during periods of rapid skeletal growth. Although problems after injury to the physis are uncommon, missed injuries to this area can lead to premature closure with resultant focal bone growth arrest. Fortunately, fractures across the physis usually occur in a predictable pattern. Knowledge of these patterns is key for the emergency physician to avoid this potential orthopedic pitfall.

EPIDEMIOLOGY

Physeal injuries have been reported to account for between 15% and 30% of all skeletal injuries in children,[1-4] occurring most commonly after the age of 10.[4,5] Approximately 80% of physeal injuries will occur between the ages of 10 and 16 years, with a median age of 13 years.[6,7] Injuries to the physis occur much more frequently in boys than girls, reflective of the overall increased incidence of musculoskeletal injury in this population, as well as later development of skeletal maturity in boys as opposed to girls.[6,8] The distal radius is the most common anatomic site of physeal injury, accounting for 30% to 60% of cases.[6,7,9-12] Physeal injuries occur most frequently in April through September when children are more likely to be playing outdoors.[8]

From the Departments of Emergency Medicine and Orthopedic Surgery, University of Virginia Health System, Charlottesville, VA.
Manuscript received and accepted July 1, 2001.
No reprints are available.
Key Words: Salter-Harris, epiphyseal injury, physeal injury, pediatrics, fractures.

0735-6757/02/2001-0013$35.00/0
doi:10.1053/ajem.2002.30096

PATHOPHYSIOLOGY

The physis is the fundamental mechanism of endochondral ossification (Fig 1). The primary function of the physis is rapid, integrated longitudinal bone growth. As such, injuries to the physis are unique to the skeletally immature patient. The growing physis consists of 4 distinct zones, listed in order from the epiphysis to the metaphysis: the zone of resting cells, the zone of proliferating cells, the zone of hypertrophic/maturing cells, and the zone of provisional calcification. It is the third zone, the zone of hypertrophic/maturing cells that is the weakest link in the physis, and consequently the zone where a cleavage plane is most likely to pass. The nutrient blood supply to the physis comes predominantly from the epiphysis. Normal growth and maturation at the physis is dependent on this intact vascular pathway.[13-16]

Although several classification systems exist to describe physeal injuries, the Salter-Harris classification system is used most frequently. This classification scheme, described by the investigators in 1963, is based on the extent of involvement of the physis, epiphysis, and the joint.[9] The higher the Salter-Harris fracture classification number, the greater the chance of physeal arrest and joint incongruity. This is predominantly attributable to the fact that higher Salter-Harris fractures (III, IV, and V) are much more likely to injure the vascular supply to the physis.[9,16] The classic patterns described by Salter and Harris, and later modified by Ogden[17] are as follows (Fig 2):

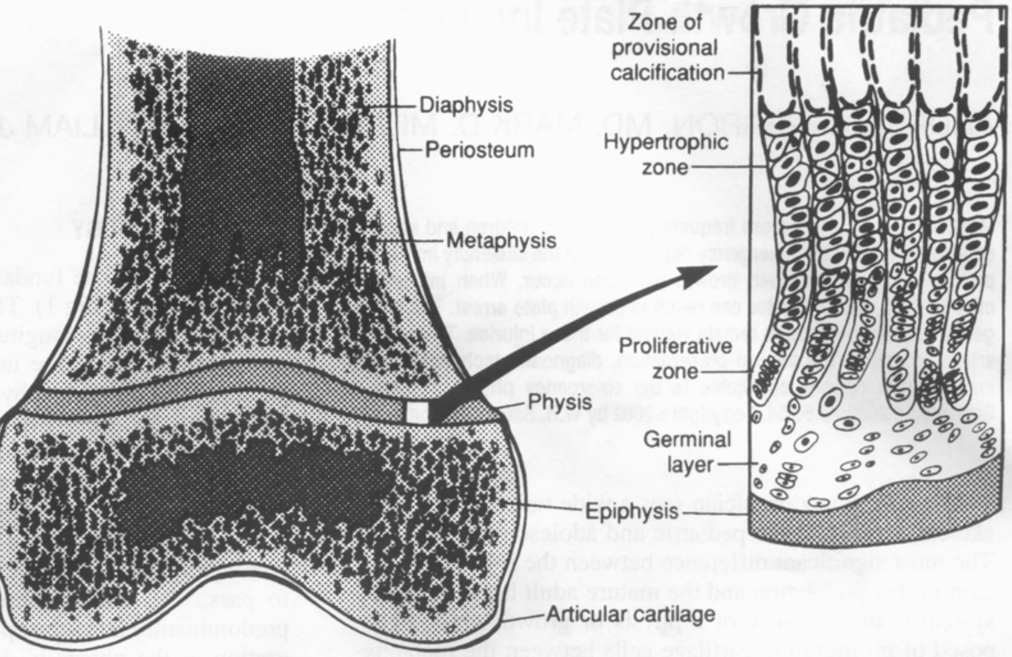
Type I

Type I fractures are seen most frequently in infants and toddlers. The injury mechanism generally involves a shearing, torsion, or avulsion movement—essentially producing a separation through the physis (Fig 3) In these injuries, which represent 6% of all physeal fractures, the epiphysis in effect separates from the metaphysis. There is no osseous fracture to the epiphysis or metaphysis. The line of cleavage runs through the hypertrophic zone of the physis, with the growing cells remaining on the epiphysis, in continuity with their nutrient blood supply. Because of this fact, Salter-Harris I fractures usually carry a good prognosis, and infrequently result in any growth disturbances.

Type II

Salter-Harris II injuries are the most common type encountered, accounting for 75% of physeal injuries.[5,9,11] The line of fracture runs through the hypertrophic cell zone of the physis and then out through a segment of metaphyseal bone (Fig 4). The segment of metaphyseal bone is referred to as the "Thurston-Holland" sign or fragment. As with type I fractures, growth is usually preserved, because the repro-

FIGURE 1. Salter-Harris classification of physeal injuries. Reprinted from Tolo VT, Wood B: Pediatric Orthopaedics in Primary Care, Williams & Wilkins, 1994 with permission.[26]



ductive layers of the physis maintain their connection to the epiphysis and their nutrient blood supply.

Type III

The hallmark of a Salter-Harris type III fracture is an intraarticular fracture of the epiphysis with extension through the hypertrophic cell layer of the physis (Fig 5). Type III fractures are relatively rare, accounting for approximately 10% of physeal injuries.[5,9,11] The prognosis for normal bone growth is generally good, but more guarded than with type I or II injuries. The chance for growth disturbance is related to preservation of blood supply of the epiphyseal bone fragment. The greater the displacement and/or fragmentation, the greater the chance for blood supply disruption and subsequent growth disturbance.[5,9,11,18]

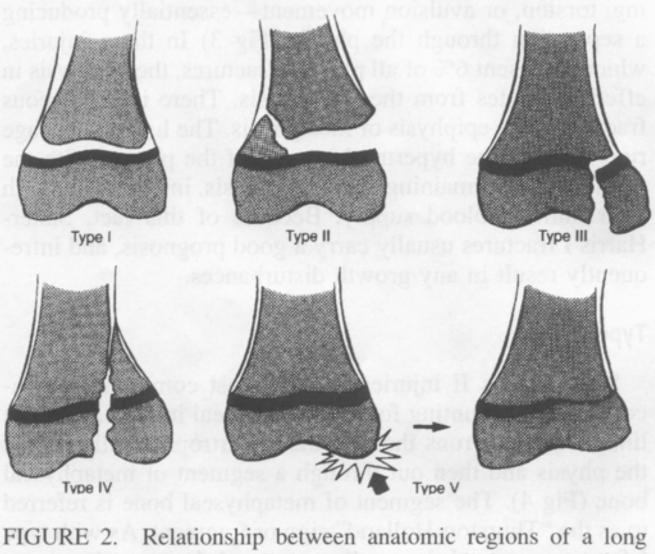


FIGURE 2. Relationship between anatomic regions of a long bone and the physis. Detail demonstrates 4 cellular zones of the physis. Reprinted from Tolo VT, Wood B: Pediatric Orthopaedics in Primary Care, Williams & Wilkins, 1994 with permission.[26]

Type IV

A Salter-Harris type IV fracture line originates at the articular surface, crosses the epiphysis, extends through the full thickness of the physis, and exits through a segment of the metaphysis (Fig 6). Type IV injuries are seen most

FIGURE 3. Salter-Harris type I fracture of the distal tibia. The anterior portion of the physis is widened (black arrows), and there has been posterior movement of the epiphysis open, white arrow.) Reprinted from Tolo VT, Wood B: Pediatric Orthopaedics in Primary Care, Williams & Wilkins, 1994 with permission.[26]

FIGURE 4. Salter-Harris type II fracture of the distal radius. The fracture line runs obliquely through the distal metaphysis. This metaphyseal fragment of bone is called the "Thurston-Holland" sign.

commonly at the lower end of the humerus.[9,11] Like type III injuries, type IV injuries represent approximately 10% of all physeal fractures.[5,9,11] As with type III fractures, future growth disturbance is at risk, dependent on the degree of blood supply disruption from the epiphysis.

Type V

Salter-Harris type V injuries are fortunately the most rare fracture pattern (they account for approximately 1% or less of physeal injuries[5,9,11]), as they are by the far the most likely injury to result in focal bone growth arrest.[3,4,5,9,11] These injuries occur most frequently at the knee or ankle, and are the result of a severe abduction or adduction injury that transmit profound compressive forces across the physis. This resultant axial compression crushes the physis, and specifically injures the cells of the reserve and proliferative zones. With a type V fracture, usually there is minimal or no displacement of the epiphysis. Type V injuries are most often diagnosed in retrospect, once a bone growth abnormality has been identified on serial radiographs.[19]

DIAGNOSIS

Clinical Presentation

In terms of evaluating and treating orthopedic injuries in the skeletally immature patient, the emergency physician needs to maintain awareness that the physis represents the weak link in this patient population. The ligaments of children have more relative strength and are more compliant than those of adults, often tolerating mechanical forces at the expense of epiphyseal integrity. The physis will separate or fracture before disruption or "spraining" of the adjacent strong, flexible ligament, and the same injury that will result in a ligament injury or even joint dislocation in the adult patient population, will frequently result in physeal injuries in children.

History and physical examination will lead the examiner toward the diagnosis. A fall on outstretched hand (FOOSH) is a typical mechanism for physeal injuries to the distal radius.[8] Abduction, adduction, and twisting mechanisms are frequently encountered with lower extremity physeal injuries. Notably, acute trauma is not always necessary for physeal injuries. Repetitive stress injuries can also damage the physis, as is seen in the little leaguer's shoulder syndrome.[20] On physical examination, findings can range from subtle to obvious injury. Point tenderness over a physis is reason enough to suspect a growth plate injury, regardless of subsequent radiographic findings. With type I and type V injuries, the history and physical examination are particularly key, as there may be no significant findings appreciated on x-ray film. Salter-Harris type V fractures are often not apparent or diagnosed until subsequent bone growth abnormalities occur.[18]

Radiographic Findings

Injuries to the physis can be difficult to detect because it is a radiolucent structure. An acute fracture involving only the physis can occur without any radiographic abnormality. They can also appear as a widened physis. Careful correlation with clinical findings and the selective use of contralateral comparison films will help to minimize errors in the diagnosis. Type II, III, and IV fractures are usually evident on plain x-ray film. Types I and V can be radiographically occult in the acute setting. Type V injuries may show a joint effusion on plain films, but this is a nonspecific finding.[5,18]

Numerous adjunctive studies that can be used when physeal injury is clinically suspected, but radiographs are negative have been identified in the literature. Judicious use of stress radiography, frequently under orthopedist supervision can be helpful in the acute setting. Ultrasonography, bone scintiography, and magnetic resonance imaging (MRI) have all been advocated for the assessment of these injuries.[21-25] As initial treatment is unlikely to change based on these advanced studies, however, their use in the emergency department is usually not warranted.

TREATMENT

If the diagnosis of "sprain" is being entertained the emergency physician in the skeletally immature patient, the practitioner should question why this injury does not represent a Salter-Harris injury. With negative radiographs and point tenderness over a physis, it is prudent to treat these patients as if they have Salter-Harris type I injury. It is equally prudent to counsel the parents and patients regarding the potential for future growth abnor-

FIGURE 5. Salter-Harris type III fracture of the distal radial epiphysis.

FIGURE 6. Salter-Harris type IV fracture of the distal tibia. There is a fracture through both the epiphysis (arrows), and the metaphysis (arrowhead).

malities, even with minor injuries. Parents should be counseled that treatment is being given for the "worst case" scenario, and it may well turn out that their child does not have a fracture, but that this can only be determined with serial radiographs.

Treatment for type I injuries consists of splint immobilization, intermittent icing, and elevation. Referral to an orthopedic surgeon for re-evaluation and follow-up is warranted, and the prognosis with type I injuries in most cases is good. Type II injuries, if there is no angulation or significant displacement of the fracture fragment, can be similarly managed with splinting and outpatient follow-up. The prognosis for this type of fracture is also excellent. Type III fractures usually require an orthopedic consultation in the emergency department, as it is critically important to achieve anatomic alignment of the epiphyseal fracture fragment for both blood supply maintenance and joint congruity. Near perfect alignment of the articular surface is a critical factor in attempting to assure a good outcome from these injuries. Open reduction and internal fixation techniques are frequently required in these types of fractures. Type IV injuries have an even higher likelihood of requiring operative intervention to achieve anatomic reduction than type III injuries. These injuries, even with good reduction, carry a significant risk of growth disturbance.[5,9,11] Type V injuries carry the worst prognosis, and focal bone growth arrest can be anticipated with these fortunately rare fractures. When diagnosed, orthopedic consultation is warranted. Usually affecting the lower extremities, patients with type V injuries are usually casted and kept nonweight-bearing.

SUMMARY

Orthopedic injury is a frequent occurrence in the pediatric and adolescent patient population. When orthopedic injury is coupled with a skeletally immature patient, growth plate injury can result. The emergency physician needs to maintain a high level of suspicion for these injuries, even in the face of negative radiographs. Although bone growth abnormalities are relatively rare after physeal injury, early recognition and appropriate management will help to minimize this orthopedic pitfall.

REFERENCES

1. Mann DC, Rajmaira S: Distribution of physeal and nonphyseal fractures in 2,650 long bone fractures in children aged 0-16 yrs. J Pediatr Orthop 1990;10:713-16
2. Mizuta T, Benson W M, Foster BK, et al: Statistical analysis of the incidence of physeal injuries. J Pediatr Orthop 1987;7:518-23
3. Ogden JA: Skeletal growth mechanism injury patterns. J Pediatr Orthop 1982;2:371-377
4. Greenfield R: Orthopedic injuries, in Strange G, Ahrens W, et al (eds): Pediatric Emergency Medicine. New York, McGraw-Hill, 1996, pp113-118
5. Della-Giustina K, Della-Giustina DA: Emergency department evaluation and treatment of pediatric orthopedic injuries. Emerg Med Clin NA 1999;17:895-922
6. Rogers L:. Children's Fractures. Philadelphia, Lippincott Co., 1970
7. Peterson CA, Peterson HA: Analysis of the incidence of injuries to the epiphyseal growth plate. J Trauma 1972;12:275-281
8. Musharafieh RS, Macari G: Salter-Harris I fractures of the distal radius misdiagnosed as wrist sprain. J Emerg Med 2000;19:265-270
9. Salter RB, Harris WR: Injuries involving the epiphyseal plate. J Bone Joint Surg Am 1963;45:587-622
10. Neer CS II, Horowitz BS: Fractures of the proximal humeral epiphyseal plate. Clin Orthop 1965;41:24-31
11. Norlock P, StowerM: Fracture patterns in Nottingham children. J Pediatr Orthop 1986;6:656-660.
12. Lee BS, Esterkai JL: Fracture of the distal radial epiphysis. Clin Orthop 1984;185:90-96
13. Trueta J, Morgan JD: The vascular contribution to osteogenesis I. Studies by the injection method. J Bone Joint Surg Br 1960;42:97-112
14. Trueta J, Amato VP: The vascular contribution to osteogenesis iii. Changes in the growth cartilage caused by experimentally induced ischaemia. J Bone Joint Surg Br 1960;42:571-578
15. England SP, Sundberg S: Management of common pediatric fractures. Ped Clin NA 1996;43:991-1012
16. Robertson WW Jr: Newest knowledge of the growth plate. Clin Orthop Rel Res 1990;253:270-278
17. Ogden JA: Skeletal Injury in the Child (ed 2). WB Saunders, Philadelphia, 1990 pp 38-68
18. Kaeding CC, Whitehead R: Musculoskeletal injuries in adolescents. Prim Care Clin Off Prac 1998;25:211-223
19. Canale TS (ed): Physeal injuries, in Campbell's Operative Orthopedics. Mosby, St. Louis 1998, pp 2364-2367
20. Carson WG Jr : Little Leaguer's shoulder: A report of 23 cases. Am J Sports Med 1998;26: 575-80
21. Rizzo PF, Gould ES, Lyden JP, et al: Diagnosis of occult fractures about the hip: Magnetic resonance imaging compared with bone scanning. J Bone Joint Surg Am 993;75:395-401
22. Marks PH, Godenberg JA, Vezina WC, et al: Subchondral bone infractions in acute ligamentous knee injuries demonstrated on bone scintiography and magnetic resonance imaging. J Nucl Med 1992;33:516-520
23. Gleeson AP, Stuart MJ, Wilson B, et al: Ultrasound assessment and conservative management of inversion injuries of the ankle in children. J Bone Joint Surg Br 1995;75:484-487
24. Berger P, Ofstein RA, Jackson DW, et al: MRI demonstration of radiographically occult features: What have we been missing? Radiographics 1989;9:407-436
25. Naranja RJ, Gregg JR, Dormans JP, et al: Pediatric fracture without radiographic abnormality: Description and significance. Clin Orthop Related Res 1997;342:141-146
26. Tolo VT, Wood B: Pediatric Orthopaedics in Primary Care. Williams & Wilkins, 1994