Remodeling of Fractures
In
Children

Kaye Wilkins M.D.
Clinical professor
Of Pediatrics and Orthopedics
University of Texas Health Science Center
At
San Antonio
E-Mail: DrKWilkins@aol.com

This handout now has been published as an article in the Journal INJURY and is provided to accompany the lecture by the same name with their permission.
Principles of Fracture Remodeling in Children

There are two advantages in treating children’s fractures. First, the healing process is very rapid. Non union is a rare event in the pediatric age group (20). The second advantage is that there is a very good remodeling capacity should there be less than anatomic alignment of the affected bone once the fracture has healed. Any individual treating fractures in the pediatric age group should have a full understanding of how pediatric fractures heal and how the remodeling process occurs.

THE BASIC BIOLOGY OF FRACTURE HEALING

Healing of fractures in children has been described by two authors (15, 16) as occurring in three phases: 1) Inflammatory, 2) Reparative and 3) Remodeling. Much of the following discussion of each of these processes has been taken from their work (15, 16).

Inflammatory
The initial phase is one of acute inflammation following the loss of integrity of the osseous structure (Figure 1A). This is the result of the hematoma formation that occurs from the rupture of the blood vessels. This hematoma contains a lot of fibrin which is rapidly replaced by a collagen scaffold. This collagen scaffold serves as the lattice framework for the initial woven bone. The hematoma also incites the production of proteins which stimulate the differentiation of cells into fibroblasts, chondroblasts, osteoblasts and angioblasts all of which are essential for the formation of new bone.

Reparative Phase
It is during this phase that the initial callous is formed. There is first the invasion of the hematoma by the fibrovascular tissue from both endosteal and periosteal sources. Subsequently, new bone forms from both endochondral (usually from an endosteal source) ossification and intramembranous (usually from the cells of the periosteum) ossification. This early type of bone is laid down haphazardly and in a random manner to fill the gap between the bone ends of the fracture. Because it is weaker structurally, a larger amount needs to be produced, thus the term “Quantity Bone” (Figure 1B). This produces the so-called provisional callous which provides temporary stabilization. This callous still does not provide the rigid stability necessary for full physical activity. The reparative phase occurs during the first two to three months of the fracture healing process.

Remodeling Phase
It is during this phase, which can last months and even years in some osseous structures, that the provisional callous is gradually removed and new bone is laid down
along the lines of stress (Figure 1C). Thus we now have the production of “Quality Bone” which is rigid and can support the normal physical activity of the child.

Figure 1. Phases of fracture healing. A. The immediate angulation following the fracture. This represents the hematoma and inflammatory phase. B. At eight weeks there is good provisional callous laid down in a random manner. This is the reparative phase. C. By eighteen months the bowing has remodeled along stress lines and the angular deformity has been pretty well resolved. This is the remodeling phase

BASIC PRINCIPLES OF THE REMODELING PROCESS

The Location Affects Remodeling

*Metaphysis.* There is a difference in the rate of remodeling as to the location of the fracture site. The metaphysis serves as an active remodeling area in the development of normal bone growth. It is the area where the quantity of woven bone produced in the adjacent physis is replaced with the more structurally sound quality compact bone of the diaphysis. Thus, this area has already in place an increased vascularity with much more osteogenic potential to facilitate fracture healing. The osteogenesis in this area is normally active.

*Diaphysis.* The diaphysis is primarily an area in which there is relatively dormant osteogenesis. Most of the bone production here is a balance of subperiosteal intramembranous ossification on the surface coupled with endosteal bone reabsorption in the medullary canal. The bone here is rigid, compact cortical bone and thus is relatively
avascular. As a result, there is less remodeling potential in this area. Fractures in this area take longer to heal and remodel.

**How Does the Remodeling Process Occur?**

*Angulation.*

**PHYSIS.** In the skeletally immature individual 75% of the angular remodeling takes place in the physis (29). Pauwels (21), Ryoppy and Karaharju (23) have demonstrated that both physis adjacent to a fracture tend to realign to become perpendicular to the forces acting through them by a process of asymmetrical growth. The concave side is stimulated to grow more rapidly to align the physis so as to become perpendicular to the long axis of the shaft of the bone (Figure 2). Once the physis is realigned, it then resumes symmetrical growth.

![Figure 2. Physeal realignment. A. The appearance two weeks post-injury of a child with severe cerebral palsy. The 30° of alignment of the long axis of the shaft with the physis was accepted. B. By nine months the physis has realigned itself to be within 60° of the long axis of the shaft. C. At eighteen months there is almost complete realignment of the distal physis with the shaft, the angle now being 85°.](image)

**DIAPHYSIS.** In the diaphysis remodeling follows Wolf’s law (28). Here there is increased pressure (compression) on the concave side which stimulates new bone formation. On the convex side, the bone is under tension and thus there is reabsorption of the convexity (Figure 3). About 20% of the remodeling of the angulation occurs in this area.
Length.

FEMORAL OVERGROWTH. It has been recognized for a long time that the fracture healing process stimulates bone growth (25). This growth stimulation is most prominent with most fractures involving the femoral shaft (Figure 4). Various length amounts have been reported for femoral overgrowth following fractures of the shaft. Probably the most detailed and accurate study was that by Shapiro (24). In his review of seventy-four patients under the age of thirteen, he found the average overgrowth was 0.92 cm. (Range 0.4-2.7). He found the overgrowth to be independent of age, fracture level or the position of the fracture at the time of healing. In the majority of patients there was some effect of growth stimulation for as long as three years and six months post-injury. It is felt that this growth stimulation was due to an increase of blood flow to the adjacent growth areas in response the fracture healing process.

TIBIAL OVERGROWTH. On the other hand, growth stimulation following fractures of the tibial shaft is age-dependent (13). The maximum stimulation of 4.2 mm occurred in the three to five year age group. In older children, the stimulation was less with some actual growth inhibition as the child reached maturity. There does appear to be a greater tendency to increase tibial overgrowth in those patients with open fractures (5).

Figure 4. Femoral overgrowth. This eight year old male sustained a fracture femur eighteen months previously. X-rays of both distal femurs show that there has been a 3 cm. migration of the Harris-Park growth arrest lines on the fractured side versus only 2 cm of migration these lines on the normal side.
**Rotation.**

Remodeling of rotation for practical purposes does not occur (7).

**Relationship to Growth Potential.**

**UPPER EXTREMITY.** In the upper extremity the proximal and distal growth centers account for the majority of growth in the extremity. Thus, the remodeling potential in these areas is extensive. Fractures about the elbow, especially the distal humerus, have very little remodeling potential.

**LOWER EXTREMITY.** The opposite is true of the lower extremity. If there is any expected remodeling, it occurs to a greater degree in the distal femur and proximal tibia (knee region). However, the amount of remodeling potential is less than that seen in the upper extremity.

**Overall Factors Affecting the Remodeling Potential**

The three major factors which have a bearing on the potential for angular remodeling are:

1. Skeletal age.
2. Distance to the joint.
3. Orientation to the joint axis.

**REMODELING OF SPECIFIC FRACTURES**

The remodeling capacity of fractures in the various parts of the upper and lower extremities varies considerably. One of the best reviews of this subject can be found in the recent article by Gasco and De Pablos (11). In the following section, we will review the remodeling capacity of the various areas and the recommended degrees of angular deformity or shortening which can be expected to remodel into an acceptable cosmetic and functional result.

**Fractures of the Hand.**

**Phalanges.** Very little remodeling can be expected in the fractures involving the distal portions (supracondylar and condylar areas) of the proximal and middle phalanges(12). In the proximal portions of these proximal and middle phalanges, some remodeling can be expected in the sagittal plane. Less can be expected in the coronal plane. Unfortunately, very little information is available in the literature as to the acceptable degrees of angulation for phalangeal fractures in children.

**Metacarpals.** Most of the controversy centers in regards to the acceptable angulation of apex dorsal fractures of the fourth and fifth metacarpal necks. Some are
very liberal in their manipulative indications accepting up to only 35-40° of apex dorsal angulations (2). Others are very conservative and have found that the ultimate function with those fractures which are not manipulated is equal to those who were manipulated (4, 18). The only difference in those that were not manipulated was the absence of the prominence of the metacarpal head (knuckle) in those not manipulated.

A summary of the expected degrees of remodeling of the various fractures of the bones of the hand is presented in Table I.

<table>
<thead>
<tr>
<th>Fractures</th>
<th>Acceptable Angular Malalignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal and Middle Phalanges (12)</td>
<td>&lt;10 years 20-25° in any plane, &gt;10 years 10-15° in any plane</td>
</tr>
<tr>
<td>Metacarpal Neck</td>
<td>35-40° apex dorsal (2) Others state almost none of these fractures need to be realigned (4, 18).</td>
</tr>
<tr>
<td>Metacarpal Shaft</td>
<td>No good data found</td>
</tr>
</tbody>
</table>

Table I. Acceptable Angular Malalignment of Hand Fractures

Fractures of the Distal Radial Physis.

This area has probably one of the greatest potential for remodeling of any fracture in the immature skeleton (Figure 5). Aitken (1) demonstrated many years ago that these fractures have a tremendous capacity for remodeling. He pointed out that up to 50% displacement of the fracture fragments can be expected to remodel fully if there is at least one and one half years of growth remaining.

![Figure 5-A Top](image1)
![Figure 5-B Top](image2)
![Figure 5-C Top](image3)

**Figure 5. Remodeling of the distal radial physis.** A. The appearance of the fracture fragments on cast removal four weeks post-injury. There is marked displacement of early callous formation. B. At three months the fracture has shown considerable remodeling of both the metaphysis and early realignment of the epiphysis. C. By fifteen months there is complete realignment of the distal epiphysis and remodeling of the metaphysis. The nonunion of the ulnar styloid was asymptomatic.
Fractures of the Distal Radial Metaphysis.

**Angular Remodeling.** The distal radial metaphyseal fractures likewise have a great potential for angular remodeling. The commonly accepted angulation that will fully remodel with five years of growth remaining is 30-35° in the sagittal plane and 10° in the coronal plane (FR 79, 30). In many cases however, the remodeling angulation may not be complete but there are no functional or cosmetic residual.

**Bayonet Remodeling.** Bayonet apposition can be expected to remodel in patients up to twelve years as long as the linear alignment is nearly anatomic (30) (Figure 6).

![Figure 6](image)

**Figure 6. Bayonet remodeling.** A. Position of the fracture fragments show early callous formation. This was the best position of the fracture fragments that could be achieved by closed reduction. B. At eighteen months there has been essentially complete realignment of the distal metaphysis with the proximal metaphysis. This patient had a full range of forearm and wrist motion.

**Reduction Necessary?** In a recent report Do and associates (8) felt that the degree of remodeling in this area was so great that the majority of their distal radial metaphyseal fractures did not even require a primary reduction. They accepted up to 15° of primary angulation and 1 cm. of shortening in boys up to fourteen years of age and girls up to twelve years of age. It was their opinion that it was a waste of time and financial resources to do a manipulation on these displaced fractures meeting these criteria. It was their observation that even those fractures that were completely unreduced had essentially complete remodeling at the termination of their growth.

Fractures of the Radial and Ulnar Shafts.

**Multiple Factors.** Acceptable malalignment of the shafts of the radius (and ulna as well) is dependent on multiple factors. Based upon his wide experience with these
Fractures, Price (22) has set down some guidelines for the various factors involved (Table II). He also found that impingement across the interosseous space by the fracture fragment was an unpredictable factor in determining the ultimate outcome.

<table>
<thead>
<tr>
<th>Age</th>
<th>Angulation</th>
<th>Malrotation</th>
<th>Displacement</th>
<th>Loss of radial bow</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 9yrs</td>
<td>15°</td>
<td>45°</td>
<td>Complete</td>
<td>Yes</td>
</tr>
<tr>
<td>&lt; 9yrs</td>
<td>10°</td>
<td>30°</td>
<td>Complete</td>
<td>Partial</td>
</tr>
</tbody>
</table>

Table II. Acceptable Malalignment for Radial Shaft Fractures.(22)

**Plastic Deformation.** In a study by Vorlat and De Boeck (26), it was found that over the age of six years greater than 10° of plastic deformation of either the radial or ulnar shafts would result in an unacceptable result.

**Fractures of the Radial Neck.**

**Angulation.** There is not a total consensus on the amount of angulation of a radial neck fracture that can be accepted with resultant satisfactory remodeling. The most commonly accepted number is 30° of angulation (2, 6). However, other studies (9, BO98, VO 98) have demonstrated that even those with up to 50° of angulation can be expected to achieve good results.

**Translocation.** Originally it was felt that as little as 2 mm of translocation results in a poor outcome. However, more recent studies have shown that up to 5 mm of translocation will remodel (6).

**Clinical Examination.** Probably the best method of determining what degree of deformity will result in an acceptable outcome involves a clinical examination under sedation or anesthesia to determine the passive range of forearm motion. If there is at least 50° of supination and 50° of pronation, the patient should be expected to have a satisfactory functional result.

**Supracondylar Fractures of the Distal Humerus.**

**Angulation – No.** Very little angulation in the sagittal plane can be expected to remodel. Up to loss of 20° of the shaft-condylar angle can be tolerated. This is usually only manifest as a lack of full elbow flexion with some increase in elbow hyperextension. In the coronal plane, no angular remodeling can be expected. Angulation into varus will result in an unacceptable cosmetic deformity. It has also been shown that cubitus varus produces some functional effects such as recurrent fractures of the lateral humeral condyle or late ulnar nerve neuropathy (30).

**Translocation – Yes.** On the other hand, translocation of as much as one hundred percent in either plane has been shown to demonstrate complete remodeling (30).
Fractures of the Humeral Shaft.

There is considerable remodeling of the humeral shaft especially in the very young age groups. A good example of the remodeling capacity in the infant is seen in Figure 3. Kwon and Sarwark (19) have reviewed the literature and come up with some guidelines as to acceptable displacement (Table III). Fortunately, minimal angulation is well hidden by the muscles of the arm.

<table>
<thead>
<tr>
<th>Type of Displacement</th>
<th>Amt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varus Angulation</td>
<td>20-30°</td>
</tr>
<tr>
<td>Apex Anterior Bowing</td>
<td>20°</td>
</tr>
<tr>
<td>Loss of Internal Rotation</td>
<td>15°</td>
</tr>
<tr>
<td>Bayonet Shortening</td>
<td>2 cm.</td>
</tr>
</tbody>
</table>

Table III. Acceptable Displacement for Humerus Shaft Fractures (19)

Fractures of the Proximal Humerus.

Proximal Physeal Injuries. Because of the presence of fractures through the proximal humeral physis tend to develop angular deformities because of the presence of the rotator cuff muscles acting only on the proximal fragment. Opposing muscles are still attached to the distal fragment. Fortunately however, because of the marked flexibility and circumduction nature of the shoulder both considerable displacement and angulation can be tolerated in the younger age group. Beaty (3) has set out guidelines for each age group (Table IV). In those patients that use their upper extremities for high performance athletic activities less than a near anatomic reduction however may result in some loss of athletic performance.

<table>
<thead>
<tr>
<th>Age</th>
<th>Displacement (degrees,%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 yrs</td>
<td>Up to 70° angulation, 100% displacement</td>
</tr>
<tr>
<td>5 – 12 yrs</td>
<td>40-70° angulation</td>
</tr>
<tr>
<td>&gt;12 yrs</td>
<td>Up to 40° displacement, 50% apposition</td>
</tr>
</tbody>
</table>

Table IV. Acceptable Displacement for Proximal Humeral Fractures (3)

Proximal Metaphyseal Injuries. With this fracture pattern there is some resistance to external rotation and abduction of the proximal fragment because of the persistence of muscle insertion of the pectoralis major on the proximal fragment. Thus many of these fractures if complete, tend to present with bayonet apposition. By and large this bayonet apposition can be expected to remodel to a satisfactory degree if there is at least two years of growth remaining.
Fractures of the Femoral Shaft.

**Angular Malalignment.** Malalignment in both sagittal and coronal planes is somewhat age dependent. Kasser (17) has outlined very nicely his recommendations for acceptable angulation in the various planes as it relates to the specific age groups (Table V). Because of the normal natural anterior bow of the femur, more angulation can be tolerated in the sagittal plane.

<table>
<thead>
<tr>
<th>Age</th>
<th>Varus/Valgus</th>
<th>Sagittal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth-2yrs</td>
<td>30°</td>
<td>30°</td>
</tr>
<tr>
<td>2-5yrs.</td>
<td>15°</td>
<td>20°</td>
</tr>
<tr>
<td>6-10 yrs.</td>
<td>10°</td>
<td>15°</td>
</tr>
<tr>
<td>11 yrs +</td>
<td>5°</td>
<td>10°</td>
</tr>
</tbody>
</table>

Table V. Acceptable Angular Malalignment For Fractures of the Femoral Shaft (17)

**Shortening.** The amount of shortening expected to correct has been discussed previously in this section on femoral overgrowth. It must be remembered that a combination of angulation with shortening has an additive effect and can spell trouble regarding an acceptable outcome (Figure 7).

**Loss of Rotation.** As mentioned previously, Davids (7) has shown that rotation does not significantly remodel. He did find in his studies that up to 25° can be well tolerated.

![Figure 7-A](image1.png)  ![Figure 7-B](image2.png)  ![Figure 7-C](image3.png)

**Figure 7. Combined deformities equals trouble.** A. A six year old female who is five weeks post-injury shows 4 cm. of shortening on the A/P radiograph. B. On the lateral radiograph, in addition to the shortening there is 33 degrees of apex anterior angulation. C. At three years the combined angulation and shortening have produced a resultant 3.5 cm. discrepancy which has persisted and not changed over the last year. This shortening resulted in both unacceptable functional and cosmetic results.

Fractures of the Tibial Shaft.
Angular Malalignment. The tibia is very unforgiving in its ability to remodel. This may be because it is composed of a very large amount of diaphyseal bone. Remodeling in the sagittal plane is better than in the coronal plane. Varus has a better chance to remodel than valgus (14). Heinrich has set out some good guidelines for the remodeling potential of tibial shaft fractures according to the patient’s age (Table VI) (14).

<table>
<thead>
<tr>
<th>Deformity</th>
<th>&lt;8yrs</th>
<th>&gt;8yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valgus</td>
<td>5°</td>
<td>5°</td>
</tr>
<tr>
<td>Varus</td>
<td>10°</td>
<td>5°</td>
</tr>
<tr>
<td>Anterior Angulation</td>
<td>10°</td>
<td>5°</td>
</tr>
<tr>
<td>Posterior angulation</td>
<td>5°</td>
<td>0°</td>
</tr>
<tr>
<td>Shortening</td>
<td>10 mm</td>
<td>5 mm</td>
</tr>
<tr>
<td>Rotation</td>
<td>5°</td>
<td>5°</td>
</tr>
</tbody>
</table>

Table VI. Acceptable Angulation of Malalignment for Fractures of the Femoral Shaft (14)

Translation. Because of the subcutaneous nature of the tibial shaft there may be concern of the effect of translocation on the clinical appearance. One hundred percent translocation will result in a satisfactory outcome in the young child, whereas in the adolescent the goal should be to achieve at least 50% apposition (14).

STRIVE FOR THE BEST

Fortunately for the treating surgeon, children have a tremendous capacity to remodel malalignment of their fractures should it occur. *This is no excuse for the treating surgeon not to make every attempt to obtain as anatomical an alignment as possible.* If this cannot be achieved by conservative methods, then serious consideration should be given to achieving a satisfactory reduction by operative means.

SUMMARY

In treating fractures in children, the surgeon must have a good knowledge of the three phases of bone healing, i.e. inflammatory, reparative and remodeling and understand how they contribute to the final recovery of the fracture healing process. By and large the ability to remodel is dependent upon the bone involved, the patient’s age, the proximity to the joint and its orientation to the joint axis. In the typical long bone, 75% of the remodeling occurs by reorientation of the physis while appositional remodeling of the diaphysis can be expected to contribute only 25% to the remodeling process.

The various values of acceptable alignment for each of the major fracture patterns listed should serve only as guidelines. The patient’s functional capacity and the surgeon’s experience should also be factors in determining whether to depend upon the
remodeling capacity of the specific fracture or to consider performing a more aggressive, invasive technique to achieve a satisfactory result

References


