In the past ten to fifteen years, investigators have demonstrated conclusively that some injuries about the wrist have profound long-term consequences relative to function of the wrist. Problem fractures and non-unions of the scaphoid have been associated, in particular, with major alterations in the kinematics of the wrist. Considering its vulnerable blood supply, irregular shape, peculiar oblique alignment across the plane of motion of the mid-carpal joint, and complex function as a link between the proximal and distal carpal rows, it is not surprising that the carpal scaphoid presents a number of diverse challenges to clinicians seeking optimum methods of treating such fractures. Despite previous reports of rates of union that exceeded 95 per cent after the wrist was treated with simple immobilization in a cast, recent studies of scaphoid fractures and non-unions, using improved assessment techniques and longer-term follow-up, have shown a considerably higher incidence of premature carpal collapse and degenerative arthritis than was previously appreciated. There have been a sufficient number of major contributions regarding the anatomy, pathomechanics, natural history, and treatment of fractures and non-unions of the carpal scaphoid to warrant a reassessment of the current methods of both diagnosis and treatment.

Vascular Anatomy

Studies of vascular injection have provided an anatomical correlate for the patterns of osteonecrosis of the scaphoid that are seen clinically. The proximal pole of the carpal scaphoid has been compared with the heads of the femur and the talus, because it is covered completely with hyaline cartilage and has a nutritional source that may be interrupted by fracture. Central to understanding the cause of failure in the treatment of many patients who have a fracture of the carpal scaphoid is a knowledge of the scaphoid’s unique extraosseous and intraosseous blood supply. In 1966, Taleisnik and Kelly reported the findings of vascular injection and Spalteholz clearing studies on fresh cadaver limbs in which the small vessels of the wrist had been dissected manually. They found three systems of extraosseous arteries entering the scaphoid from the radial artery: dorsal vessels, entering along the narrow dorsal ridge; distal vessels, entering the distal tuberosity; and a laterovolar group of vessels. The laterovolar vessels were considered the most important source of intraosseous perfusion and, combined with the dorsal vessels, were thought to be responsible for perfusion of the proximal two-thirds of the bone. It was noted that the distal vessels supplied the region of the tuberosity only.

Studies using non-dissection and débridement with sodium hypochlorite have provided apparently conflicting data. While the major blood supply was also seen arising from the radial artery, with appreciable collateral contributions from the dorsal and palmar branches of the anterior interosseous artery, only two direct vascular leashes were observed entering the scaphoid. The most important of these was from the scaphoid branches of the radial artery and entered the bone through foraminae along its dorsal ridge; it supplied 70 to 80 per cent of the bone, including the entire proximal pole. A second vessel, or group of vessels, arose from the palmar and superficial palmar branches of the radial artery and entered the carpal scaphoid in the region of its distal tubercle; it perfused the distal 20 to 30 per cent of the bone, including the tuberosity. When the results of this study are compared with those of the study by Taleisnik and Kelly, it may be concluded that the laterovolar vessels that were described by Taleisnik and Kelly are analogous to the dorsal ridge vessels of the more recent study, and that the distal vessels noted previously correspond to the vessels of the tuberosity that were described subsequently.

It is important to correlate the results of these studies with those of previous studies that described the vascular foramina of dried scaphoids. Earlier investigators found that 13 per cent of specimens lacked vascular perforations proximal to the waist and that 20 per cent had a single proximal foramen. Others noted that dorsal vessels entered distal to the scaphoid waist in 14 per cent of specimens and proximal to it in 27 per cent. In the remaining 59 per cent of the specimens, dorsal vessels entered the bone directly at the waist. These studies suggest a correlation between the location of the fracture and the incidence of osteonecrosis of the proximal pole. Approximately 30 per cent of fractures of the middle third and nearly 100 per cent of those of the proximal fifth of the carpal scaphoid are associated with...
osteonecrosis of the proximal pole. An explanation was also provided for the delayed healing times, which may be six to eleven weeks longer for fractures of the proximal third compared with those of the middle third. In addition, a higher incidence of non-union has been noted with fractures of the proximal pole.

Studies of the arterial anatomy of the carpal scaphoid have provided relevant information on operative approaches that are designed to avoid the critical intraosseous blood supply and have confirmed that, generally, the palmar approach to be the safest with respect to preserving the dorsal vascularity of the scaphoid. Botte et al. recently reported the effects of the dorsal and the palmar operative approach on the internal vascularity of the scaphoid. They found the palmar approach to be the safest with respect to preserving the dorsal nutrient vessels entering through that region were sometimes disrupted. The dorsal operative approach to the scaphoid placed the vessels of the dorsal ridge at highest risk, particularly when the vascular leash was not visualized directly and protected. Despite efforts to protect it, the dorsal leash was inadvertently damaged with this approach in one of the twelve specimens. Therefore, the palmar operative approach continues to be preferred when operative exposure of the carpal scaphoid is needed. If there is a compelling reason, such as the presence of scaphocapitate fracture syndrome or of a small proximal fragment, to expose the fracture fragments from the dorsum, then the vascular leash should be isolated and protected.

There are no clinically applicable or reproducible methods of assessing the blood supply of the carpal scaphoid accurately. On the basis of a comparison of preoperative radiographs and direct observations of bleeding cancellous bone at the time of operation, Green noted that the radiographic appearance of sclerosis of the proximal pole did not correlate well with true osteonecrosis. He found visualization of punctate bleeding to be a more specific method of determining vascularity of the proximal pole. Furthermore, he established the importance of vascularization of the proximal pole in healing by showing a direct correlation between bleeding bone and the rate of union after operative reduction and bone-grafting. Although there is considerable interest in correlating findings from scintigraphy and magnetic resonance imaging with the vascularity of small bone fragments, conclusive data on the sensitivity of these techniques are not available.

Biomechanics

Recent studies have supported the concept that the wrist functions as two carpal rows, with the proximal row acting geometrically as a variable intercalated segment located between the radius and triangular fibrocartilage complex on one side and the distal carpal row on the other. Since the proximal carpal row has no direct tendinous or ligamentous attachments, its motions are determined by its proximal and distal contacts with the forearm and with the distal carpal row. The scaphoid, the most mobile of the carpal bones, bridges the mid-carpal joint and concurrently provides three planes of motion. The same compressive loads that tend to cause zigzag collapse of the proximal carpal row also cause angulation and displacement of the proximal and distal poles of the fractured carpal scaphoid. The distal fragment tends to collapse into flexion and to move synchronously with the distal carpal row, while the proximal fragment extends with the lunate and the triquetral bone. With mild or moderate displacement, fragments will either heal in excessive angulation or fail to unite at all.

Recent biomechanical studies have shown the consequence of foreshortening of the scaphoid, a deformity that is normally prevented by the continuity of the palmar cortex, to be that the proximal and distal poles begin to act independently of one another. Smith et al. noted that, in contrast to other fractures in which the proximal segment remains stable, both fragments of the scaphoid displace with respect to each other and to the adjacent carpal bones. Consequently, increased interfragmentary motion occurs with all planes of motion of the wrist, an observation that explains, in part, the higher incidence of non-union that has been noted with unstable fracture patterns. In addition, lack of recognition of this deformity and undertreatment may result in the scaphoid collapsing into flexion, with healing in the so-called humpback position. Experimental studies simulating non-union of the scaphoid have demonstrated progressively decreasing extension of the wrist as angulation of the scaphoid increases. With only a 5-degree flexion deformity of the scaphoid, 24 per cent of extension of the wrist was lost.

Imaging and Diagnosis

An adequate initial radiographic examination of the painful wrist includes neutral, ulnar deviation, posteroanterior, and lateral radiographs, as well as oblique radiographs made with the wrist in pronation. Occasionally, plain radiographs that are made within the first few weeks after injury fail to demonstrate a fracture. When a patient has tenderness in the dorsolateral aspect of the scaphoid and the radiographs are negative for fracture, it has become common to immobilize the wrist in a thumb-spica splint or cast for seven to ten days. If the tenderness persists and repeat radiographs are negative, immobilization may be continued for an additional seven to ten days. By that time, usually the scaphoid either will not be tender or will have a demonstrable fracture radiographically. If radiographs continue to be negative after the second trial of immobilization and if symptoms persist, then bone-scanning, trispiral tomography, or axially directed computed tomography is indicated.

The use of scintigraphy in the diagnosis of fractures of the carpal scaphoid has received increased attention in recent years. Concerned about the prolonged immobilization needed for wrists that have equivocal findings, Ganel et al. studied forty-nine suspected fractures of the scaphoid.
tial radiographs showed the fracture clearly in eleven wrists, were non-diagnostic in thirty-one wrists, and were negative in seven wrists. Radionuclide imaging was performed two to three hours after administration of technetium-99m methylene diphosphonate, twenty-four to seventy-two hours after injury. Of the eleven wrists that had a radiographically demonstrated fracture, all had a positive scan. Of the thirty-eight wrists that had a non-diagnostic or a negative radiographic study, eight had a positive scan and subsequently demonstrated a fracture. Although the false-positive rate using this technique has ranged from 6 to 16 per cent, no false-negative results have been reported. The bone scan has become an important adjunct in the assessment of injuries about the carpal scaphoid when a fracture cannot be confirmed radiographically.

Precise imaging of fracture fragments for determination of their angulation and displacement is complicated by the scaphoid's peculiar peanut-like shape. Plain radiographs often fail to demonstrate the characteristic dorsal angulation of the proximal pole-lunate complex and the concomitant flexion of the distal pole. Polytomographic images demonstrate the distal fragment only on lateral images and the proximal fragment only on medial images. A recent report showed that the scaphoid may be visualized most completely when six to eight computerized axial-tomographic sections are made along the true longitudinal axis. Such scans clearly show the deformity that is caused by dorsal angulation through the site of the fracture. A computerized tomographic scan should be made if foreshortening due to angulation is suspected.

Treatment

Non-Displaced Fractures

In the past decade, studies designed to improve the results of treatment have focused on methods of immobilization for stable fractures and on types of internal fixation for unstable ones. Several earlier reports recommended immobilization, with extension of the wrist and moderate radial or ulnar deviation, for maintaining alignment of fragments of a stable scaphoid fracture. However, data from some studies have differed.

Noting that tension in the palmar radioscaphocapitate ligament leads to displacement of the distal pole of the scaphoid, Weber and Chao suggested that fractures through the waist be treated by a method that relaxes the palmar radiocarpal ligaments. They recommended placing the wrist in slight radial deviation and slight palmar flexion. Subsequently, Weber noted that neutral flexion and slight radial deviation allowed maximum opposition of the fracture fragments, and he reported a rate of union of 100 per cent for non-displaced fractures that were treated in this position.

There has been considerable controversy as to whether immobilization in a short or a long thumb-spica cast is the most appropriate treatment for patients who have a fracture of the carpal scaphoid. A recent prospective randomized clinical trial demonstrated a statistically significant advantage for treatment with a long thumb-spica cast. The authors noted decreased times to union and reduced rates of delayed union and non-union in the experimental group that was treated with a long rather than a short thumb-spica cast. Their findings are supported by anatomical data demonstrating that shear stresses transmitted to the scaphoid by way of the palmar radiocarpal ligaments during pronation and supination are eliminated when the cast extends proximal to the elbow. Undisplaced fractures united in eight to twelve weeks when they were treated with a long thumb-spica cast. The period of immobilization that was needed for union was extended by two to six weeks when a short cast was used.

Healing time has also been related to the location of the fracture, with the times to union increasing for more proximal fractures. It has been reported that fractures of the distal third heal in approximately six to eight weeks; those of the middle third, in eight to twelve weeks; and those of the proximal third, in approximately twelve to twenty-three weeks.

Currently, the recommended position for immobilization is slight flexion and radial deviation of the wrist. A long thumb-spica cast is used for six weeks, followed by a short thumb-spica cast until clinical and radiographic signs of union are seen. If radiographs fail to clearly demonstrate trabeculae crossing the site of the fracture, computed tomographic sections along the axis of the carpal scaphoid are made.

Fractures of the Carpal Scaphoid: Displaced or Angulated, or Both

Instability of a fracture fragment of the scaphoid is defined as displacement of the fragment by one millimeter or more as seen on any radiograph or as angulation demonstrated by a radiolucent angle of more than 15 degrees or a scapholunate angle of more than 60 degrees, or both. Previously, Russe divided fractures of the scaphoid waist into horizontal oblique, transverse, and vertical oblique configurations, on the basis of the relationship of the fracture lines to the bone's longitudinal axis. Vertical oblique fractures were considered least stable because of shear forces acting on the site of the fracture. More recently, Herbert and Fisher classified a number of distinct fracture patterns as inherently unstable, including fractures of the proximal pole, those associated with perilunate dislocation, and comminuted fractures. Rates of non-union after non-operative treatment of unstable fractures have approached 50 per cent. When healing has occurred, the incidence of malposition and late collapse deformity has been high enough to have caused some authorities to recommend open reduction and internal fixation for all unstable fractures of the scaphoid.

Some biomechanical and clinical studies in the last ten years have focused on the optimum methods of achieving stability in openly reduced fractures. Smooth Kirschner wires, cancellous bone screws, and specially designed scaphoid screws have been used for fixation. The Herbert...
screw, introduced in 1984, has generated considerable interest. This screw is threaded at both ends and can be countersunk beneath the articular surface, obviating the need for removal after the fracture has healed. It is designed to achieve compression by use of a differential thread-pitch between its proximal and distal ends, and it has a guiding jig that maintains reduction and interfragmentary compression during insertion. However, recent biomechanical studies have noted that the interfragmentary compressive forces generated by the Herbert screw were less than those associated with conventional screws. Using paired scaphoids from cadaver and simulated bones made of polyurethane foam, Shaw found that use of the Herbert screw generated a mean maximum compressive force of 4.4 kilograms, as compared with the 17.0 kilograms associated with the ASIF 4.0-millimeter cancellous screw. The mode of failure for both screws was by thread-stripping. Although problems with the older designs of screw have been well documented, the predicted advantages of fixation with the Herbert self-compressing screw—that is, enhanced stability, earlier mobilization of the wrist, and a shorter time to union—have not yet been demonstrated conclusively in a controlled clinical trial. The reported rate of union for acute, unstable fractures that were treated operatively has ranged from 54 to 97 per cent. Failures have been attributed to delays in fixation, malposition of the screw, and poor alignment. Although considerable early stability may be achieved with rigid internal fixation, most authors have recommended that immobilization be continued in a short thumb-spica cast until union of the fracture is certain both radiographically and clinically.

Non-Union of the Carpal Scaphoid

Natural History

Until recently, the natural history of non-union of the carpal scaphoid had not been established conclusively. Earlier studies suggested that such non-unions cause few symptoms and little disability. In contrast, recent findings have indicated a distinct progression of arthritic changes over time. Mack et al., in 1984, reviewed forty-seven symptomatic non-unions of the scaphoid and found a correlation between the presence of arthritis and the time since fracture. Degenerative changes were confined to the scaphoid in patients who had a non-union of five to ten years' duration, involved the radioscpahoid joint in patients who had a non-union of ten to twenty years' duration, and affected the wrist generally in patients who had a non-union of more than twenty years' duration. There was an increased incidence of progressive osteoarthrosis in patients who had a displaced non-union and in those who had evidence of instability of the wrist (defined as a scapholunate angle of more than 70 degrees or a radiolunate angle of more than 10 degrees). Mack et al. found displacement of the fracture and instability of the wrist to be major factors in the development of progressive degenerative changes. Also of interest was the increase in the incidence of displaced non-unions as the time since fracture increased, suggesting that undisplaced non-unions may become displaced or angulated over time.

Recent studies have extended the findings of Mack et al. In a review of fifty-six untreated non-unions of the carpal scaphoid, Ruby et al. reported an overall incidence of arthritis of the wrist of 55 per cent. In patients who had sustained the initial injury more than five years earlier, the incidence of arthritis was 97 per cent. Ruby et al. noted a distinct sequence of arthritic changes, occurring initially at the scaphoid-radial styloid joint and later progressing to the scaphocapitate and capitolunate joints. Undisplaced fractures most often affected the scaphoid-radial styloid joint, while displaced fractures involved all three joints. Whereas 46 per cent of the patients had no symptoms until a second injury occurred, 89 per cent ultimately had symptoms. In a similar retrospective study, Vender et al. reported on sixty-four patients who had a symptomatic non-union of the carpal scaphoid. They focused on the sequence of arthritic changes, noting specifically that the proximal scaphoid-radial styloid and radiolunate joints were spared degenerative changes, even when severe arthritis was present. A similarity was noted between the progressive arthritic changes of symptomatic non-union of the scaphoid and those of rotatory subluxation of the scaphoid. In both of these conditions, arthritic changes began at the distal scaphoid-radial styloid joint and later progressed to the capitolunate joint (scapholunate advanced-collapse pattern of arthritis).

From these studies, it may be surmised that symptomatic non-union of the scaphoid is associated with arthritic changes that follow a predictable sequence, becoming worse with time and eventually affecting all patients. While an undisplaced non-union may portend a better prognosis than a displaced one, it, too, may displace and, over time, may cause symptoms. Patients who have radiographically identifiable arthritic changes do not necessarily have symptoms; however, painful motion of the wrist eventually develops in most of them.

Treatment

Although objective data are lacking, most authorities have agreed that scaphoid fractures that are recognized late (three to six months after injury) and do not have displacement of the fragments or collapse can be treated effectively by non-operative means. A recent study on the use of pulsed electromagnetic fields for delayed unions and established non-unions reported a rate of union of 80 per cent in forty-four patients who were treated with immobilization in a thumb-spica cast and pulsed electromagnetic fields. Healing, which occurred after 4.3 months of treatment, was not delayed when there was increased radiodensity of the proximal fragment. Treatment in a long thumb-spica cast for four to six weeks, followed by use of a short thumb-spica cast, yielded the highest rate of union, which was achieved in 90 per cent of wrists that had been injured less than five years earlier. Of the wrists that had been injured more than five years earlier, union occurred in only 29 per cent. Analysis of the failures suggested that wrists that have a synovial
non-union, carpal collapse, degenerative arthritis, or displacement of the fracture are not treated effectively with pulsed electromagnetic fields.

Green prospectively studied the efficacy of Russe's palmar bone graft for non-union of the scaphoid and stressed several technical aspects of the operative procedure. The site of the fracture is excavated thoroughly with sharp hand-held osteotomes and a curet in order to avoid the thermal injury to the bone that is caused by power instruments. The proximal pole is examined for punctate bleeding. A cavity is created that is large enough to accept two corticocancellous bone grafts, three by sixteen millimeters, which are harvested either from the distal end of the radius or from the iliac crest. The grafts are sandwiched together with the cortical sides facing outward and are inserted into the scaphoid, and the remaining cavity is filled with two-millimeter chips of cancellous bone. Cortical grafts support the reduced scaphoid, making additional fixation unnecessary. The rate of union in Green's series was related directly to the vascularity of the proximal pole; the rate was 92 per cent in scaphoids that had good vascularity, 71 per cent in 100 per cent when vascularity was fair or poor, and 0 per cent when bleeding was absent (five scaphoids).

Stark et al. reported a 97 per cent rate of union using open reduction and internal fixation with Kirschner wires and grafts of cancellous bone from the iliac crest. Their only failures were in patients in whom the scaphoid had radiographic evidence of osteonecrosis. Similarly, Steicher and Schreiber reported union in 93 per cent of the scaphoids in which bone grafts from the distal end of the radius and immobilization in a short thumb-spica cast were used. The interval to union was similar to that reported by Stark et al., and there was no evidence of morbidity at the donor site.

Fisk stressed the importance of restoration of normal carpal alignment and tension along the palmar radiocarpal ligaments; he recommended that wedge-shaped grafts from the radial styloid process be used in the treatment of non-union of the scaphoid with collapse. Fisk's technique considerably, recommending preoperative planning based on radiographs of the contralateral wrist, palmar operative approach, resection of the non-union, filling of the defect with a palmar-radial wedge-graft, and internal fixation with Kirschner wires. He reported union in 100 per cent of patients and consistent restoration of carpal alignment and scaphoid length. Cooney et al. reported a 73 per cent rate of union using this technique and recommended avoiding it when osteonecrosis is present.

References
FRACTURES AND NON-UNIONS OF THE CARPAL SCAPHOID