The case:

A 5-year-old boy was brought to the emergency department after a fall from a jungle gym. He had persistent pain and swelling of his left forearm.

Figure: Anteroposterior radiograph of the left forearm.

Your diagnosis?

For answer, see next page.
In this case, the anteroposterior view of the left forearm (Figure 1) showed abnormal bowing of the ulna and dislocation of the radial head. There were no fracture lines, so that this is a Monteggia equivalent. Bone density was normal. This plastic ulnar bowing was the result of longitudinal compressive force applied to the naturally curved bone with tensile stress at the convex surface of the bone and compressive stress at the concave surface resulting in fixed plastic bowing. The majority of these fractures are in children. Bowing fractures may go undetected, and depending on the age of the patient and the degree of bowing, this can lead to functional or cosmetic abnormalities.

The hallmark radiographic finding of a plastic bowing fracture is bowing curvature of the bone without a cortical break. Plastic curvature of a bone may be an isolated finding, although more commonly it is found in association with fractures or dislocations of accompanying bones in the forearm (Figure 2) or lower leg (Figure 3). Subtle or obvious, prompt diagnosis of a bowing fracture with appropriate treatment can prevent secondary sequelae (Figure 4).

Clinical Presentation

Bowing fractures were first described by Borden in 1974. Most bowing fractures occur in children but some can also be seen in adults. In children and young adolescents, the radius and ulna are the most commonly affected bones, followed by the fibula. However, bowing fractures have been reported in all long bones. A specific traumatic event is usually identified. The majority of pediatric patients present with a forearm bowing fracture after a fall. The mechanism of injury is a fall on an outstretched hand resulting in a longitudinal compressive force. Adult injury patterns in the upper extremity are different and usually due to slow bending forces such as when a forearm is trapped in a rotating machine. Fibular bowing fractures can result from longitudinal force produced from a fall, but in contrast to the upper extremity, most are the result of a direct blow to the antero-
lateral aspect of the fixed leg with the force translated into sheer and compressive vectors. They are most often associated with a tibial fracture. Patients with bowing fractures present with persistent pain and swelling. Presenting symptoms are similar to those of more common fracture patterns. Deformity can be visible if bowing is great enough. Range of motion may be limited, with a decrease in pronation and supination when the forearm is involved.

**Pathophysiology**

Bowing fractures are indisputably fractures. No fracture lines are visible on radiographs, but microscopically the bowed bone shows oblique microfractures of the compressed concave cortex. These microfractures extend from the medullary cavity to the perios- teum. Assuming the bone is normal, the factors that result in an acute injury leading to a bowing fracture rather than the more common complete or greenstick fracture are many. They include the direction and duration of stress, as well as the fact that the osteoid density of bone is less in a child than in an adult. In part, this is because children’s bones are more porous than mature bones. The Haversian canals occupy a much greater part of the bone in a child compared with an adult. The end product of these differences when longitudinal stress is applied to a long bone is shown by a stress-deformity curve (Figure 5).

The relationship between applied stress and resultant deformity of the ulnas of dogs was studied in a laboratory setting. Tensile (distraction) stress was produced at the convex surface of the bone while simultaneously compressive stress was applied to the concave surface. When the ulna was subjected to low-level an-gulated longitudinal force, the bone bent but reverted back to normal after the force was removed. However, when force short of causing a fracture was applied, the bone stayed bent. Expressed graphically, the stress-deformity curve (Figure 5) indicates what happens to a long bone when single forces of increasing magnitude are applied. When low-level stresses up to the level E are applied, the bone is deformed but reverts to normal when the stress is removed. This area where there is complete recovery is designated the elastic zone. However, if applied stress increases and is greater than level E, the plastic zone (P) is entered and there is persistent plastic bowing of the bone. Further increase in stress would lead to a gross fracture that is the limit of the plastic zone. The plastic zone is much wider in children than in adults, mak-
ing them more susceptible to bowing fractures.

Between points P and E on the curve, stress and deformity are no longer proportional so that a single stress does not result in plastic bowing, but when the same stress is applied multiple times, the curve shifts from the elastic to the plastic zone and fixed abnormality occurs (ie, a stress fracture). The segment of the curve between E and P is called the fatigue zone.3,9

In the forearm, the outcome of stress applied to one bone can be altered by the outcome of the stress applied to the adjacent bone. In a series of 17 children with forearm bowing fractures, 13 children had fractures of the adjoining bone while 4 had bowing of both the radius and ulna with no overt fracture.3 It was postulated that the force on the forearms resulted in the gross fracture of one forearm bone with the dissipated remaining force decreased enough to be within the plastic zone of the curve for the other bone, thus leading to a plastic bowed bone.3

In mature bone compared with children’s bone, the slope of the elastic response curve is steeper and the width of the plastic zone is narrower. These factors make an adult bowing fracture less likely. Nonetheless, there have been at least 30 reports of adults with plastic bowing forearm fractures as well as at least 3 fibular bowing fractures.3

**IMAGING**

**Radiography**

Bowing fractures appear as abnormally bowed bones on radiographs. Given morphologic variation between individuals and variations dependent on age, imaging findings may be subtle.

To evaluate for a bowing fracture effectively, both anteroposterior and lateral radiographs are required because abnormal bowing may only be visible on one view (Figure 6).1 A method of measuring bowing of the radius on radiographs has been described.10 This method uses the anteroposterior view, as this view correlates with injury that could affect supination or pronation. In certain clinical situations, comparison views of the bone of the opposite extremity may be required to confirm subtle bowing (Figure 7).1 However, obtaining these additional radiographs is not recommended as a routine practice.

Plastic deformities usually consist of broad curvatures that blend into normal bone at both ends. There are no fracture lines. Most often, bowing fractures of the forearm and leg are associated with a visible fracture of the non-bowed bone, usually diaphyseal (Figures 2-4, Figure 6, Figure 8). In some cases, there is dislocation of the opposite bone rather than a fracture. Plastic ulnar bowing with radial head dislocation is termed a Monteggia equivalent (Figure 6: Lateral forearm radiograph showing an undisplaced fracture of the distal radius in a 7-year-old boy (A). Anteroposterior forearm radiograph showing an ulnar bowing fracture in addition to a distal radius fracture (B).

Figure 7: A 7-year-old girl’s left arm was caught in a closing garage door. Anteroposterior radiograph of the right humerus is normal (A). Anteroposterior radiograph of the left humerus showing a plastic bowing fracture (B).
Femoral bowing and tibial bowing with fibular fractures have also been reported. Bowing of 2 adjacent bones without a gross fracture is infrequent. Obvious bowing fractures require no further imaging. Apparent isolated radial head dislocation requires scrutiny for subtle injuries including ulnar bowing. A corollary is that obvious bowing of 1 long bone requires scrutiny of the opposite bone and joints. Special attention is also indicated when there is deformity on physical examination but no overt fracture or bowing deformities, a displaced complete fracture of the forearm or lower leg, or isolated dislocation of the proximal fibula. Subtle bowing deformities may not be identified on initial imaging. If there are persistent signs or symptoms after injury, follow-up imaging may show bowing deformity. Reactive periosteal new bone can develop at the apex of the concave margin of the bowed bone during the earliest phases of healing, but this is unusual (Figure 8). More often there is cortical thickening of the concave cortex. The time interval for the development of periosteal reaction is variable, depending on the patient’s age.

**Nuclear Scintigraphy**

In most cases, a bowing fracture can be readily diagnosed on radiographs. However, sometimes it is difficult to differentiate an acute, evolving injury from a chronic, static deformity. Differentiating an acute from a chronic injury can have therapeutic importance as clinical management may be different. Acute fractures differ in appearance from chronic injuries on nuclear scintigraphy. A healing acute fracture has increased metabolic activity and will show abnormally increased tracer deposition on skeletal scintigraphy, in contrast to a tracer-neutral deposition pattern that is seen in a static deformity (Figure 9).

**Computed Tomography and Magnetic Resonance Imaging**

Computed tomography and magnetic resonance imaging are not indicated for the diagnosis of acute bowing fractures. However, in theory, this injury pattern may be identified while completing these tests for other reasons.

**Differential Diagnosis of Incomplete Fractures**

**Greenstick Fracture**

This injury is the result of longitudinal stress similar to a bowing fracture. However, after the stress enters further into the plastic zone (Figure 3), the long bone bows with preservation of the concave cortex, while the convex cortex fails. The fracture line crosses only one cortex.

**Buckle Fracture**

This fracture is the result of eccentric, longitudinal stress and appears as eccentric buckling of the concave cortex at the metaphyseal junction.

**Stress Fracture**

This fracture is the result of repetitive stress to normal bone in the segment of the stress-deformity curve between P and E (fatigue zone) (Figure 5). Initially, there is a fracture involving only one cortex that can appear as a fracture line in long bones along with later periosteal new bone formation. Continued repetitive stress may lead to a complete fracture.

**TREATMENT**

If left untreated, bowing fractures can result in abnormal range of motion or growth of the opposite bone. Management decisions are based on the age of the patient, time interval from injury, severity of the deformity, and associated injuries. Published recommendations for treatment of bowing fractures vary. Some authors recommend no reduction of bowed bones in children 4 to 6 years old, as they have the potential to remodel. Others recommend reduction of the fracture if there is greater than 20° of bowing. For patients 10 years or older, reduction is recommended, as these children have decreased potential for remodeling. Reduction of bowing is recommended at all ages if the bowed bone prevents reduction of a fracture or dislocation of the associated bone.

Recommendations vary for patients in the 6 to 10 year age group. Some authors recommend no reduction. Others recommend reduction if there is deformity of greater than 20°, when there is obvious deformity on physical examination, or when there is substantial limitation of forearm rotation. Still, another recom-
mendation is to reduce bowing fractures in patients older than 6 years when there is cosmetically unacceptable bowing deformity of greater than 10°. To perform closed reduction of a bowed bone, it may be necessary to apply a counterforce of 100% to 200% of the patient’s weight for several minutes. A small study (14 patients) used a method of applying force to the bowed radius or ulna by placing the apex of the curve of the bone on a sand bag. The mean reduction of angulation was 85%, and there were no complications.

**Conclusion**

Plastic bowing fractures of long bones, much more common in children than in adults, are usually due to longitudinal compression forces falling within the plastic zone of a stress-deformity curve. Deformity ranges from overt to subtle and can be diagnostically challenging. Whether managed conservatively, with closed reduction, or surgically, careful scrutiny of radiographs is essential for identification of this injury pattern. Recommendations for treatment vary. Management decisions should include consideration of the patient’s age, degree of bowing abnormality, and associated injuries.

**References**