FRACTURES of the Tibia in Children

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Metaphyseal Fractures
Of the
Proximal Tibia

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METAPHYSEAL FRACTURES OF THE TIBIA

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Fractures of the proximal tibial metaphysis can be deceiving in that what appears to be initially a simple undisplaced fracture can lead to a significant cosmetic deformity even with the best of treatment. Thus the message of this chapter is that when explaining the outcome of this type of fracture to the parents, the treating surgeon must emphasize before the treatment is initiated that the child may develop a significant valgus angulation regardless of the adequacy of the treatment. The cause can be a biological phenomenon and not necessarily the result of inadequate treatment by the surgeon. Explaining the potential for the deformity before the treatment is initiated helps greatly when it occurs. The surgeon would be considered knowledgeable in predicting the deformity before it developed. Trying to explain why it happened after the deformity has occurred often only adds to the parents’ skepticism about the skill of the treating surgeon.

This chapter will explore the pathogenesis, treatment options - including attempts at prevention or minimization of the deformity, and the long-term prognosis of the valgus angulation deformity once it develops.

HISTORICAL PERSPECTIVE

The first article in the English literature warning of this complication was published over 40 years ago, when Cozen (8) described four cases of valgus deformity following greenstick fractures of the proximal tibial metaphysis. Almost 20 years later, he and Jackson (15) added seven more cases, with an 18- to 20-year follow-up in three of the original cases. Following Cozen’s initial warning of the development of this deformity after fractures of the proximal tibial metaphysis, many other case reports and series have been reported in the literature (3-6, 8, 22, 26-27, 29). Thus the danger of a valgus deformity developing following a greenstick proximal tibial metaphyseal fracture has become firmly established in the recent orthopedic literature.

INCIDENCE

Maximum valgus alignment appears to occur when the child undergoes the valgus stage of lower extremity development, which usually is manifest between the ages of 2 and 8 years (24, 26).

When considering all nonphyseal fractures of the tibia, that is, metaphyseal and diaphyseal, the incidence of fractures involving only the proximal tibial metaphysis is about 3% (19, 29).

PATHOGENESIS
There has been no one explanation as to why the valgus deformity occurs following proximal metaphyseal fractures. It must be remembered that a valgus angulation can develop spontaneously without fractures of the tibia. This deformity previously was observed when bone grafts were originally obtained from the proximal tibial metaphysis for the Grice-Green technique of subtalar arthrodesis. It has also developed following acute hematogenous osteomyelitis of the tibia (28).

There are two broad categories of etiological conditions which can be factors in the subsequent development of valgus angulation following proximal metaphyseal fractures. The first group is composed of iatrogenic conditions, because they can be controlled by the surgeon. The second group involves various biological parameters which produce asymmetrical overgrowth contributing to valgus angulation. These various etiological factors are summarized in Table I.

### Iatrogenic Conditions

#### Inadequate Reduction

Inadequate reduction is most commonly due to failure to manipulate the leg into the reduced position. This usually results in an immediate valgus deformity which is accentuated when the secondary biological overgrowth occurs (Fig.1). Placing the leg in a bent-knee, long-leg cast often makes it difficult to evaluate the adequacy of the reduction both clinically and radiographically (21).

#### Interposed Tissue

Tissue interposed medially at the fracture site has been incriminated as a factor in failing to achieve an adequate initial reduction (Fig.2). Weber (31) found the tendinous insertion of the pes anserinus plus the periosteum which also had been stripped off the metaphysis distally to be interposed in the fracture site in his four cases. In addition, he theorized that this disruption of the medial periosteum released its inhibition to growth medially, allowing the medial physis to grow more rapidly, thus producing a delayed valgus angulation. This interposition of the pes anserinus was confirmed by the work of Bassey (4), who routinely repaired the tendon.

Coates (7) found in two of his cases that the interposed material was the superficial part of the medial collateral ligament instead of the pes anserinus tendon.

#### Premature Weight Bearing

Pollen (20) felt that too early weight bearing allowed the reduction to be lost, creating recurrence of the initial valgus angulation. Bahnson and Lovell (2) theorized that weight bearing produced compression or inhibition on the proximal tibial physis laterally along with distraction forces medially which allowed more rapid growth in this area. This cause of localized lateral growth inhibition produced by weight bearing is no longer mentioned in the recent literature.

### Biological Conditions
Biological factors usually are responsible for the gradual increase in valgus deformity that occurs over a 6- to 18-month period of time after the initial fracture has healed.

There are many explanations as to why this unequal growth develops.

**Tibial Overgrowth**

The fact that the tibia overgrows in length and does so asymmetrically has now been well established by various studies (3, 10, 16, 22, 28, 33). First, there is an increased migration of the Harris-Park growth arrest lines. Not only is migration greater on both the proximal and distal fracture sites (Fig. 3), but it is also asymmetrical, being greater on the medial versus the lateral side of the proximal tibia (10) (Fig.4). This asymmetrical growth has been confirmed by unequal uptake of technetium using quantitative bone scans (16, 17, 33).

The exact cause of why the medial side grows faster than the lateral side is still not completely known. Various theories have been proposed such as increased blood supply medially, temporary loss of lateral growth and loss of the inhibition factor of the intact periosteum. The data supporting each of these various theories will be examined in detail.

Ogden (18) has demonstrated in cadaver studies that the blood flow to the medial side of the proximal tibial metaphysis is significantly greater than on the lateral side. Thus, he feels that the hyperemia caused by the fracture is asymmetrical, producing an increased stimulation to the medial side of the proximal tibial metaphysis.

Ogden (18) has also speculated about temporary cessation of lateral physis growth as a mechanism; however, no permanent osseous bridges have been demonstrated.

Most of the data supporting the theory that intact periosteum inhibits longitudinal growth come from animal studies. Early studies show that in chickens (9) and rats (30) circumferential release of the periosteum resulted in overgrowth of the long bone affected. Originally this was suspected to be due to increased vascularity from the surgical release per se of the periosteum. Subsequent studies in rabbits (1, 12) have shown that the release of only the medial metaphyseal periosteum can produce asymmetrical valgus growth stimulation. In Aronson’s (1) study, isolated lateral release of the periosteum produced a varus deformity. In none of the above animal studies were structural changes able to be demonstrated in histological examination of the physes.

Thus, there is some experimental evidence that release of the periosteum per se may release its restricting effect and contribute to the asymmetrical growth. However, Jordan, (16) feels he negates this theory, because in cases where he carefully repaired the medial periosteum, valgus overgrowth still occurred.

**Tethering by the Fibula**

The theory of tethering by the fibula was popularized by the original Studie’s of Taylor (28) in which he studied valgus overgrowth after tibial osteotomies. He noted that when the fibula was not simultaneously osteotomized, the tibia often drifted into a late-onset valgus after
the Osteotomy had healed. When the fibula was simultaneously osteotomized there was very little valgus angulation. However, prophylactic fibular osteotomy following a proximal tibial metaphyseal fracture has failed to prevent the subsequent valgus overgrowth (16). In addition, this author and others (16) have seen valgus angulation develop in those cases in which the fibula is concurrently fractured.

**Iliotibial Band Forces**

The theory of iliotibial band forces arises from the polio era, when Irwin (14) attributed the valgus deformity of the tibia in these paralytic patients to the lateral or valgus pull of the iliotibial band. There has been no support for this theory in the recent literature.

**AUTHOR’S PREFERRED ETIOLOGIES**

It is this author’s opinion that the causes are multifactorial. The cause of an immediate valgus alignment is due to failure to achieve an adequate reduction, which may or may not be due to interposed tissue at the fracture site. The cause of the late-onset deformity is due to two major biological factors, namely, asymmetrical hyperemia and, probably, asymmetrical loss of the tethering effect of the periosteum. There is not much good evidence to support the other proposed etiologies.

**DEVELOPMENT OF THE DEFORMITY**

Two long-term studies by Skak (27) and Zionts and MacEwen (32) have documented the rate and patterns of deformity that develop following these types of fractures. First, the deformity begins to develop during the healing process of the original fracture. It seems to develop most rapidly during the first year postinjury, but some increase in angulation can be expected for as long as 18 months. According to Herring and Moseley (11), the valgus deformity becomes clinically apparent when it reaches 10-15°.

In the Zionts and MacEwen study (32), the average overgrowth was 1 cm, but ranged as high as 1.7 cm. The diaphyseal-metaphyseal angle increased an average of 9.6°. The average time to obtain the maximum angulation was 12.6 months.

**CORRECTION OF THE DEFORMITY**

Many of the long-term studies show that most of the deformities resolve with time (*Fig. 5*). A great deal of the deformity corrects proximally, but some of it corrects distally, producing an S-shaped type of tibia. Only on rare occasions does an operative correction need to be performed, and then it should be done only close to the termination of growth.

**TREATMENT**

Treatment of these fractures is divided into two stages: First, there is the treatment of the acute fracture. The second stage is how to manage the late valgus angularion.

**Acute Fractures**
Initially, the fracture must be reduced anatomically to minimize the amount of valgus angulation. The parents of the patient must be told that this can best be done under either very heavy sedation or a general anesthesia so a good varus molding can be applied to the extremity with the knee in extension. Parsch (19) found that when this was done, the incidence of cosmetically apparent valgus was essentially nonexistent.

The parents need to understand before the manipulation that a minor surgical procedure may be necessary to remove any interposed tissue should an anatomical reduction not be obtained. Some authors (22, 27) question whether removing the interposed tissue makes any difference in the ultimate outcome.

**Treatment of the Valgus Deformity**

It has been shown by many (3, 11, 13, 31) that performing a corrective osteotomy may produce a temporary correction, but in the following months, the deformity will recur due to the stimulating effect of the osteotomy (Fig. 6). Since most of these ultimately have a satisfactorily functional and cosmetic outcome at the termination of growth, it is felt that watching and waiting is the best approach (See Fig.5). Should the deformity persist into the early adolescent years, selective medial proximal tibial hemiepiphysodesis is felt by many (3, 23, 32) to be the best way to obtain a correction of the angular deformity (Fig.7).

**CONCLUSION**

Tibia valga following greenstick proximal metaphyseal fractures involves both iatrogenic and biological factors. The iatrogenic problems can be eliminated by obtaining an anatomic reduction and immobilizing the leg in a well-molded, long-leg, extended-knee cast for 4-6 weeks. The resultant deformity is best managed only at the termination of growth. A corrective osteotomy soon after the fracture may result in a recurrent deformity and should be avoided. The parents should be warned before treatment is initiated that a valgus deformity may develop despite the best of care.

**REFERENCES**


Table I. Etiological factors producing tibia valga

I. Iatrogenic conditions
   - Inadequate reduction
   - Interposed tissue
   - Premature weight bearing

II. Biological conditions
   - Asymmetrical tibial growth due to:
     - Increased medial blood supply
     - Temporary cessation of lateral physeal growth
     - Loss of periosteal inhibition of growth
     - Tethering of the fibula
     - Iliotibial band forces

Illustrations

A.

B.
Figure 1. Inadequate reduction. (A) A 7-year-old who had a proximal tibial metaphyseal fracture which was inadequately reduced. (B) The overgrowth of the proximal tibia plus the inadequate reduction accentuated the valgus deformity of the tibia.
Figure 2. Interposed Tissue. A. X-ray taken 6 weeks post-fracture shows a gap in the medial cortex (arrow) due to interposed periosteum and medial collateral ligament tissues. B. X-rays taken 6 mo. post-fracture demonstrate marked valgus overgrowth along with a residual scar at the site of the interposed tissue (arrow).
Figure 3. Unequal overgrowth. (A) A 3½ year-old who had a proximal tibial metaphyseal fracture which was essentially anatomically reduced. (B) Four months later there is valgus deformity of the tibia with acceleration of the distal migration of the Harris-Park growth arrest lines on the left versus the right (arrows). (D) Post metaphyseal fracture at four months showing the overgrowth manifest by distal migration of the Harris-Park growth arrest lines on the injured left
side (arrow). This is compared with (C) the uninjured side showing very little unequal overgrowth or distal migration of the Harris-Park growth arrest line (arrow) since the injury.

Figure 4. Asymmetrical Growth. The growth is not only accelerated but is asymmetrical and manifest by increased migration from the Harris-Park growth arrest line on the medial side versus the lateral side (arrows) of the fractured tibia.

FIGURE 5. Spontaneous correction of deformity. (A) A 3-year-old following proximal metaphyseal fracture showing a moderate valgus deformity of the proximal tibia. (B) Fifteen years later the valgus deformity on the right is completely resolved. There is a little curving of the midshaft showing where some of the correction ultimately occurred.
FIGURE 6. Overgrowth following tibial osteotomy. (A) A 5-year-old had a valgus deformity following a proximal tibial metaphyseal fracture. The fracture line is healed. This patient underwent a proximal tibial medial closing wedge osteotomy. The unequal growth on the medial side versus the lateral side is evident from the Harris-Park growth arrest lines from the original injury. B. However, the deformity recurred and this shows that there is new stimulation of growth as manifest by another unequal growth of the Harris-Park growth arrest lines from the proximal tibial physis (arrows).

FIGURE 7. Final correction of deformity. (A) A 13-year-old who had a proximal tibial metaphyseal fracture with valgus angulation and underwent a tibial osteotomy. There has been some recurrence of the deformity. (B) A proximal medial physeal stapling was performed and the deformity was gradually corrected.
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I. CLASSIFICATION

A. Shaft Fractures
   1. Isolated Tibial Fractures
      a. Longitudinal (spiral, oblique)
      b. Transverse
   2. Fractures of both tibia and fibula
      a. Longitudinal
      b. Transverse
   3. Isolated Fibular Shaft Fractures
   4. Plastic deformation
      a. Usually in fibula alone
      b. Has been reported to occur in the tibia as well\(^{(15A)}\)

B. Metaphyseal Fractures
   1. Proximal
   2. Distal

C. Special Fractures
   1. Stress Fractures
   2. Soccer Injuries
   3. Toddlers Fractures
   4. Bicycle Spoke Injuries
   5. Ipsilateral Femoral-Tibial Fractures
   6. Pathological fractures of the shaft/metaphyses

II. FRACTURES OF THE TIBIAL AND/OR FIBULAR SHAFTS

A. Incidence - What are the Statistics?
   1. Most common fracture of the lower extremity\(^{(2,19)}\)
   2. 15% of all childhood fractures\(^{(1,8)}\)
   3. Male: Female ratio averages 2 - 2.5\(^{(9,17)}\)
   4. Most common associated injuries
      a. Head injuries first
      b. Ipsilateral femoral shaft fractures second\(^{(12)}\)
   5. Relationship to ankle fractures
      a. Boys: shaft fractures more common
      b. Girls: ankle fractures more common\(^{(12)}\)
      c. Overall younger child - shaft fractures more common
      d. Overall older child - ankle fractures more common
   6. Isolated tibial shaft fractures 70%. Fractures of both tibia and fibula 30\(^{(18)}\).
   7. Right of left side incidence approximately equal.

B. Mechanism - Related to age and type of fracture pattern.
1. Rotational forces result in spiral injuries.
   a. Isolated tibial fractures most common.
   b. Below the age of 4, this is the most common type\(^{(12,14)}\).
   c. Rotational Forces result in tibial/fibular shaft fractures in younger child, where as these same forces result in ankle fractures in the adolescent\(^{(12)}\).
   d. Usually these fractures result from simple falls or indirect violence\(^{(18)}\).

2. Transverse fractures.
   a. Usually the result of direct violence in all age groups.
   b. In the younger individuals these fractures can be caused by bending forces\(^{(12)}\).
   c. Transverse fractures occur with greater incidence in older males because of increased exposure to direct trauma, i.e., riding motorcycles, bicycles or hit by auto\(^{(12)}\).
   d. Transverse fractures of both tibia and fibula more than combined tibia/fibular spiral (longitudinal) fractures in all age groups and both sexes.

3. Etiology may be culturally related.
   a. Sweden study\(^{(12)}\).
      -- Traffic Accidents: 27%
      -- Sporting Events: 30%
   b. Jordan (Aman) Study\(^{(17)}\).
      -- Traffic Accidents: 63%
      -- Sporting Events: 04%

4. Relationship to child abuse.
   a. While it has usually been taught that isolated spiral fractures of a long bone in infants or children should raise a high incidence of suspicion for child abuse, recent reviews of this type fracture show that it is rarely associated with child abuse\(^{(14, 14A)}\).

Pathology

1. Isolated tibial longitudinal fractures
   a. Muscle forces across fracture site produces varus angulation because of rotation at proximal and distal tibiofibular joints.
   b. Look for unrecognized plastic deformity of fibula which may produce excessive valgus or varus angulation.

2. Complete fractures of both tibia and fibula.
   a. Tends to angulate into valgus because of combined flexor and extensor muscle forces.
   b. If longitudinal fractures, shortening tends to be accentuated.
   c. Recurvatum may also be an associated angular deformity.

3. Isolated fractures of the fibula
   a. Usually transverse from direct blow
   b. If isolated longitudinal fracture is seen - look for concurrent fracture of the distal tibial physis.
1. **Isolated longitudinal tibial fractures**
   a. Usually treated in long leg cast. The results appear the same whether the knee is bent or extended.
   b. Needs to be in long leg cast to control rotation for comfort.
   c. Discuss with parents beforehand the possibility of developing mild varus angulation. Reassure that it will remodel.
   d. Second cast can be short leg cast after 3-4 weeks. In small children air casts used for ankle sprains have become effective.

2. **Combined tibia and fibular fractures**
   a. Look for shortening.
   b. Mould cast into varus to counteract tendency towards valgus.
   c. Mechanisms to limit shortening.
      1) Knee flexed and ankle plantar flexed\(^{(18)}\)
      2) Calcaneal pin traction\(^{(19)}\)
      3) External fixation devices.
   d. Be prepared to wedge or change cast if angulation develops.

3. **Isolated fibular fractures**
   a. Treat only as needed for comfort.
   b. Angulation usually remodels.

**E. Remodeling and Overgrowth**

1. Need to be accurate with tibial shaft fractures. Very little room for remodeling and overgrowth.

2. **Remodeling potential**
   a. Remodeling can be expected to correct only up to 10% of the angulation\(^{(9)}\).
   b. Deformity in two planes, poorer recovery than only one plane.
   c. The greater the deformity, the less total degree correction achieved because it is a percentage of the total angulation (10%).
   d. Fracture type - no effect on remodeling.
   e. The younger the patient, the better the remodeling.
   f. Posterior and valgus angulation recover less than varus and anterior angulation. Up to 15° can be accepted.
   g. Physal tilt may compensate for the deformity without correction of primary angulation\(^{(17)}\).
   h. Rotational deformities don’t remodel to any significant degree\(^{(17)}\).
   i. Effects of remodeling for angulation cease after 18 months\(^{(9)}\).

3. **Tibial Overgrowth**
   a. Usually only occurs up to age 9 or 10. (In older individuals there may be growth inhibition).
   b. Can expect only up to 0.5 cm. of growth stimulation at most\(^{(7,17)}\).
   c. Two studies with conflicting results
      1) Shannak (Jordan) 1988\(^{(17)}\)
         -- Greater shortening, greater stimulation
         -- Comminuted fractures have greatest stimulation, followed by spiral fractures.
      2) Grieff & Bergman (Denmark) 1980\(^{(7)}\).
amount of shortening, angulation or type of fracture appeared to have no effect on overgrowth.
d. Thus, one centimeter is the upper limits of acceptable shortening.
e. Higher degree of overgrowth in open fractures especially in those stabilized out to anatomical length (28).
f. In ipsilateral fractures, combined overgrowth can be as much as 1.8 cm (2A).

F. Union Rate
1. Non-union rate almost nonexistent.
2. Time of union increases with age.
   a. Six to 8 weeks in 4 years old.
   b. Ten to twelve weeks in a 14 year old (99).
3. Longer healing with high energy fractures, i.e., transverse or open fractures.
4. Type I and Type II open fractures average 20 weeks to heal (2A).

G. Associated Injuries
1. Head injuries (26)
   a. Most frequent cause is auto-pedestrian accidents.
   b. Longer healing time probably related to injuries of greater magnitude.
   c. Most can be adequately treated by closed methods.
   d. Tibial fractures, per se, no effect on patient’s final recovery.
2. Ipsilateral femoral shaft fractures.
   a. Usually need to mobilize tibial fracture in external fixation if traction is to be applied to femur.
   b. Can use either pins in plaster or external fixation devices.
   c. In children over 10 years of age there is a high incidence of associated knee ligament injuries with ipsilateral fractures (2A).

H. Operative Indication
1. Open fractures
   a. Often can be immobilized with simple cross pin or pins and plaster.
2. Severe shortening
   a. May require external fixation to maintain length.
3. Ipsilateral fractures - use pins in plaster or external fixation.
4. Hemophiliacs
   -- internal stabilization decreases need for prolonged factor replacement.

I. Complications
1. Vascular (direct injuries)
   a. Direct injury to anterior tibial artery is possible with proximal tibial fractures or distal tibial shaft fractures with severe posterior displacement (49).
   b. Direct injury to deep posterior tibial artery rare (49).
2. Compartment Syndrome
   a. Anterior compartment syndrome may occur with minor injuries.
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2. Compartment Syndrome
   a. Anterior compartment syndrome may occur with minor injuries.
b. Deep posterior compartment
   1) Often develops incipiently and manifests with late onset of clawfoot deformity.
   2) Recognized with increased pain on passive dorsiflexion of toes, weak toe flexion\(^{13}\).
c. Don’t do fibulectomy in growing child.
d. Don’t forget compartment syndromes can occur in as many as 5% of open fractures\(^{28}\).

3. Physeal Arrest
   a. Proximal tibial physeal arrest described in those patients with isolated tibial shaft fractures\(^{10,12,A,15}\).

4. Except for overgrowth the complications and problems associated with open fractures in children are very similar to those in adults\(^{28}\).
5. The complication rate overall is increased in those patients who have ipsilateral fractures\(^{24}\).

III. METAPHYSEAL FRACTURES

A. Proximal - Prone to develop valgus overgrowth of tibia despite fact of anatomic alignment.

B. Distal
   1. Often fail into recurvatum.
   2. In addition, varus or valgus angulation may also develop.
   3. Treatment
      a. Reduce and hold with foot and ankle in long leg cast with knee flexed and ankle plantar flexed for 3 to 4 weeks until stable. Then convert to short leg cast after a period of active motion.
      b. Varus 6°, valgus 10° or antcurvatum 10° are acceptable for remodeling\(^{18}\).
   4. If oblique and both tibia and fibula are involved, operative fixation to maintain length (plate or percutaneous pins) may be necessary.

IV. SPECIAL FRACTURES

A. Stress Fractures
   1. Tibia
      a. Most common bone affected for stress fracture in child\(^{3}\).
      b. Most commonly on proximal medial or proximal lateral tibia. Never anterior surface alone.
      c. Differential Diagnosis
         1) tumor
         2) osteomyelitis
   2. Fibula
      a. Reported in children as young as 2 to 8 years\(^{60}\).
      b. May carry eponym of "ice skaters" fracture.
      c. No x-ray changes for two weeks.
3. Treatment: Both types by rest and muscle strengthening.

B. Toddlers Fracture
1. First described by Dunbar in 1964 as a spiral fracture of the distal tibial metaphysis occurring before age 2-1/2 yrs.\(^{(3)}\).
2. Often initial x-rays show only deep soft tissue swelling. Periosteal new bone forms in 2-3 weeks.
3. Differentiation from child abuse\(^{(18a)}\).
   a. Toddler’s fractures are metaphyseal where as child abuse fractures are usually diaphyseal.
   b. Parents usually voluntarily offer history of mild trauma in toddler’s fractures, whereas the history of trauma is often vague in child abuse.

C. Soccer Fracture
1. Undisplaced mid shaft fracture of tibia.
2. Occurs when anterior surface struck directly by the anterior foot of opposing player.
3. Fracture often stellate or transverse but usually undisplaced.
4. Prevented by use of shin guards.

D. Bicycle Spoke Injuries.
1. Fracture of distal tibia occurs with considerable soft tissue trauma when foot caught between spokes and bicycle frame\(^{(11)}\).
2. Shearing force of spokes creates considerable superficial soft tissue injury with delayed full thickness skin loss.
3. Presence of occult fracture may be overlooked because of the magnitude of superficial skin injury.

E. Pathological Fractures
1. Occurs most commonly when a fibroosseous defect weakens the tibial or fibular shaft or metaphysis.
2. Most are usually benign but malignant lesions are possible.
3. Fractures usually are allowed to heal, then treated with curetment and bone graft. Curetment and grafting can be done acutely.

REFERENCES


